
UTAH GEOLOGICAL AND MINERALOGICAL SURVEY
affiliated with
THE COLLEGE OF MINES AND MINERAL INDUSTRIES
University of Utah, Salt Lake City, Utah

OIL AND GAS POSSIBILITIES OF UTAH, RE-EVALUATED

BULLETIN 54 • PRICE \$6.50 • JANUARY, 1963



**OIL AND GAS POSSIBILITIES
OF UTAH, RE-EVALUATED**

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

The Utah Geological and Mineralogical Survey, authorized by act of the Utah State Legislature in 1931, became a reality in 1941 and functioned for eight years within the Department of Publicity and Industrial Development. By law it was transferred from the Department of Publicity and Industrial Development, and since July 1, 1949, it has functioned under the aegis of the College of Mines and Mineral Industries, University of Utah.

The Utah code, Annotated, 1953 Replacement Volume 5, Chapter 36, 53-36-2, provides that the Utah Geological and Mineralogical Survey "shall have for its objects":

1. "The collection and distribution of reliable information regarding the mineral resources of the State.
2. "The survey of the geological formations of the State with special reference to their economic contents, values and uses, such as: the ores of the various metals, coal, oil-shale, hydro-carbons, oil, gas, industrial clays, cement materials, mineral waters and other surface and underground water supplies, mineral fertilizers, asphalt, bitumen, structural materials, road-making materials, their kind and availability; and the promotion of the marketing of the mineral products of the State.
3. "The investigation of the kind, amount, and availability of the various mineral substances contained in State lands, with a view of the most effective and profitable administration of such lands for the State.
4. "The consideration of such other scientific and economic problems as, in the judgment of the Board of Regents, should come within the field of the Survey.
5. "Cooperation with Utah state bureaus dealing with related subjects, with the United States Geological Survey and with the United States Bureau of Mines, in their respective functions including field investigations, and the preparation, publication, and distribution of reports and bulletins embodying the results of the work of the Survey.
6. "The preparation, publication, distribution and sale of maps, reports and bulletins embodying the results of the work of the Survey. The collection and establishment of exhibits of the mineral resources of Utah.
7. "Any income from the sale of maps and reports or from gifts or from other sources for the Survey shall be turned over to the State Treasurer and credited by him to a fund to be known as the Survey Fund to be used under the direction of the Director of the Survey for publication of maps, bulletins or other reports of investigation of the Geological and Mineralogical Survey."

The Utah Geological and Mineralogical Survey publishes maps, circulars, and bulletins, which can be obtained from the Survey office.

Address:

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY
103 Civil Engineering Building
University of Utah
Salt Lake City 12, Utah

DIRECTORS :

William P. Hewitt, 1961-
Arthur L. Crawford, 1949-1961

ERRATA FOR BULLETIN 54

ERRATA

In the TABLE OF CONTENTS, Part III, Evaluation by Areas, the names of Mead LeRoy Jensen, author of Paper 25, p. 275-284, and of F. W. Christiansen, author of Paper 29, p. 327-338, were omitted; Part II, Stratigraphic Setting, Igneous Rocks of Utah—Paper 15, read Paul D. an Proctor and Kenneth C. Bullock instead of Paul D. Proctor and Kenneth C. Bullock. On page 39, the authors of Paper 5, should read "Eliot Blackwelder¹ Arthur Granger², and Robert E. Cohenour²" instead of "Eliot Blackwelder¹, Arthur Granger¹, and Robert C. Cohenour²". For this, we make public apology.

In the INTRODUCTION, under Purpose and Scope, third paragraph, third line, read 91,000 barrels instead of 15,000 barrels. The second page of the INTRODUCTION, first paragraph, third line, should read "o. of print" instead of "of out print".

Page 48. Figure 15. Star indicates locality.

Page 312. Figure 99 courtesy of Arthur L. Crawford.

Page 332. Figure 103 taken from Lewis F. Wells.

Page 333. Figure 104 taken from E. M. Spieker.

Page 336. Figure 105 adapted from tectonic map of the U. S. Geological Survey.

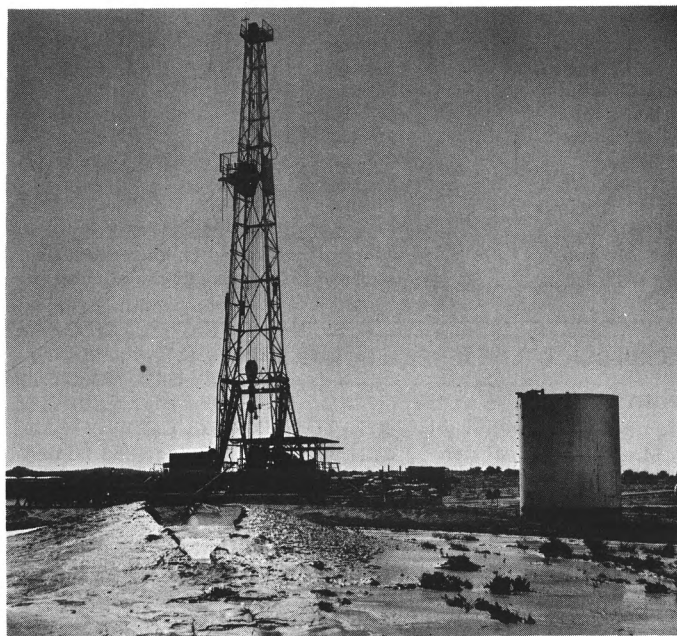
Page 338. Cited References. Christiansen, F. W., 1963, Polygonal Fracture and Fold Systems in the Salt Crust near Wendover, Utah. *Science*, Vol. 139, p. 607 (Feb. 15, 1963).

Page 493, under Directions for Exploration, paragraph 3, line 1, read "transitional" instead of "trnasitional".

Page 525, last paragraph, second line, read "stick" instead of "stock."

OIL AND GAS POSSIBILITIES OF UTAH, RE-EVALUATED

Compiled and Edited by Arthur L. Crawford



Pure Oil Company Big Flat Wildcat Well. Return cuttings and water from well pile up at end of blooey line. (Photograph courtesy of "Oil and Gas Journal", Dec. 4, 1961, p. 125.)



Utah Geological and Mineralogical Survey
affiliated with
The College of Mines and Mineral Industries
University of Utah, Salt Lake City, Utah

BULLETIN 54 • PRICE \$6.50 • JANUARY, 1963

Copyright Utah Geological and Mineralogical Survey

UNIVERSITY OF UTAH
A. Ray Olpin, Ph.D., President

BOARD OF REGENTS

Royden G. Derrick	Chairman
Spencer S. Eccles	Vice Chairman
Rulon L. Bradley	Secretary
George S. Eccles	Treasurer
Clarence Bamberger	Member
Reed W. Brinton	Member
Richard L. Evans	Member
George M. Fister	Member
Carvel Mattsson	Member
Wilford M. Burton	Member
Leland B. Flint	Member
Mitchell Melich	Member
Mrs. A. U. Miner	Member
A. Ray Olpin	President, Univ. of Utah, Ex-officio Member
Lamont F. Toronto	Secretary of State, Ex-officio Member
Maurice L. Watts	Alumni Assoc., Ex-officio Member

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

ADVISORY BOARD

Mr. J. M. Ehrhorn, Chairman	U.S. Smelting, Refining, and Mining Co.
Mr. J. W. Wade	Retired
Dean A. J. Eardley	University of Utah
Dr. C. J. Christensen	University of Utah
Dean J. S. Williams	Utah State University
Dean D. F. Petersen	Utah State University
Dr. L. F. Hintze	Brigham Young University
Mr. M. P. Romney	Utah Mining Association
Mr. A. J. Thuli	Kennecott Copper Corp., A.I.M.E.
Mr. Walker Kennedy	Liberty Fuel Co., Utah-Wyo. Coal Oper. Assoc.
Mr. L. S. Hilpert	U.S. Geological Survey
Mr. B. H. Clemmons	U.S. Bureau of Mines
Mr. J. C. Osmond	Consulting Geologist, I.A.P.G.
Mr. W. T. Nightingale	Mountain Fuel Supply Co., R.M.O.G.A.
Mr. LaVaun Cox	Utah Petroleum Council
Mr. E. I. Lentz	Western Phosphates Inc.
Mr. E. C. Knowlton	Utah Sand and Gravel Products Corp.
Mr. R. S. Stone	U.S. Steel Corporation

STAFF

William P. Hewitt	Director
Arthur L. Crawford	Assistant Director
Merriam F. Bleyl	Office Manager
Linda V.D. Robinett	Bookkeeper
Hellmut H. Doelling	Chief Draftsman
Kenneth C. Thomson	Curator, Library of Samples
Vicky Ann Goold	Typist

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS _____	<u>Pages</u> viii-xii
INTRODUCTION _____	xiii
STATUS OF OIL AND GAS EXPLORATION AND PRODUCTION IN UTAH - PAPER 1 _____	1-10
Harold E. Meyer	

PART I. SURFACE AND STRUCTURAL SETTING

THE PHYSIOGRAPHY OF UTAH - PAPER 2 _____	11-18
Walter R. Buss	
STRUCTURAL EVOLUTION OF UTAH - PAPER 3 _____	19-30
Armand J. Eardley	

PART II. STRATIGRAPHIC SETTING

STRATIGRAPHIC CORRELATION CHART - PAPER 4 _____	33-38
Frank Neighbor, Louis Wells, Gregory Elias	
PRECAMBRIAN ROCKS OF UTAH - PAPER 5 _____	39-44
Eliot Blackwelder, Arthur Granger, Robert Cohenour	
CAMBRIAN ROCKS OF UTAH - PAPER 6 _____	45-50
F. W. Christiansen	
SUMMARY OF ORDOVICIAN STRATIGRAPHY OF UTAH - PAPER 7 _____	51-62
Lehi F. Hintze	
SILURIAN STRATA IN UTAH - PAPER 8 _____	63-74
Richard W. Rush	
DEVONIAN SYSTEM OF UTAH - PAPER 9 _____	75-88
J. Keith Rigby	
CARBONIFEROUS AND PERMIAN ROCKS OF UTAH - PAPER 10 _____	89-108
J. Stewart Williams	
TRIASSIC AND JURASSIC SYSTEMS IN UTAH - PAPER 11 _____	109-122
William Lee Stokes	
CRETACEOUS SYSTEM OF UTAH - PAPER 12 _____	123-140
John A. Burger	
TERTIARY ROCKS OF UTAH - PAPER 13 _____	141-146
Clyde T. Hardy	
QUATERNARY SYSTEM OF UTAH - PAPER 14 _____	147-154
Ray E. Marsell	
IGNEOUS ROCKS OF UTAH - PAPER 15 _____	155-169
Paul D. Proctor and Kenneth C. Bullock	

PART III. EVALUATION BY AREAS

THE UINTA BASIN AND NORTHEASTERN UTAH

THE UINTA BASIN -- STRUCTURE, STRATIGRAPHY, AND TECTONIC HISTORY - PAPER 16 _____	175-176
Alan R. Hansen	
CLAY BASIN OF DAGGETT COUNTY - PAPER 17 _____	177-182
M. M. Fidler	
NORTHERN UTAH - PAPER 18 _____	183-192
Lyle A. Hale	
STRATIGRAPHY AND OIL POSSIBILITIES OF THE GREEN RIVER FORMATION IN THE UINTA BASIN, UTAH - PAPER 19 _____	193-198
Livingstone Porter	
ECONOMIC ASPECTS OF UINTA BASIN GAS DEVELOPMENTS - PAPER 20 _____	199-206
L. W. Folsom	
GREEN RIVER OIL SHALE POTENTIAL IN UTAH - PAPER 21 _____	207-214
M. Darwin Quigley and Jack R. Price	
GILSONITE AND OTHER BITUMINOUS RESOURCES OF CENTRAL UINTAH COUNTY, UTAH - PAPER 22 _____	215-224
Arthur L. Crawford and Robert G. Pruitt	
BITUMINOUS SANDSTONE AND LIMESTONE DEPOSITS OF UTAH - PAPER 23 _____	225-248
Robert E. Covington	
COMPOSITION AND ORIGIN OF THE BITUMENS OF THE UINTA BASIN - PAPER 24 _____	249-274
John M. Hunt	
THE BEARING OF SULFUR ISOTOPES ON COLORADO PLATEAU URANIUM AND PETROLEUM DEPOSITS - PAPER 25 _____	275-284

The Great Basin and the Southwestern Corner of Utah

OIL AND GAS POSSIBILITIES IN THE GREAT BASIN OF UTAH - PAPER 26 _____	287-302
Edgar B. Heylmun	
GEOLOGY AND OIL POSSIBILITIES OF WASHINGTON COUNTY - _____	303-318
Earl F. Cook	

The Transition Zone Between the Great Basin and the Canyonlands

OIL AND GAS POSSIBILITIES OF THE MARKAGUNT AND KOLOB PLATEAUS - PAPER 28 _____	320-326
Richard L. Threet	
OIL AND GAS POSSIBILITIES OF THE TRANSITION ZONE IN CENTRAL UTAH - PAPER 29 _____	327-338

The High Plateaus

CLEAR CREEK GAS FIELD AND ADJACENT AREAS - PAPER 30 _____	341-352
Paul T. Walton	
GEOLOGY AND OIL AND GAS POSSIBILITIES OF EAST CENTRAL UTAH - PAPER 31 _____	353-380
Stanford R. Mahoney and Robert P. Kunkel	
THE KAIPAROWITS REGION AND ADJACENT AREAS - PAPER 32 _____	381-384
Edgar B. Heylman	
PALEOZOIC TECTONICS OF THE COLORADO PLATEAU - PAPER 33 _____	385-386
Richard W. Fetzner	
BASEMENT ROCKS AND RELATIONSHIP TO OVERLYING SEDIMENTS OF PARADOX BASIN - PAPER 34 _____	387-404
W. Don Quigley	
DESERT CREEK ZONE, SOUTHEAST SAN JUAN COUNTY, UTAH - PAPER 35 _____	405-412
Kenneth C. Carter	
OIL AND GAS POSSIBILITIES OF THE ISMAY ZONE - PAPER 36 _____	413-428
William C. Hafeman	
GEOLOGY OF THE LISBON OIL AND GAS FIELD, SAN JUAN COUNTY, UTAH - PAPER 37 _____	429-446
Robert P. Kunkel and Robert B. Shick	
OIL AND GAS OCCURRENCES IN THE PROPOSED CANYONLANDS NATIONAL MONUMENT OF SOUTHEASTERN UTAH - PAPER 38 _____	447-468
Milan S. Papulak	
MEXICAN HAT OIL FIELD (RELATION TO THE PARADOX BASIN AND AN ESTIMATE OF FUTURE POSSIBILITIES) - PAPER 39 _____	469-482
Sherman E. Wengerd	
OIL AND GAS OBJECTIVES WORTHY OF EXPLORATION IN SAN JUAN COUNTY - PAPER 40 _____	483-486
Dorsey Hager	
PARADOX BASIN SALT DISCONFORMITIES (AND THEIR RELATIONSHIPS TO OIL PRODUCTION) - PAPER 41 _____	487-494
John E. Welsh	

PART IV. PAPERS OF GENERAL CONCERN TO THE PETROLEUM INDUSTRY

CHARACTERISTICS OF CRUDE OILS FROM UTAH - PAPER 42 _____	497-510
W. J. Wenger and J. S. Ball	
OIL AND GAS LEASING IN UTAH - PAPER 43 _____	511-518
N. G. Morgan, Sr., and Virgil V. Peterson	
POTASH DEVELOPMENTS IN THE PARADOX BASIN AND THEIR RELATIONSHIP TO THE PETROLEUM INDUSTRY - PAPER 44 _____	519-526
Robert J. Hite	

LIST OF ILLUSTRATIONS

Figures		Page
Figure 1	Oil and Gas Fields of Utah _____	2
Figure 2	Oil and Gas Pipeline Map of Utah _____	3
Figure 3	Physiographic Map of Utah _____	14
Figure 4	Map of Utah Showing Physiographic Divisions _____	15
Figure 5	Thickness Maps of the Lower Paleozoic Systems _____	20
Figure 6	Thickness Maps of the Upper Paleozoic Systems _____	21
Figure 7	Thickness and Distribution Maps of the Mesozoic _____	22
Figure 8a	Latest Cretaceous orogeny _____	25
Figure 8b	Deposition of Paleocene and Lower Eocene Clastics _____	25
Figure 9a	Basin and Range Fault System _____	28
Figure 9b	Igneous Rocks _____	28
Figure 10	Location of Precambrian Exposures _____	40
Figure 11	Map Showing Areas Uplifted in Late Precambrian _____	46
Figure 12	Map Showing Distribution of Cambrian System _____	46
Figure 13	Index Map to Section in Figure 14 _____	47
Figure 14	Section from North-Central Utah to Western Colorado _____	47
Figure 15	Selected Cambrian System Sections _____	48
Figure 16	Index Map of Ordovician Localities _____	52
Figure 17	Correlation of Ordovician Sections of Miogeosyncline _____	52
Figure 18	Correlation of Ordovician Sections with Surrounding Area _____	54
Figure 19	Isopachs of the Pognip-Garden City Limestone _____	58
Figure 20	Isopachs of the Ordovician Quartzites _____	58
Figure 21	Isopachs of the Fish Haven Dolomite _____	59
Figure 22	Isopachs of the Ordovician System _____	59
Figure 23	Index Map of Western Utah and Eastern Nevada _____	64
Figure 24	Distribution of Silurian Outcrops, Western Millard Co. _____	66
Figure 25	Generalized Stratigraphic Column, Upper Ordovician Silurian and Devonian Rocks, Western Millard Co. _____	68
Figure 26	General Correlation Sections _____	70
Figure 27	Silurian Isopachs _____	71
Figure 28	Devonian Paleotectonic Elements of Utah _____	75
Figure 29	Isopachous Map of the Devonian System of Utah _____	78
Figure 30	Devonian Stratigraphic Terms, 1958 _____	82
Figure 31	Tentative Correlation of the Devonian Formations _____	84
Figure 32	Kinderhookian-Osagean Time _____	89
Figure 33	Meramecian - Chesterian Time _____	89
Figure 34	Mississippian Correlation Chart _____	92
Figure 35	Springerian Time _____	94
Figure 36	Morrowan Time _____	94
Figure 37	Atokan Time _____	94
Figure 38	Desmoinesian Time _____	94
Figure 39	Missourian Time _____	97
Figure 40	Virgilian Time _____	97
Figure 41	Pennsylvanian Correlation Chart _____	99
Figure 42	Wolfcampian Time _____	101
Figure 43	Leonardian Time _____	103
Figure 44	Guadalupian Time _____	103
Figure 45	Permian Correlation Chart _____	105
Figure 46	Evolution of Triassic Nomenclature _____	114
Figure 47	Jurassic Correlations in Utah _____	120
Figure 48	Outcrops of Cretaceous System in Utah _____	124

	<u>Page</u>
Figure 49	Generalized Chart of Tertiary Formations _____ 142
Figure 50	Index Map, Igneous Rocks of Utah _____ 156
Figure 50 a	QLM Triangle _____ 168
Figure 51	Index Map of Areas Treated by Symposium Authors _____ 170
Figure 52	Geologic and Structure Map of Clay Basin Gas Field _____ 178
Figure 53	Cross Section of Clay Basin Gas Field _____ 179
Figure 54	Areal Map of Northern Utah _____ 184
Figure 55	Reconnaissance Geologic Map, Coalville Anticline _____ 188
Figure 56	Index Map to Uinta Basin _____ 193
Figure 57	Structural Features of the Uinta Basin _____ 194
Figure 58	Green River Formation Facies Distribution _____ 196
Figure 59	Southwest-Northeast Section, Post-Mesaverde, Pre-Green River _____ 200
Figure 60	W-E Section, Post Mesaverde, Pre Green River _____ 202
Figure 61	Late Cretaceous-Early Tertiary Formations _____ 204
Figure 62	Total Oil in the Oil Shale, Uinta Basin _____ 212
Figure 63	Gilsonite Vein Systems in Central Uintah County _____ 216
Figure 64	Bonanza Gilsonite Veins and Oil Shale Beds _____ 218
Figure 65	Relationship of Gilsonite to Gas and Oil Producing Areas _____ 220
Figure 66	Sectional View of the Oil Shale Zone, Green River Fm. _____ 222
Figure 67	Index Map of Green River Formation _____ 223
Figure 68	Location of Asphaltic Sands of Uinta Basin _____ 226
Figure 69	Aerial Photograph of Asphalt Ridge Area _____ 228
Figure 70	Geologic Map, Asphalt Ridge _____ 230
Figure 71	Geologic Cross Profile, Asphalt Ridge _____ 233
Figure 72	Photograph of the County Pit _____ 234
Figure 73	Photograph of Outcrop of Asphaltic Sand and Tar Seep _____ 236
Figure 74	Geologic Map, Whiterocks Area _____ 238
Figure 75	Photograph of Whiterocks Canyon Area _____ 240
Figure 76	Surface Cross Section, Whiterocks River, West Side _____ 241
Figure 77	Geologic Cross Profile, Whiterocks Area _____ 242
Figure 78	Photograph in Whiterocks Canyon _____ 246
Figure 79	Index Map, Uinta Basin _____ 250
Figure 80	Subdivision of the Tertiary in Uinta Basin _____ 251
Figure 81	Types of Deposits of Bitumens with Sedimentary Facies _____ 252
Figure 82	Terminology and Classification of Bituminous Substances _____ 254
Figure 83	Physical and Chemical Properties of Bitumens _____ 256
Figure 84	Solubility Data for Uinta Basin Bitumens _____ 258
Figure 85	Frequency Distribution of the Refractive Indices of Uinta Basin Bitumens _____ 259
Figure 86	Refractive Index and Fixed Carbon Content of the Uinta Basin Bitumens _____ 260
Figure 87	Infrared Spectrograms of Bitumens of the Uinta Basin _____ 262
Figure 88	Infrared Spectrograms of Liquid and Solid Bitumens _____ 263
Figure 89	Sulfur and Nitrogen Content of the Uinta Basin Bitumens _____ 265
Figure 90	Relation Between Elemental Constituents and Asphal- tenes in 10 gilsonite samples _____ 266
Figure 91	Histograms of Infrared Patterns of Bitumens in Source Beds Compared to Veins _____ 270
Figure 92	Change in Composition of Bitumens and Minerals with Environment _____ 272
Figure 93	Sulfur Isotopic Ratios of Sulfides Collected from Uranium Mines and Prospects _____ 278
Figure 94	Sulfur Content and Isotopic Composition of Hydro- carbons and Oil Shale from Eocene Formations _____ 282

	<u>Page</u>
Figure 95	Map of the Great Basin of Utah _____ 288
Figure 96	Stratigraphic Cross Section of Cenozoic Rocks _____ 282
Figure 97	Some Structural Features of Utah's Dixie _____ 308
Figure 98	Air Photograph of Virgin Anticline _____ 310
Figure 99	Oil Seep in the Timpoweap Formation _____ 312
Figure 100	Structure Contour Map, Virgin Oil Field _____ 314
Figure 101	Markagunt and Kolob Plateaus Index Map _____ 322
Figure 102	Index Map of Transition Zone _____ 328
Figure 103	Cross Section through Strawberry Valley Area _____ 332
Figure 104	Cross Section, West-East _____ 333
Figure 105	Geologic Map of Transition Area _____ 336
Figure 106	Stratigraphic Column, Wasatch Plateau _____ 342
Figure 107	Structure Map, Wasatch Plateau Region _____ 346
Figure 108	Detail Section of Producing Interval, Ferron SS. _____ 348
Figure 109	Isopach of Net Sandstone Thickness, Ferron SS. _____ 350
Figure 110	Index Map of Major Structural Features of Utah _____ 354
Figure 111	Generalized Tectonic Map of East Central Utah _____ 356
Figure 112	Index Map to Cross Section _____ 360
Figure 113	Cross Section, Gordon Creek to San Rafael Swell _____ 362
Figure 114	Cross Section, San Rafael Swell to Paradox Basin _____ 364
Figure 115	Cross Section, San Rafael Swell to Central Colorado _____ 368
Figure 116	Cross Section, D - D' _____ 370
Figure 117	Cross Section, E - E' _____ 372
Figure 118	Thickness Facies Map, Desert Creek Zone _____ 406
Figure 119	S-N Cross Section, SE San Juan County _____ 408
Figure 120	Cross Section, Upper Ismay Facies Changes _____ 414
Figure 121	Basin-Wide Correlation Cross Section _____ 418
Figure 122	Regional Facies of the Upper Phase, Lower Ismay Zone _____ 422
Figure 123	Regional Facies of the Upper Phase, Upper Ismay Zone _____ 426
Figure 124	Structure Contour Map, Ismay Zone _____ 430
Figure 125	Lisbon Salt Valley Anticline _____ 434
Figure 126	Isopach Map, Salt Member of the Paradox _____ 436
Figure 127	Structure Contour Map, Top of Mississippian _____ 438
Figure 128	Structure Contour Map, Top of Devonian _____ 440
Figure 129	Section A-A', NW-SE Section through Lisbon _____ 442
Figure 130	Section B-B', SW-NE Section through Lisbon _____ 444
Figure 131	Index Map of Salt Anticline Region _____ 448
Figure 132	Canyonlands Area _____ 449
Figure 133	Generalized Structure Contour Map, Chinle _____ 450
Figure 134	Generalized Structure Contour Map, Mississippian _____ 452
Figure 135	Generalized Structure Contour Map, Paradox Salt _____ 454
Figure 136	Isopach Map of Pennsylvanian Paradox Salt _____ 456
Figure 137	Cross Section A-A' _____ 458
Figure 138	Cross Section B-B' _____ 459
Figure 139	Cross Section C-C' _____ 460
Figure 140	Cross Section D-D' _____ 461
Figure 141	Comparison of Pennsylvanian Oil and Gas _____ 466
Figure 142	Index Map of Four Corners Area _____ 470
Figure 143	Cross Section, Mexican Hat Area _____ 472
Figure 144	Pennsylvanian Correlations, Four Corners _____ 474
Figure 145	Photomosaic, Mexican Hat Area _____ 476
Figure 146	Columnar Section, Mexican Hat Area _____ 478
Figure 147	Deep Test in Southeastern Utah _____ 484
Figure 148	Three Concepts Used to Explain the Occurrence of the Evaporites of the Paradox Basin _____ 488

	<u>Page</u>
Figure 149	Correlation of the Sediments Deposited Immediately Before and After the Deposition of the Evaporites of the Paradox Basin. _____ 490
Figure 150	That Part of the Paradox Basin Adjacent to the San Rafael Swell Uplift. _____ 491
Figure 151	Evaporite-Caltic-Carbonate Triangle _____ 492
Figure 152	Correlation - Index Curves of Utah Oils _____ 504
Figure 153	Correlation - Index Curves of Utah Oils _____ 505
Figure 154	Correlation - Index Curves of Utah Oils _____ 509
Figure 155	Distribution of halite and potash in Paradox Basin. _____ 520
Figure 156	Cane Creek Oil and Gas Withdrawals _____ 522
Figure 157	Seven Mile Oil and Gas Withdrawals _____ 523

TABLES

Table I	Utah Oil Production -- 1895-1961 _____ 1
Table II	Summary of Well Status _____ 4
Table III	Utah Oil Fields, 1961 _____ 6
Table IV	Utah Gas Fields, 1961 _____ 7
Table V	Unit Agreements in Effect Jan. 1, 1962 _____ 8
Table VI	Correlation Chart of Utah and Adjacent Areas _____ 33
Table VII	Table of Terms for Silurian Rocks in Western Utah _____ 65
Table VIII	Composition of Intrusive Igneous Rocks of Utah _____ 160
Table IX	Generalized Volcanic Rock Sequence, Pine Valley Mountains, Utah _____ 162
Table X	Generalized Volcanic Rock Sequence of Iron Springs- Marysville - Tintic Districts, Utah _____ 163
Table XI	Lead-Alpha Age Determinations of Igneous Rocks _____ 164
Table XII	Age Relationships of Cenozoic Igneous Rocks of Utah _____ 165
Table XIII	Fixed Carbon Analyses of Uinta Basin Bitumens _____ 257
Table XIV	Hydrogen to Carbon Atomic Ratios for Natural Bitumens _____ 264
Table XV	Chromatographic Separation of Ozocerite, Liquid Gilsonite, and 2 Crude Oil Residues _____ 267
Table XVI	Mass Spectrometry Analyses of Uinta Basin Bitumens _____ 267
Table XVII	Index to Stratigraphy of Washington County _____ 304
Table XVIII	Discovery and Production Information _____ 366
Table XIX	Supplement to Cross Sections _____ 374
Table XX	Chart of Completed Wells with Oil and Gas Shows _____ 464
Table XXI	Stratigraphic Table _____ 485
Table XXII	Routine Analysis of Crude Oil From Weber Sandstone, Ashley Creek Field, Uintah County, Utah _____ 498
Table XXIII	Summary of Data Showing Source of Utah Oil Samples _____ 500
Table XXIV	Summary of Data Characteristics of Utah Oils _____ 501
Table XXV	Summary of Data Distillation Yields of Utah Oils _____ 502
Table XXIIIa	Summary of Data Showing Sources of Utah Oil Samples _____ 506
Table XXIVa	Summary of Data Characteristics of Utah Oils _____ 507
Table XXVa	Summary of Data Distillation Yields of Utah Oils _____ 508

INTRODUCTION

PURPOSE AND SCOPE

The Oil and Gas Possibilities of Utah, a symposium compiled by George H. Hansen and Mendell M. Bell, was published in 1949 by the Utah Geological and Mineralogical Survey. Widely used, and out of print for many years it played a significant role in the expansion of Utah's petroleum industry.

While the 1949 Symposium was being edited, Utah's first commercially profitable oil well was discovered by the Equity Oil Company in what is now the Ashley Valley field. Prior to this discovery, the Utah Oil and Refining Company imported its crude material from outside the state.

Today there are situated in Utah one minor and three major refineries, with a combined daily capacity of 98,000 barrels of crude oil. These are served by two crude oil pipelines, having a combined capacity of 15,000 barrels and an outgoing products line of 56,000 barrels capacity per day. When facilities now projected are finished, four major gas lines and one gilsonite slurry line will serve the area.

Since 1949 oil and gas in Utah have been found in at least one formation in every geologic age from the Devonian through the Tertiary. Good shows have been found in the Cambrian, and the Rozel tar wells enigma might ultimately be classified as Quaternary in origin.

This volume, Oil and Gas Possibilities of Utah, Re-Evaluated, a symposium with 44 papers is a new appraisal of Utah's hydrocarbon potential. It is hoped it will be of assistance to those interested in the extensive petroleum program now under way in the State of Utah, and that it will be as well received as was the 1949 volume.

ACKNOWLEDGMENTS

This bulletin is a compilation from many sources. The contributors, without compensation, have complied with whatever has been asked to meet the needs of the situation. To these authors must go the greatest share of credit for the accuracy of their reports. Furthermore, opinions expressed and conclusions reached are in all cases the views of the authors. For this unstinted and wholehearted cooperation, the State of Utah is deeply indebted.

Many geologists besides those whose names appear as authors of papers have given information and assistance. In all cases, except where anonymity was requested, it has been our aim to give acknowledgment in the proper place. If in this we have failed, it was an oversight. Therefore, to all who have contributed, whether specifically mentioned or not, the compiler and the Utah Geological and Mineralogical Survey hereby make grateful acknowledgment. Special thanks are extended to Messers. Graham Campbell, Dorsey Hager, Edgar Heylman, and Robert Kunkel for help as an informal advisory committee on this publication.

We acknowledge with thanks the permission of American Gilsonite Company to reproduce the soft-pencil line-drawings of Lorence F. Bjorklund that appeared in *The Story of Gilsonite*, by Herbert F. Kretchman, 1957, now of out print. To those who have supplied photographs, acknowledgment is recorded within the text.

Dr. George H. Hansen, senior compiler of the 1949 symposium, and Mr. Arthur L. Crawford planned the format of the present volume. Doctor Hansen solicited the initial papers, but the bulk of the solicitations, and responsibility for all of the editing has fallen on the shoulders of Mr. Crawford. The magnitude of the task is best appreciated when one considers the formidable problem of dealing with 54 contributors.

Finally, the generous whole-hearted support of the Survey's staff, both those currently employed as well as those who have left the Survey office, is gratefully acknowledged. Among those who have shouldered heavy responsibilities, the services of Elizabeth V. Larson, former Office Manager, are recalled by everyone concerned, and it is with special gratitude that we acknowledge Mrs. Robert L. Bleyl, Office Manager and Manuscript Typist, whose dedication to this task, far beyond the limits of secretarial demands, has made this volume a reality.

Paper 1 STATUS OF OIL AND GAS EXPLORATION AND PRODUCTION IN UTAH

by Harold E. Meyer¹

Since 1959 Utah has produced oil and gas valued in excess of one hundred million dollars and has entered the list of the top ten producing states in the United States. Furthermore, Utah has pipelines and auxilliary transportation, gathering, and marketing facilities, including refineries, representing invested capital of several hundred million dollars. During the next three years (1962-1964) another one hundred million dollars is projected in new or expanded crude oil and gas pipeline systems, expanding refining facilities, and field gathering systems. The western half of the state may possibly be opened to systematic exploratory drilling, as a market outlet for gas may result from a pending pipeline construction application. Thus, exploration, previously concentrated in the eastern half, could be state-wide.

Accelerated drilling during the late 1950's was a direct result of crude oil and gas pipeline construction and discoveries in the eastern and southeastern portions of the state.

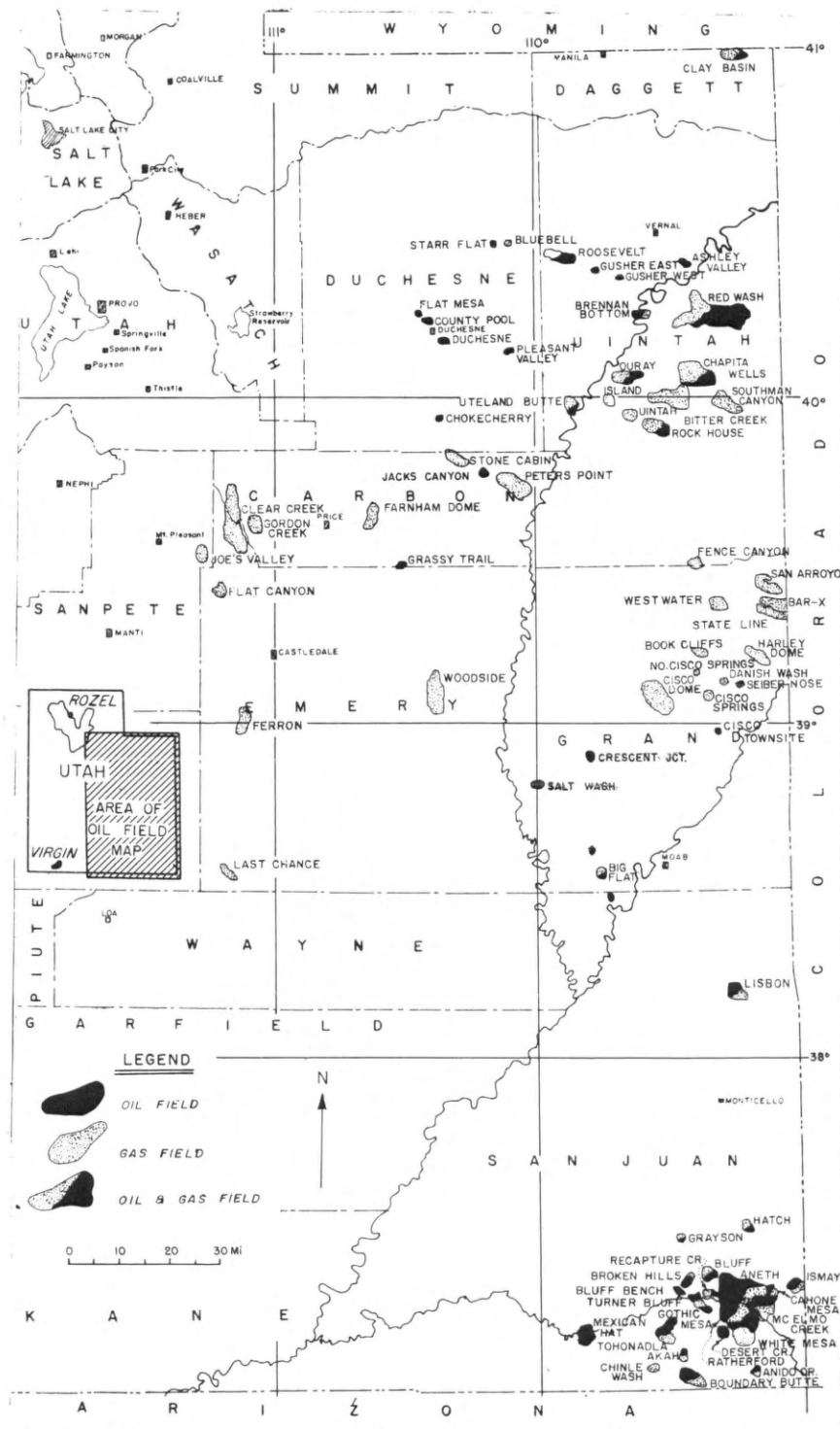
There has been drilling in nearly every county; ten of Utah's 29 counties have produced oil, petroleum gas, or other commercial gaseous or hydrocarbon substances. San Juan, Uintah, Grand, Emery, Duchesne, and Carbon Counties have led in exploration and production. During the late 1950's the success ratio of Utah wells was higher than that of any other Rocky Mountain state.

TABLE I

UTAH OIL PRODUCTION -- 1895-1961

Year	Number of Wells Drld	Footage Drld	Producing Oil Wells	Active Fields	Production (net bbls)
1895	20	12,000	none commercial	-	-
1903	3	1,000	none commercial	-	-
1927	34	70,000	none commercial	-	-
1947	14	45,000	none commercial	10	Less than 1,000
1948	23	100,000	6	15	15,138
1949	55	267,000	19	16	638,885
1950	61	295,000	32	18	1,208,593
1951	76	364,000	50	21	1,319,769
1952	84	515,000	56	24	1,677,383
1953	73	410,000	63	29	1,813,575
1954	82	505,000	82	35	1,921,223
1955	150	592,426	100	46	2,150,431
1956	191	782,417	139	19	2,478,385
1957	369	1,457,613	251	34	4,258,464
1958	435	2,208,894	532	34	24,633,536
1959	339	1,718,035	698	38	39,960,179
1960	273	1,360,665	797	40	37,594,109
1961	275	1,488,851	820	41	33,072,000

1. Publisher, Utah Oil Report, Salt Lake City, Utah.



The all-time value of oil, gas, and gilsonite production in Utah probably exceeds five hundred million dollars. Several times this value in petroleum has been processed in Utah from nearby, but out-of-state, sources. The value of crude oil and gas produced in Utah now ranks "neck and neck" with copper and exceeds the combined value of coal, uranium, and iron--the three mineral products next in line of importance. The average daily production of crude per well in Utah exceeds by nearly one hundred per cent the average daily production per well in any other state in the United States.

To date, Utah's peak year was 1959, with nearly 40 million barrels of crude oil produced for a head value exceeding one hundred million dollars. Recent decreases are due to the advent of a supervisory agency, closer adherence to conservation principles, and the normal slow-down which is typical in field development programs. Table II details the results of 1961 drilling exploration:

TABLE II
SUMMARY OF WELL STATUS
(Drilling and Completed during 1961)

<u>County</u>	<u>Drilling</u>	<u>Shut-Down</u>	<u>Dry</u>	<u>Oil</u>	<u>Gas</u>	<u>Total</u>	<u>Footage</u>
Carbon	2	1	1		1	5	10,406
Daggett			1			1	2,000
Duchesne	3	1	3		1	8	31,729
Emery	1		14		1	16	85,941
Garfield			4			4	23,453
Grand	1	3	13	6	10	33	153,906
Sanpete	1					3	18,055
San Juan	8		43	55	4	110	641,800
Summit			1			11	2,105
Uintah	8	3	12	26	38	87	497,463
Wasatch		1				1	400
Washington	1	1	1			3	1,350
Wayne	—	—	3	—	—	3	20,243
Totals	25	10	98	87	55	275	1,488,851

Only two of Utah's oil fields lie west of the Plateau Province (Figure 1). The Virgin and Rozel fields are in Utah's extreme southwestern and northwestern counties, respectively. Both fields are submarginal and have had little economic importance. As all of the major fields and pipeline auxiliaries are located in the eastern half of the state, Figure 1, showing the oil fields, is limited to eastern Utah to permit the use of a larger scale. Tables III and IV list the 1961 oil and gas fields, respectively, of Utah and the available pertinent information concerning them.

Utah has a total of 52.7 million acres. Of this approximately 21 per cent is privately owned, 6 per cent is state and local government land, and 73 per cent is Federal government and Indian land. For the past 10 years 18-25 million acres have been under active oil and gas lease. Utah has title to four sections in each surveyed township, with exceptions. Largely because of pressure from Utah's oil and gas developments, the United States has now virtually completed cadastral surveys in eastern, southern, and central counties.

New records in income from bonuses, rentals, and royalties, from private, state, federal, and Indian lands, have been established each succeeding year since 1948. The record bonus for a lease (paid to the Navajo Tribe for acreage in San Juan County) exceeded \$5,000 per acre.

With the supervising agency, categories of land ownership in Utah are shown below:

	<u>Supervising Agency:</u>
A. Public domain, acquired; Naval Petroleum Reserves; withdrawn, restricted or other lands under supervision of other government agencies, i.e. national forests, etc.	U.S. Dept. of Interior
B. Tribal or allotted lands of the various Indian tribes or members thereof.	"
C. All state-owned or supervised lands.	Utah Oil and Gas Conservation Commission.
D. Individual (or Fee Lands) for which no mineral rights have been reserved to federal, state, or Indian agencies.	"

Seventy-seven federally supervised unit agreements were actively operating in Utah at the end of 1961 (Table V). An average of ten to twelve units are under formulation in the state, with as many in active process of termination. Those being formed will ensure orderly drilling and/or development, while those being terminated will release operators from unnecessary expense and permit further exploration elsewhere. Many areas are again unitized, perhaps with regrouping of acreage resulting from additional research or new theories which lead operators to risk more capital.

Following the discovery of the Ashley field in 1948, geophysical exploration was intensified in the Uinta Basin. During the second half of the 1950's an average of 85 to 90 crew months per year were logged. The state-wide average per year was 233 crew months. This activity included seismograph, gravity, magnetometer (aerial and ground), and core or strat-hole drilling. It spread from the Uinta Basin into nearly all sections of the state. The advent of a major natural gas pipeline in the extreme eastern part stimulated geophysical exploration along the Colorado border, and the discovery of the Aneth field and others in the southern part of the Paradox Basin accelerated geophysical prospecting in the southeastern and east-central portions. Also, geophysical exploration in the central portion of Utah facilitated discovery of several gas fields in that area during the middle 1950's, and resulted in the construction by the Utah Natural Gas Company of a gas pipeline from these fields to the Salt Lake City market area. An extension into southern Uintah and northern Grand Counties has been authorized. Other new fields in these two counties will soon find markets.

Geophysical activity in nearby areas usually follows intimated approval of, or proposed routes for pipeline construction. New gas fields lacking outlets may be shut-in for long periods; but, oil-producing fields are quickly tied into markets by truck or rail transportation. Pipeline outlets for major oil fields find early construction and expansion to existing refining areas in the Salt Lake City region, or to California, Texas, New Mexico, or intervening points.

TABLE III

UTAH OIL FIELDS 1961

Field	County	Average Daily Production (bbls)	Number of Wells 1961			Cumulative Year 1961
			Drilled	Producing	Producible	
Akah	San Juan	67.5		2	2	24,584
Aneth	San Juan	20267	10	190	208	
Anido Creek	San Juan	821	6	4	4	
Ashley Valley	Uintah	3185		26	27	1,157,369
Big Flat	Grand	66	2	2	4	23,838
Bluff	San Juan	154	1	5	6	55,893
Bluff Bench	San Juan			Abandoned		14
Boundary Butte	San Juan	19		3	7	6,749
Brennan Bottom	Uintah	108		4	4	39,216
Broken Hills	San Juan	19	1	1	1	6,610
Cahone Mesa	San Juan	438	1	1	1	39,216
Chapita Wells	Uintah	40	14	15	20	6,610
Cisco	Grand	5/8	1		1	
Desert Creek	San Juan	54		2	2	1,214
Duchesne	Duchesne	19		1	1	145
Gothic Mesa	San Juan	105	1	4	4	20,748
Hatch	San Juan	3		1	1	6,768
Ismay	San Juan	1877	12	35	35	40,352
Lisbon	San Juan	1644	19	14	15	865
McElmo Creek	San Juan	22454	6	101	151	685,083
Ratherford	San Juan	16013	9	145	157	599,365
Recapture Creek	San Juan	153	2	1	2	
Red Wash	San Juan	11493	26	155	170	58,553
Roosevelt	Uintah	280		5	6	4,194,878
Salt Wash	Grand	107	2	2	2	101,946
Seiber Nose	Grand	2	3		1	26,213
Tohonadia	San Juan	433		9	10	508
Turner Bluff	San Juan			Abandoned	0	153,717
Virgin	Washington	3	1		6	
White Mesa	San Juan	9523	4	64	69	1,039
Ute Trail Unit (DeKalb)	Uintah	51		13	18	
Gusher	Uintah			Shut-in	2	
Undesignated Wildcats						
Pumpelly #2, Phillips	Grand	38	2	2	2	9,159
Greater Aneth Area	San Juan	1271	12	12	13	587,972
White River, Calif. Oil Company	Uintah	50	3	1	1	
TOTALS			139	820	953	

TABLE IV
UTAH GAS FIELDS 1961

Field	County	Average Daily Production (mfc)	Number of Wells 1961		
			Drilled	Producing	Producible
Bar-X	Grand	3,198		9	13
Bend	Uintah	Shut-in			2
Blue Bell	Duchesne	169		1	1
Boundary Butte	San Juan	4,423		3	4
Chapita Wells	Uintah	1,032	12	15	20
Chinle Wash	San Juan	Shut-in			2
Cisco Dome	Grand	Shut-in			1
Cisco Springs	Grand	Shut-in			2
Cisco Townsite	Grand	Shut-in			2
Clay Basin	Daggett	5,335		10	10
Clear Creek	Carbon and Emery	25,791		10	15
Coalbed Canyon	San Juan	Shut-in			1
Danish Wash	Grand	Shut-in			3
Farnham Dome	Carbon	214	1	1	4
Ferron	Emery	Shut-in			6
Flat Canyon	Emery	282			3
Gordon Creek (CO ₂)	Carbon				4
Harley Dome	Grand	Shut-in			(Helium) 2
Island	Uintah	415	3	2	3
Joes Valley	Sanpete	37			2
Oil Springs	Uintah	Shut-in			1
Ouray and Bitter Creek	Uintah	2,318		13	18
Peters Point	Carbon	Shut-in			3
Rock House	Uintah	474	6	4	6
San Arroyo	Grand	Shut-in	1		6
Southman Canyon	Uintah	Shut-in			3
Stateline	Grand	Shut-in			3
Stone Cabin	Carbon and Duchesne	Shut-in			2
Uintah and Bitter Creek	Uintah	81	3	3	3
Westwater	Grand	6,450	2	9	11
White River	Uintah	Shut-in			2
			28	80	176

Gas Production from Oil Fields and Wildcats:

Oil Field	Grand	1,017		3	3
Oil Field	San Juan	90,486	13	68 (?)	81(?)
Oil Field	Uintah	21,106	1	57 (?)	57(?)
Wildcats	Cache	Shut-in	2	Marsh gas, private use	2
Wildcat	Duchesne	Shut-in	1		1
Wildcat	Grand	Shut-in	8		8
Wildcat	San Juan	Shut-in	9		9
Wildcat	Uintah	Shut-in	18		18
Total			52	128	149

TABLE V

UNIT AGREEMENTS IN EFFECT ON JANUARY 1, 1962

Name of Unit	Operator	Gross Acreage	Effective Date	County	Township	Range ^{1/}	Drilling or Producing Status
Aneth (Pt. Indian)	Texaco, Inc.	23,749.73	8- 9-61	San Juan	40 S	23, 24, 25 E	Water Flood
Asphalt Ridge	Pan American Petr. Co.	18,066.38		Uintah	4, 5 S	20, 21 E	
Bad Land Cliffs	Sun Oil Company	33,007.00	8-24-60	Duchesne	7 S	4 W USM	1 dry, 1 non-com. gas
					10, 11 S	14, 15 E	
Bar-X (Part in Colorado)	American Metal Climax Inc.	3,806.00	9-30-52	Grand	17 S	25, 26 E	Gas, Gas Dis.
Bend	Gulf Oil Corporation	320.00	11- 1-60	Uintah	7 S	22 E	Gas Dis., S.L.
Big Flat	Pure Oil Company	19,558.00	10-24-51	Grand	25, 26 S	19, 20 E	Oil Dis.
Blaze Canyon	Continental Oil Company	14,983.31	12- 4-61	Grand	20, 20 1/2, 21 S	18, 19 E	
Bluff	Shell Oil Company	11,900.05	5-17-51	San Juan	39, 40 S	22, 23 E	Oil
Bonanza	Mid-America Minerals Inc.	37,144.62	12-22-58	Uintah	9, 10 S	24, 25 E	
Book Cliffs	Gulf Oil Corporation	14,700.38	4-14-61	Grand	18, 19 S	22 E	Gas Dis. S.L.
Bowknot	Superior Oil Company	16,033.33	10-28-60	Grand, Emery	25, 26 S	16, 17, 17 1/2 E	
Brennan Bottom	Gulf Oil Corporation	5,728.26	10- 2-58	Uintah	7 S	20, 21 E	Oil Dis. ^{2/}
Bridger Jack	Humble Oil and Refining Co.	23,061.66	8-26-60	San Juan	27, 28 S	21, 22 E	
Bryson Canyon	Trend Oil Company	12,257.81	12-27-60	Grand	17 S	24, 25 E	Gas Dis.
Bull Canyon	Continental Oil Company	29,450.12	6-20-52	Uintah	13, 14 S	21 E	
Castle Peak	Sun Oil Company	14,535.87	1- 4-52	Duchesne and Uintah	8, 9 S	17, 18 E	
Chapita Wells	Belco Petroleum Corporation	36,502.96	12-29-51	Uintah	9, 10 S	22, 23 E	Oil Dis., non-com.
Chokecherry Canyon	United Producing Company	14,115.75	2-26-59	Duchesne	6, 7, 11 S	4, 5 W USM	Gas Dis.
						13, 14 E	
Clay Basin (part in Wyoming)	Mountain Fuel Supply Co.	11,116.83	1- 1-40	Daggett	12 N	105 W 6th Prin. Mer. Wyo.	
					3 N	24 E	
Clear Creek	Delhi-Taylor Oil Corp.	21,045.72	1- 1-57	Carbon, Emery	13, 14 S	6, 7 E	
Coalville	Ohio Oil Company	1,481.43	4- 6-59	Summit	2 N	5 E	
Comb Wash	Atlantic Refining Company	27,172.99	10-25-60	San Juan	38, 39 S	20, 21 E	
Desert Lake	Pure Oil Company	9,665.35	6-20-61	Emery	16, 17 S	10, 11 E	
Diamond Ridge	Sunray Mid-Continent	46,050.13	1-15-60	Grand	16, 17, 18 S	22, 23 E	
Emery	Skelly Oil Company	25,895.61	11- 1-61	Emery, Sevier	22, 23 S	5, 6 E	
Escalante	Phillips Petroleum Co.	29,700.43	7-28-60	Garfield	32, 33 S	2, 3 E	
Fence Canyon	Texaco, Inc.	10,079.22	1-22-60	Grand, Uintah	15, 15 1/2, 16 S	22, 23 E	
Five Mile Draw	United Producing Co., Inc.	14,144.51	5- 5-60	Duchesne	6, 7 S	3, 4, 5, W USM	
					10 S	14, 15 E	
Flat Canyon	Delhi-Taylor Oil Corp.	3,613.63	8-26-58	Emery	16 S	6 E ^{3/}	
Gordon Creek	Skelly Oil Company	26,125.72	6-20-46	Emery	13, 14, 15 S	7, 8 E	
Grand Fault	Phillips Petroleum Co.	33,252.89	4-25-61	Emery, Grand	21, 22 S	15, 16, 17 E	
Grassy Trail Creek	Cities Service Petr. Co.	6,822.80	12- 5-61	Carbon, Emery	15, 16 S	12, 13 E	
Horsehead	Pure Oil Company	11,040.00	10-26-61	San Juan	29 S	20, 21 E	
Horse Point	Tidewater Oil Company	26,349.63	8- 8-61	Grand, Uintah	15, 16, 17 S	23, 24, E	
Horseshoe Canyon	Superior Oil Company	22,862.75	6-23-61	Wayne	27, 28 S	15, 16, 17 E	
Island	Mountain Fuel Supply Co.	45,258.75	8-26-60	Duches., Uintah	9, 10 S	17, 18, 19, 20 E	
Island Mesa	Pure Oil Company	9,021.76	11-22-60	San Juan	30 S	26 E	

Jack Canyon	El Paso Nat'l Gas Company	3,515.68	6- 4-57	Emery	12 S	16 E ^{4/}
Joess Valley	Delhi-Taylor Oil Corporation	2,205.19	10-23-59	Sanpete	15 S	6 E ^{5/}
Johns Canyon	Texaco, Inc.	12,417.04	12-22-61	San Juan	40, 41 S	17, 18 E
Johnson Creek	California Oil Co.	44,595.19	9-10-57	San Juan	35, 36 S	21, 22 E
Kennedy Wash	Alamo Corporation	23,908.99	3- 2-60	Uintah	8, 9 S	23, 24 E
Lost Canyon	Pure Oil Company	10,402.52	11- 9-61	San Juan	30, 30 1/2, 31 S	19, 20 E
McElmo Creek (Indian)	Superior Oil Company	19,536.98	6-16-61	San Juan	40, 41 S	24, 25 E.
Moon Ridge	Superior Oil Company	21,277.17	7-31-61	Grand, Uintah	15 1/2, 16, 17S	21 E
Muleshoe	California Oil Company	15,390.26	8- 8-61	San Juan	27, 28 S	23, 24 E
Murphy Range	Shell Oil Company	25,760.20	8-11-61	San Juan	27, 28, 29 S	18, 19 E
Musinia	California Oil Company	37,144.64	12- 7-60	Sanpete, Sevier	20, 21 S	3, 4 E
Nequoia Arch	Humble Oil & Refining Co.	65,521.10	8-29-55	Emery, Wayne	26, 27, 28 S	13, 14, 15 E
Oil Springs	Otis Booth	20,320.48	12-22-60	Uintah	12 S	24, 25 E
Onion Creek	Richfield Oil Company	39,974.20	1-19-61	Grand	23, 24 S	23, 24, 25 E
Pariette Bench	Pan American Petr. Co.	31,750.61	10- 5-60	Duchesne, Uintah	9 S	17, 18, 19 E
Peter's Point	El Paso Nat'l Gas Co.	10,080.00	5-27-57	Emery	12, 13S	16, 17 E ^{6/}
Pintura	Pan American Petr. Co.	19,135.50	9- 6-61	Washington	39, 40 S	13 W
Rainbow	Shamrock Oil and Gas Corp.	16,700.56	8-15-61	Uintah	10, 11 S	23, 24 E
Ratherford (Indian)	Shell Oil Company	160.00	10- 1-61	San Juan	40 S	23 E
Recapture Creek	Phillips Petroleum Co.	14,931.76	10- 1-61	San Juan	41, 42 S	24 E
Red Wash	California Oil Company	48,051.00	10-31-50	Uintah	7, 8 S	22, 23, 24 E
Rock House	Shamrock Oil & Gas Corp.	23,504.43	1-11-61	Uintah	11, 12 S	23 E
Roosevelt (Indian)	Humble Oil & Refining Co.	3,321.50	12- 1-54	Uintah	1 S, 2 S	1 W, 1, 2 E USM
Salt Valley	Continental Oil Co.	83,745.02	9-29-61	Grand	21, 22, 23, 24S	19, 20, 21 E
San Arroyo	Sinclair Oil and Gas Co.	11,946.56	12-14-61	Grand	16 S	25, 26 E
Segundo Canyon	English Oil Co.	24,179.65	9- 9-61	Grand	16, 17S	21, 22 E
Southman Canyon	El Paso Nat'l Gas Co.	24,666.58	11- 7-52	Uintah	9, 10, 11 S	23, 24 E
Sowers Canyon	Humble Oil & Refining Co.	21,167.00	11-14-61	Duchesne	6, 7, 10, 11 S	6, 7 W USM
Stagecoach	Belco Petroleum Corp.	26,168.26	9-15-60	Uintah	8, 9S	11, 12, 13 E
Stone Cabin	Sun Oil Company	24,545.00	6-27-58	Emery	12 S	20, 21, 22 E
Sweetwater Creek	Skyline Oil Company	59,237.43	4-20-60	Uintah	13, 14 S	14, 15 E
Uintah	DeKalb Agricultural Ass'n	54,286.26	8-14-59	Uintah	10, 11 S	22, 23, 24 E
Ute Trail	DeKalb Agricultural Ass'n	68,467.64	7-12-56	Uintah	9, 10 S	19, 20, 21, 22 E
Walker Hollow	Humble Oil & Refining Co.	11,635.98	3-12-59	Uintah	6, 7 S	20, 21, 22, 23 E ^{1/}
Washboard Wash	Pure Oil Company	9,727.87	11- 8-61	Carbon, Emery	15, 16 S	22, 23, 24 E
Wells Draw	Mountain Fuel Supply Co.	33,866.38	11-28-61	Duchesne	10 S	9, 10 E
Westwater	Oil, Incorporated	10,962.00	7- 1-58	Grand	16, 17 S	15, 16, 17 E
White Mesa (Indian)	Continental Oil Co.	13,684.33	10- 1-61	San Juan	41 S	23, 24 E
White River	Belco Petroleum Corp.	19,467.16	2-26-57	Uintah	8 S	22, 23 E
Wonsits	Gulf Oil Corp.	24,105.54	8- 6-57	Uintah	7, 8 S	21, 22 E

TOTAL UTAH ACRES

1,789,390.54

1. Ranges for Salt Lake Meridian unless stated otherwise: U--Uintah Base and Meridian.
2. Contracted from 10,887.28 acres.
3. Contracted from 28,729.66 acres.
4. Contracted from 47,950.22 acres.

5. Contracted from 80,357.89 acres.
6. Contracted from 36,640 acres.
7. Contracted from 26,821.53 acres.

Regardless of the means of marketing, the average crude oil price, based on total production during the past ten years, has been \$2.70 to \$2.95 per barrel.

Incoming crude and products pipelines (Figure 2) bring northwestern Colorado and southwestern Wyoming oil to the Salt Lake City refinery center via Wyoming. Crude oil lines bring Rangely and other northwestern Colorado crude to Salt Lake City refineries via the Uinta Basin. The latter pipeline also serves numerous fields within the Uinta Basin. Products lines from Salt Lake City to the Pacific Northwest market Utah oil in that region.

Natural gas lines bring southwestern Wyoming and northwestern Colorado gas to the greater Salt Lake City and northern Utah markets. Natural gas lines also bring gas produced in central and eastern Utah to the same area. Mountain Fuel Supply Company and El Paso Natural Gas Company recently completed (1961) the Uinta Basin gas line to the Greater Salt Lake City marketing area and are linking previously shut-in Uinta Basin wells and undeveloped fields to the market. The news of this development in 1961 increased the pace of drilling in the Uinta Basin alone by more than fifty per cent. In 1961 Grand County gas was being delivered to El Paso's Pacific northwest line in eastern Utah.

Crude oil from the Aneth field of the Paradox Basin in southeastern Utah is now flowing southwestward to Los Angeles, California, markets via the Four Corners Pipeline Corporation line, as well as southeastward to New Mexico and Texas via the New Mexico-Texas Pipeline Corporation's line from Aneth to Houston, etc. Another pipeline is planned from the Lisbon field area to Aneth.

Condensate, distillate, natural gasoline and associated products are produced in Utah through recently constructed facilities at Clear Creek, Red Wash, Westwater, Aneth, and Lisbon fields. Additions to these lines and plant facilities are already announced. Crude and condensate from other remotely located fields in eastern Utah are reaching the same markets via truck and rail transportation.

Primary and secondary recovery programs of waterflooding and gas injection are being instituted or have been underway for several years, as is underground storage of natural gas.

Approximately \$100.9 million is invested in refining and processing facilities, the bulk of which is in the Salt Lake City area. All now, as in the past decade, are undergoing practically continuous expansion and additional construction looking towards increased capacity and expected additional Utah production. At least \$100,000,000 is invested in existing Utah transmission lines, and several hundred million dollars more in pipeline facilities await the expected increase in Utah oil and gas production.

More than 3,500 employees are engaged in exploration, production, drilling, refining, and pipelining in Utah.

When considering older oil producing states, Utah's progress along the production path has been little short of phenomenal, and all indications point towards a progressively successful future.

**PART I
SURFACE
AND
STRUCTURAL
SETTING**

-INDEX TO PART I-

<u>Paper</u>		<u>Page</u>
2	THE PHYSIOGRAPHY OF UTAH, by Walter R. Buss _____	13
	General _____	13
	Colorado Plateaus _____	13
	High Plateaus _____	16
	Canyon Lands _____	16
	Uinta Basin _____	17
	Basin and Range Province _____	17
	Middle Rocky Mountains _____	17
3	STRUCTURAL EVOLUTION OF UTAH, by A. J. Eardley _____	19
	Introduction _____	19
	Paleozoic Movements and Sedimentation _____	19
	Mesozoic Movements and Sedimentation _____	19
	Cretaceous and Tertiary Orogenies _____	23
	Cedar Hills Orogeny _____	23
	Early Laramide Orogeny _____	24
	Mid-Laramide Orogeny _____	26
	Late Laramide Orogeny _____	26
	Volcanic Activity _____	27
	Basin and Range Faulting _____	27
	Uplift of Colorado Plateau _____	28
	Cited References _____	29

Paper 2 THE PHYSIOGRAPHY OF UTAH

by *Walter R. Buss*¹

GENERAL

Physiographically, the state of Utah offers an interesting pattern (Figure 3). To the casual observer, the arrangement of mountains, plateaus, and valleys making up the surface of the state probably appears undecipherable, but a closer examination will reveal a natural grouping of these forms into regional systems.

Three of the major physiographic provinces of the United States meet at the junction of the Uinta Mountains with the Wasatch Mountains (Figure 4): the Middle Rocky Mountains, the Basin and Range province, and the Colorado Plateaus. The areas involved in these three provinces represent 95 per cent of the state's total area. Small sections of two other major provinces, the Wyoming Basin and the Columbia Plateaus, extend into the northern part of the state.

The elevation of the state as a whole averages 6,100 feet, but varies from approximately 2,000 feet at Beaver Dam Creek in the extreme southwestern corner to 13,498 feet at Kings Peak in the Uinta Mountains at the northeast. A broad highland belt, which includes the Wasatch Mountains and the High Plateaus, extends in a gentle arc, concave to the west, from the northern boundary to the southwestern corner of the state. This highland divides the state into two areas of different climatic characters, due to differences in elevation and to the areas' positions on opposite sides of the highland. Rainfall averages thirteen inches, but varies from five to sixty inches.

The state's largest river, the Colorado, (chiefly through the Green and other western tributaries) drains most of the area east of the highland belt. The Wasatch Mountains, much of the western part of the High Plateaus, and the area west of this belt lie within the Great Basin, an area without an outlet to the sea. Three of the four largest rivers of this area, the Bear, the Weber, and the Provo, empty into Great Salt Lake (the Provo by way of Utah Lake and the Jordan River). The fourth, the Sevier River, draining several of the west-central counties, formerly emptied into Sevier Lake, which, due to extensive irrigation, is now a dry saline basin. Other smaller streams drain to similar enclosed basins.

COLORADO PLATEAUS

In area the Colorado Plateaus are most important, covering about one-half the state. This province is characterized by nearly horizontal strata having a regional dip to the north and northeast; the strata are broken on the west by north-south trending faults and modified in the central and eastern sections by a series of regional flexures and dome mountain groups. The western boundary is unusually sharp. It extends along the western base of the Markagunt Plateau, the Tushar Mountains, and the Pavant Range, curving slightly northeastward to join the Wasatch Mountains near Nephi. From this point the boundary turns eastward to Thistle, Soldier Summit, and along the southern foothill belt of the Uinta Mountains.

1. Head, Department of Geography and Geology, Weber College, Ogden, Utah.



Figure 3: Physiographic Map of Utah. (Photograph from Army Map Series Relief Maps.)

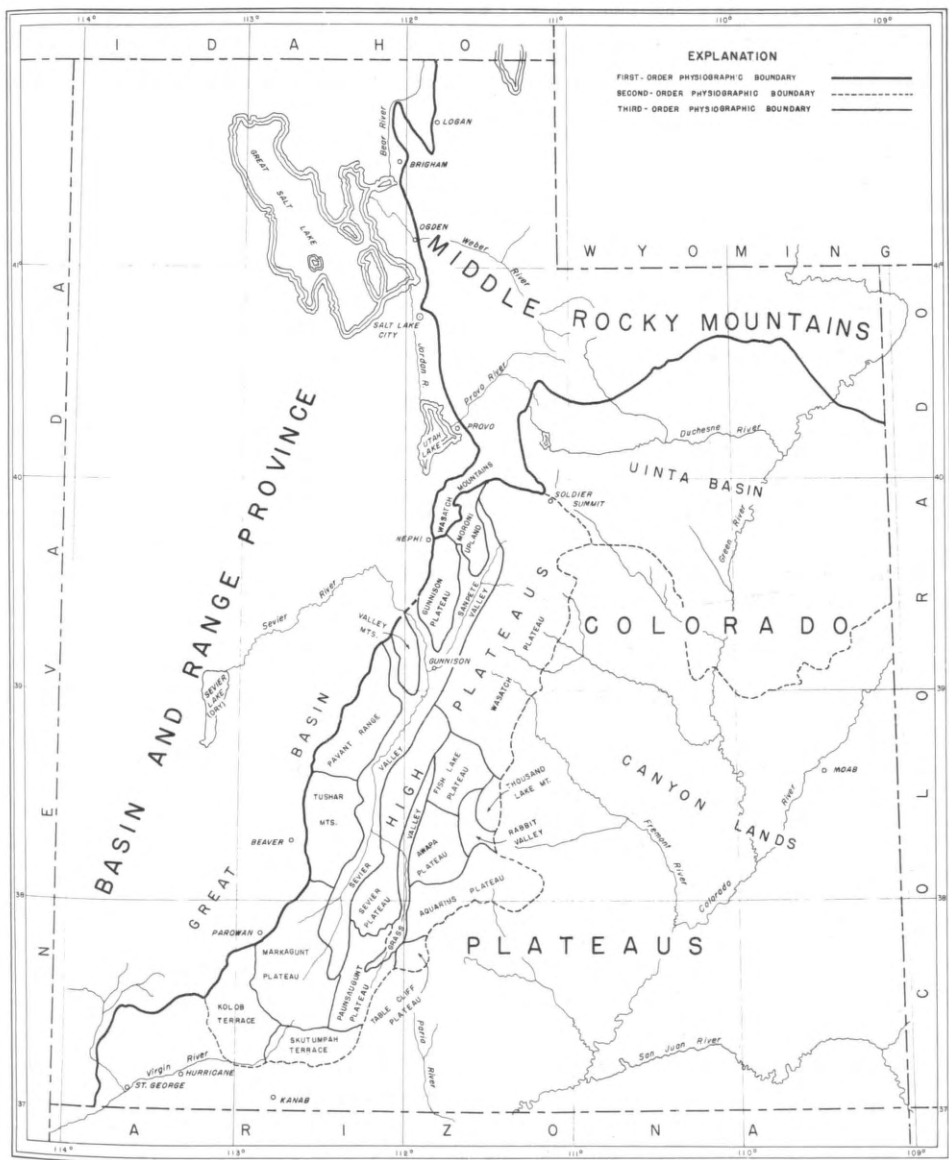


Figure 4.

Within the Colorado Plateaus three subprovinces are recognized. The High Plateaus constitute a belt 25 to 80 miles wide, extending 175 miles from Nephi and Soldier Summit south along the western edge of the province to the southward-facing terraces of the Great Staircase of southern Utah. East of the High Plateaus are the Canyon Lands, an area of deep, narrow, vertical-walled canyons cut by the Colorado River and its tributaries and of many almost inaccessible mesas and small plateaus. The third subprovince, the Uinta Basin, is a broad down-warp between the Uinta Mountains and the Book Cliffs.

High Plateaus

The physiographic features of the High Plateaus merit consideration because of their structure and arrangement. They are the highest true plateaus in North America, averaging from 8,000 to 10,000 feet in altitude, and at some points attaining more than 11,000 feet.

They fall naturally into three parallel strips, separated from each other by normal faults or monoclines. In general, the separating faults or monoclines are downthrown to the west. The blocks themselves have been tilted slightly to the east, thus presenting a rugged, steep western front and a gentle, often rolling, eastern slope. Valleys eroded along the lines of displacement reveal the geology with a clarity not usually found in other regions.

The western boundary is the Hurricane Fault, a zone with the downthrown block to the west and a displacement of 2,000 to 5,000 feet or more. From the Hurricane region north to Parowan, the upthrown block shows a rather steep front; but between this point and a point a few miles south of Beaver, the displacement is a series of echelon faults apparently not connected to the main Hurricane. Probably this line of displacement extends northward along the west base of the Tushar and Pavant ranges, but its character can only be inferred from the steep west face of these uplifts. Sevier Valley, between the western and middle strips, has developed along the Sevier and Markagunt faults on the downthrown side of the Wasatch monocline. Erosion along the Paunsaugunt fault by the East Fork of the Sevier River and Otter Creek has developed Grass Valley. The eastern edge of the High Plateaus is an erosional escarpment developed by the stripping off of Tertiary, Cretaceous, and Jurassic strata from the Canyon Lands by the tributaries of the Colorado River.

Each of the plateaus is essentially linear in form with steep cliffs or slopes on one or more sides. In general, the western side is steepest, due to faulting or monoclinical folding, and the eastern side, if steep, is erosional. The present physiographic features of the High Plateaus are carved largely from sedimentary and volcanic rocks of Tertiary age. Some of the plateaus are only lava-capped, but others are composed entirely of volcanic materials.

Canyon Lands

The Canyon Lands subprovince averages from 5,000 to 6,000 feet in elevation, and is characterized by deep, narrow, sinuous canyons and steep-sided buttes, mesas, and small plateaus. Its location in the rainshadow of the High Plateaus causes it to be a region of scanty rainfall and generally arid conditions, further aggravated by the deep canyons which lower the water table.

Within the area three distinct mountain groups, the Henry, La Sal, and Abajo Mountains, and a single mountain (Navajo) rise abruptly 3,000 to 5,000 feet

above the general level of the surface. Their origin is attributed to the injection of igneous material doming the overlying sedimentary rocks. In the Henry Mountains the sedimentary cover has been stripped from the igneous cores of the five mountains involved, and to a lesser extent the cores of the other two groups are also laid bare. At Navajo Mountain no igneous rock is exposed. In addition to these mountains, there are other large uplifts, the San Rafael Swell, the Monument Uplift, and the Circle Cliffs. These exert little control on the drainage, for the Colorado River or its tributaries cross one or more of them without regard for structure.

Uinta Basin

The Uinta Basin is both a structural and a topographic basin about 170 miles long and 100 miles wide. It is surfaced with Tertiary sediments which, in places, have been eroded into distinctive "badlands." Cretaceous and Jurassic rocks outcrop in the Book Cliffs at the south and form cuerdas along the foothills of the Uinta Mountains at the north. The basin is generally arid, though the higher benches support a pygmy forest.

BASIN AND RANGE PROVINCE

West of the Wasatch Mountains and the High Plateaus is the arid Basin and Range province, characterized by short, north-south trending mountain ranges and valleys. There are some thirty-five or more named ranges in the area, but the longest is only about fifty miles in length if the Wasatch Mountains are excluded.

Though the maximum elevation is a little over 12,000 feet, these ranges probably average 8,000 feet or less in elevation, but present a highly serrated profile. Each has a complex geologic history. Many are bounded on one or both sides by a normal fault or fault zone. For the most part, these ranges are composed of Paleozoic marine sediments, although large intrusive masses occur in some, and Tertiary volcanic materials are present in others.

The eastern boundary of this province is usually placed along the line of the Hurricane Fault and the western base of the Wasatch Mountains. However, there are differences of opinion regarding the exact boundary between the Basin and Range and the Colorado Plateaus provinces at the southern end of the Wasatch Mountains, and between the Basin and Range and Middle Rocky Mountains provinces with regard to the Wasatch Mountains themselves.

The Pleistocene Lake Bonneville occupied many basins in the northern part of this province, as shown by the many shorelines and other features.

MIDDLE ROCKY MOUNTAINS

The distinctive features in Utah of the third province are the Uinta and Wasatch Mountains. The Uinta Mountains constitute the only major range with an east-west orientation in the United States. Numerous peaks rise above 13,000 feet; the highest, Kings Peak, is 13,498 feet. Structurally, the Uinta Mountains form a broad, asymmetrical anticline with the steepest dips on the north side and normal faults on both sides. Since uplift of the range, erosion has removed an estimated 15,000 to 20,000 feet of strata from the top, leaving cuerdas and hogbacks along the flanks. A part of this erosion was due to numerous glaciers

during Pleistocene time. Near the east end of the range, a series of deep canyons mark the course of the Green River, an entrenchment so out of harmony with the general structure that it is believed that the range was at least partially buried by early to middle Tertiary sediments before the river established its present course.

The Wasatch Mountains average 10,000 feet in elevation with Mount Timpanogos, the highest peak, rising to 11,750 feet. For most of their length they are broken into two parallel ridges separated by mountain-rimmed valleys. Many streams cross one or both ridges in narrow, steep canyons, and add materially to the water supply of the heavily populated area along the western face of the range. The largest streams are the Bear, Weber, and Provo Rivers. All head near each other at the western end of the Uinta Mountains. The Bear flows north and west around the north end of the Wasatch. All others flow westward through the range, and their steep-walled canyons present interesting questions regarding age and history.

They mark the eastern edge of the Basin and Range province and have many features typical of Basin and Range mountains. Their height and steep western front are attributed to movement along the Wasatch fault; and their two parallel ridges represent individual fault blocks. In contrast, their folded structures ally them with the Middle Rocky Mountains, and also they represent a transition to the Colorado Plateau.

During Pleistocene times they contained many small glaciers, with the greatest development in the Cottonwood-American Fork-Timpanogos area. Like the Uinta Mountains, the appearance of the Wasatch Mountains has been modified greatly by this recent ice activity.

Paper 3 STRUCTURAL EVOLUTION OF UTAH

by Armand J. Eardley¹

INTRODUCTION

The following short paper reviews the structural evolution of Utah in post-Proterozoic time, and it should serve as an introduction to the other papers that follow. Differences of opinion and interpretation in this review from those of the following more detailed and specific accounts are bound to occur, but they will probably point the way to unsolved problems, and, in effect, be valuable.

PALEOZOIC MOVEMENTS AND SEDIMENTATION

The major Paleozoic provinces of sedimentation in Utah are shown in the upper left map of Figure 5. The miogeosyncline to the west and northwest was one of accumulation of thick sedimentary sequences, whereas the region to the east was one of meager sedimentation and is generally referred to as the shelf. The major part of the shelf in Utah is the Transcontinental arch, which received in early and mid-Paleozoic a thinner veneer of sediments than other parts of the shelf.

The boundary between the shelf and miogeosyncline, called the Wasatch line, was fairly sharply defined and remained in nearly the same position throughout the Paleozoic era. This may be seen by inspection of the maps of Figures 5 and 6.

Principle structures that should be noted are as follows: The Tooele arch developed in Ordovician time, and considerable sand accumulated in its site. The Stansbury anticline rose at the close of the Devonian, and a southeasterly trend across Utah began to take shape at this time. The Mississippian saw further development in the southeast direction; the Pennsylvanian was a time of conspicuous unrest with the subsidence and fill of the Oquirrh and Paradox basins and the rise of the Uncompahgre, Zuni, Emery, and Circle Cliffs uplifts, all establishing a strong northwesterly-southeasterly structural pattern. Compressional orogeny began in the Late Devonian in the Antler belt of central Nevada and continued through the Mississippian and Early Pennsylvanian, with coarse clastics being shed both to the east and west. The Permian was a time of sedimentation over most of Utah with a deep basin forming in the central and southwesterly part. Northern Utah was a region of sedimentation of phosphatic shale and limestone as well as much chert.

MESOZOIC MOVEMENTS AND SEDIMENTATION

By Triassic time the great Cordilleran geosyncline had become divided into a western trough in California and western Nevada, and an eastern trough in Utah, western Wyoming, and eastern Idaho. The medial Cordilleran geanticline that rose was composed of the thick Paleozoic sediments, and was the source of much of the Mesozoic sediments in the eastern trough (see maps of Figure 7).

1. Dean, College of Mines and Mineral Industries; formerly Head, Department of Geology, University of Utah, Salt Lake City, Utah.

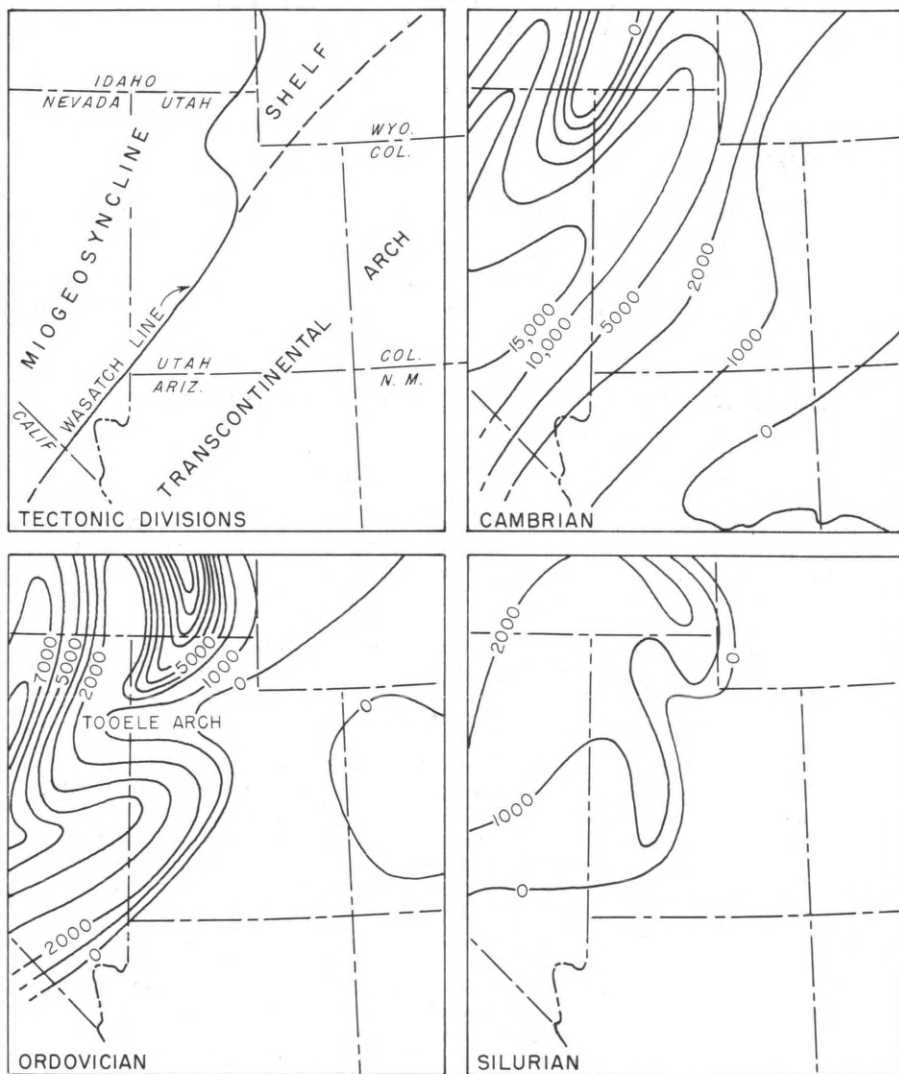


Figure 5. Thickness maps of the lower Paleozoic systems.

The ocean waters still had access to the eastern trough across the geanticline in Early Triassic time when the marine limestones of the Thaynes formation were deposited, but thereafter the marine invasions came from the north, and in the Cretaceous merged with seas from the Gulf of Mexico (Nolan, 1943).

The Triassic and Jurassic sediments are not coarse in their westernmost outcrops in Utah. Therefore, the shorelines against the geanticline must have

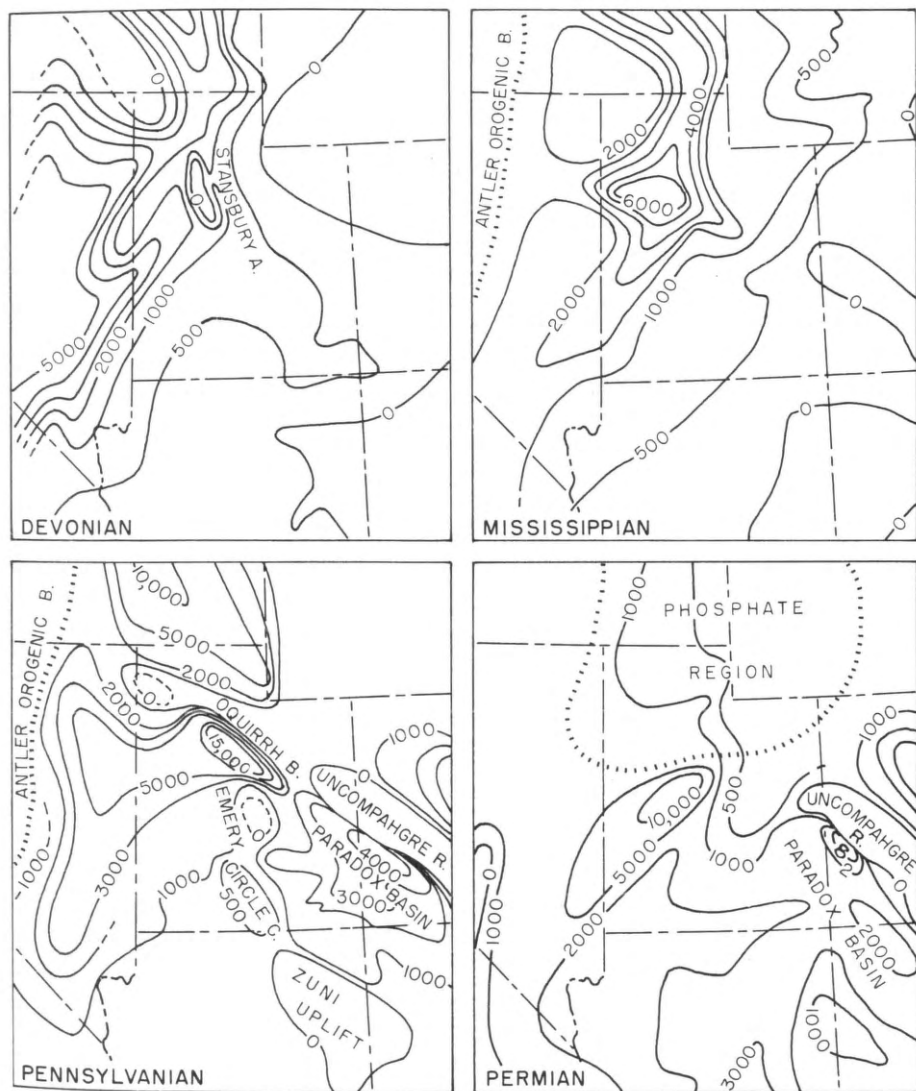
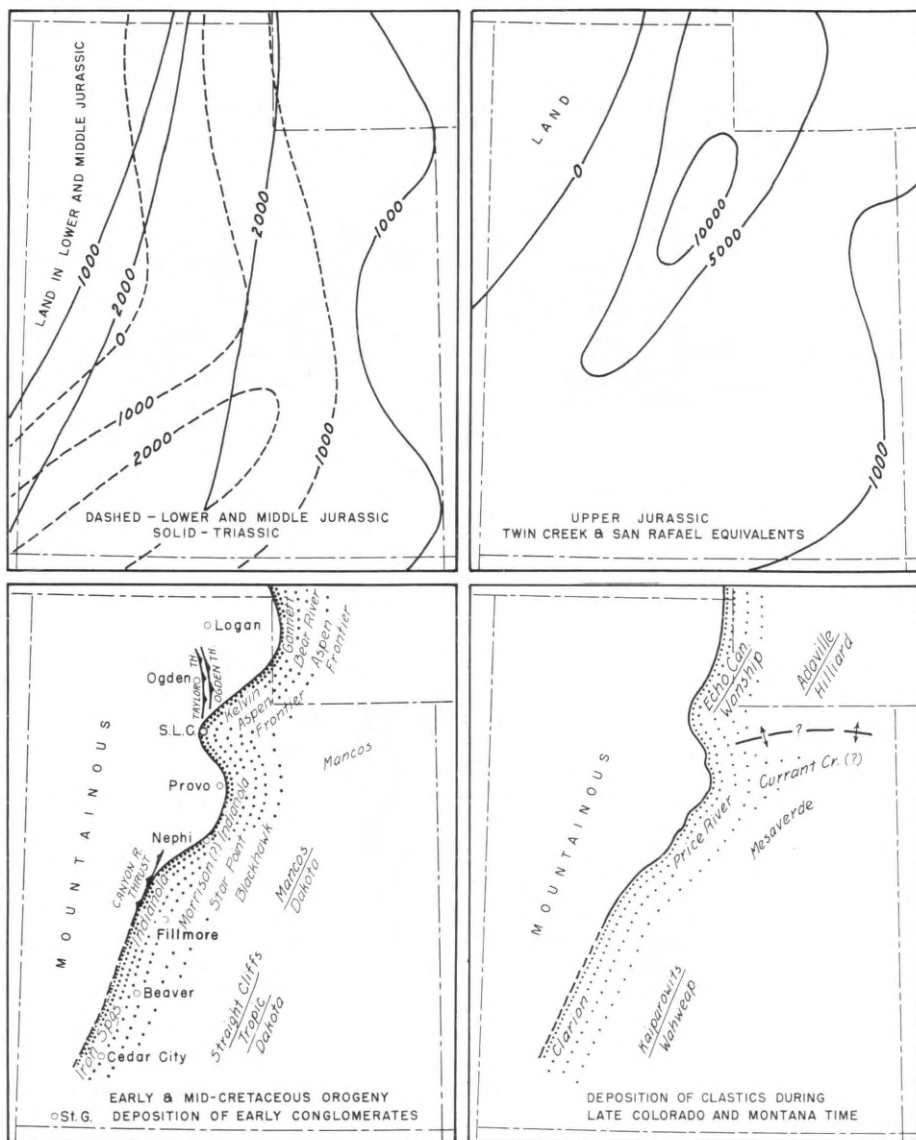


Figure 6. Thickness maps of the upper Paleozoic systems.

lain somewhat west of the present limits of the formations, or else the western source land was low. A very deep trough became localized in central Utah in the Late Jurassic, and during part of the time evaporite conditions prevailed.

Early and mid-Cretaceous paleogeography cannot be constructed to everyone's satisfaction until correlations have been agreed upon. The position of the margin of the western highland that rose vigorously to furnish the conglomerates is detailed on the lower left map of Figure 7. The formations deformed in this Cretaceous orogeny were chiefly the Paleozoic, but the western edges of the Triassic and Jurassic deposits were also upturned or folded, and removed by erosion.



With the deposition of the basal conglomerates and immediately following, a trough sank rapidly and an extremely thick body of sediments of Colorado age accumulated in it. They are now chiefly sandstones, siltstones, conglomerates, and coals.

CRETACEOUS AND TERTIARY OROGENIES

Cedar Hills Orogeny

The Nevadan orogeny, in which the sediments of the western basins in Nevada and California were intensely folded and thrust faulted, and then intruded by great batholiths, occurred in several phases beginning in the Late Jurassic. The major batholiths were emplaced during the early part of the Late Cretaceous. Orogeny spread eastward across the entire Cordilleran geanticline to the eastern trough, and by the beginning of Cretaceous time its elevatory effects were marked by complementary deposition of coarse clastics.

In southeastern Idaho, Mansfield (1927) believes that the Lower Cretaceous Gannett group with several coarse sandstones and conglomerates signifies a sharp uplift of the land to the west as a reflection of the intense Nevadan orogeny still farther west. Probably this uplift in the Utah trough area was a fore-runner of the main orogeny which resulted in the deposition of about 3,000 feet of coarse debris of early Late Cretaceous age, the Wayan formation (J. B. Reeside, personal communication), unconformably on the Gannett.

Near the south end of the Wasatch Mountains in the Cedar Hills, Gunnison Plateau, and Sanpete Valley are immense, coarse deposits probably of early Late Cretaceous age. They make up the basal part of the Indianola group (Spieker, 1946) and are definitely pre-early Upper Cretaceous and post-Upper Jurassic. Since the conglomerates, sandstones, and shales together with some higher fossiliferous marine beds are a lithologic unit, Spieker believes that the deposit is a response to a single uplift and, therefore, that the orogeny occurred at the beginning of Late Cretaceous time. Because of the thick deposit of mid-Cretaceous age in the Cedar Hills, and the information obtained there about the disturbance, the orogeny has been called after them, namely, the Cedar Hills orogeny (Eardley, 1951).

The clastics of the Indianola group are coarsest and thickest (15,000 feet) toward the west in the Cedar Hills and the Gunnison Plateau. They grade eastward into the Mancos shale at the east front of the Wasatch Plateau (Spieker, 1946).

The belt of the Cedar Hills orogeny must have extended from southern Nevada northward through Utah to eastern Idaho. In southern Nevada the Overton conglomerate in the Muddy Mountains is of early Late Cretaceous age (Hewett, 1941) and rests in angular unconformity on folded and thrust faulted Mesozoic rocks, the youngest of which are Jurassic in age (Longwell, 1928). The Overton conglomerate and the angular unconformity are believed to mark the Cedar Hills orogeny in southern Nevada, and the suggestion is made that the belt of orogeny extended continuously between southern Nevada and central Utah by way of the Iron Springs formation in southwestern Utah (Mackin, 1947).

North of the Cedar Hills, in north-central Utah, the Kelvin formation, composed of a basal pebble and cobble conglomerate and overlying red sandstones and siltstones, is probably the equivalent of the lower part of the Indianola group.

It is about 3,000 feet thick and grades eastward into finer clastic sediments. The uplift lay immediately west of the present Wasatch Mountains, and Permian cherts and Pennsylvanian quartzites in the uplift furnished most of the pebbles of the conglomerate. The site of accumulation of the conglomerate became a trough of subsidence, and in the Colorado epoch of Late Cretaceous time over 5,000 feet of strata collected in it. Volcanoes nearby emitted dust which collected as tuff in the lower part of the sequence (the Aspen formation), and then sandstones with numerous oysters and fresh-water shales and sandstones with coal seams accumulated alternately (Frontier formation).

EARLY LARAMIDE OROGENY

A compressional phase of Montana age is clearly recorded in the Wasatch Plateau of central Utah and in the Wasatch Mountains of north-central Utah. (Examine the lower right map of Figure 7).

In central Utah and southeast of Nephi, Spieker (1946) finds that the main orogeny occurred between middle and late Montana time. A great angular unconformity exists with the Price River conglomerates and sandstones resting on the bevelled edges of the Colorado and Jurassic beds. In addition to the unconformity, the orogeny is recorded in the strongly folded and thrust strata of the southern Wasatch Mountains and the continuation of that fold belt southward through Sanpete and Sevier Valleys, the Gunnison Plateau, and the western margin of the Wasatch Plateau. The area affected doubtless extends far westward into the Great Basin. In Mount Nebo, the southern end of the Wasatch Range, the folded strata rise high above the surrounding territory, but in the districts to the south and east they were planed off by erosion immediately after the folding and for the most part buried by the orogenic sediments of the Price River and later formations. The eastern margin of the folded belt follows rather closely the trend of the eastern borders of Sanpete and Sevier Valleys.

North of the Uinta Mountains and east of the Wasatch are two post-Frontier and pre-Tertiary formations that attest orogeny. The lower Wanship formation rests across the bevelled and faulted Frontier (Williams and Madsen, in press), but the unconformity is thought to be local. The Wanship is made up chiefly of sandstone and shale except for a basal conglomerate. Its age is Niobrara and hence pre-Montanian. Apparently conformably on the Wanship formation is the very coarse Echo Canyon conglomerate which marks, evidently, superior orogeny to the west. The Echo Canyon conglomerate had previously been called Almy (Paleocene), but the discovery of pelecypod fossils in its lower part proves that it is all pre-Tertiary. Its lower part is Niobrara (Coloradan), and its upper part is probably Montanian (Williams and Madsen, in press). The Echo Canyon conglomerate appears to be a little older than the Price River conglomerate south of the Uinta Mountains, but otherwise compares closely with the Price River, and the two mark a major orogeny in the western part of the state.

All orogenic events that occurred in Montanian time are arbitrarily classed as early Laramide by the writer, and hence the orogeny marked by the Price River and Echo Canyon conglomerates is here called the early Laramide, although it may have commenced somewhat before the beginning of Montana time north of the Uinta Mountains.

In a late phase of the early Laramide orogeny, the Echo Canyon conglomerate was folded and extensively eroded. This is the time of formation of most of the conspicuous folds and thrusts of the Utah region west and north of the Colorado Plateau.

The structures formed during this phase are shown in the left hand map of Figure 8. Some of these structures may have formed during the Cedar Hills orogeny, and the first phase of the early Laramide orogeny. The age of the structures in the miogeosynclinal areas cannot generally be recognized, but in the Wasatch Mountains area the conglomerates provide good evidence.

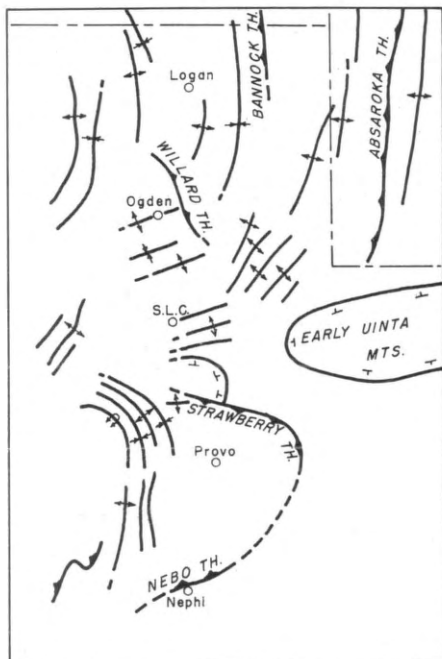


Figure 8a. Latest Cretaceous orogeny (second phase of Early Laramide).

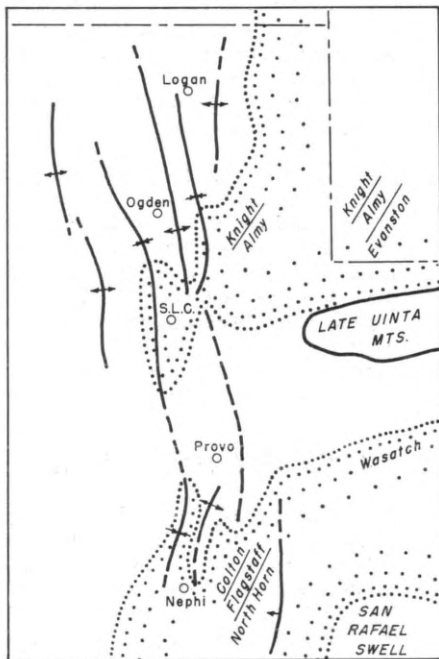


Figure 8b. Deposition of Paleocene and lower Eocene clastics (Mid-Laramide orogeny) followed by folding and faulting; main rise of the Uinta Mountains (Late Laramide).

In the Ogden area it is clear that thrusting occurred early (Taylor and Ogden thrusts), and then thrusting again (the Willard thrust). The Willard, Bannock, and Absaroka thrusts of Figure 8 were all eroded and partly covered by the Evanston, Almy, and Knight formations.

The Uinta Mountains rose as a broad arch, probably first during the deposition of the Price River formation, and then rose again following the deposition of the conglomerate.

MID-LARAMIDE OROGENY

In the north-central Wasatch Mountains and in southwestern Wyoming, a third conglomerate sequence rests in angular unconformity across the eroded Echo Canyon conglomerate and older formations. It is made up of the Evanston, Almy, and Knight formations, and near the Wasatch Mountains on the west is coarse and thick. It attests another major orogeny.

The distribution of the Evanston, Almy, and Knight clastics is shown in the right hand map of Figure 8. Also, the equivalents south of the Uinta Mountains are noted. The Evanston formation is under the Almy in the type locality and post-dates the thrusting (Tracy and Oriel, 1959). The upper part of the Evanston is Paleocene and the lower part latest Cretaceous (Tracy and Oriel, 1959, and Barrett, 1953). The upper part of the North Horn formation is likewise Paleocene, but the lower part is latest Cretaceous (Spieker, 1946).

The equivalent of the conspicuous angular unconformity between the Echo Canyon conglomerate and Almy and Knight sequence is apparently lacking south of the Uinta Mountains. The coarse conglomerates are also lacking and the Flagstaff limestone marks an extensive fresh-water lake in south-central Utah. It must be concluded that the mid-Laramide orogeny was stronger in northern than in central and southern Utah. The region affected lay to the west of the region of deposition, and since the western region had already been folded and broken by thrust faults, it cannot be discerned what new structures, if any, were formed there. At any rate, the western area experienced strong uplift in order to sustain the yield of voluminous sediments to the east.

LATE LARAMIDE OROGENY

Following the deposition of the Knight and equivalents, these rocks in the vicinity of the Wasatch Mountains were cast into broad folds with widths from trough to trough of 5 to 15 miles, and amplitudes of several thousand feet. The single ridge of the Wasatch Mountains north of Salt Lake City (the Farmington Wasatch) was first established as a broad fold at this time. The upfolding of the range was probably accompanied by normal faulting, which later became the major aspect of the deformation, and is recognized as Basin and Range type. It may be surmised that other near-by ranges have had a similar origin and history. This post-Knight folding took a northerly trend and was superposed in places discordantly across older structures. It is here called the late Laramide orogeny.

The first movement that defined the present sharp flexure and faults around the Uintas took place at the close of middle Eocene time after the Green River formation had been deposited and before the Uinta (?) formation started to accumulate (Walton, 1944). Following deposition of the Uinta (?) formation, probably near the close of the Eocene, the second and greatest uplift occurred. The Uinta (?) formation was tilted to an angle of 36 degrees on the southern flank toward the eastern end, and across the truncated edges of the beds of this and older formations. the Duchesne River formation of latest Eocene age was deposited. Toward the west end the Uinta (?) formation was tilted by the uplift, and the Duchesne River formation was deposited across 5,400 feet of its truncated beds (Walton, 1944).

The flexing of the Flagstaff limestone to form the conspicuous westward dips of the west front of the Wasatch Plateau may have occurred in late Eocene time and be related to the main Uinta uplift. If the deformation was not of late Eocene time, it must have occurred soon afterward in mid- or late Oligocene time (post-Duchesne River).

VOLCANIC ACTIVITY

The Park City volcanic field is situated approximately at the junction of the Uinta and Wasatch ranges. At the time of the eruptions, streams carried a large volume of the fragmental volcanic rocks northward into the East Canyon and Morgan Valley area and northeastward into the Evanston area of Wyoming. Existing valleys were filled with volcanic (andesitic) conglomerates, sands, and tuffs. Bones of the latest Eocene titanotheres have been found in the tuff of Morgan Valley (Norwood tuff).

It appears now that the Fowkes tuff of southwestern Wyoming is the Norwood (Eardley, 1959). It had been placed stratigraphically between the Almy and Knight formations by Veatch (1907) and considered Paleocene in age. Actually, it rests unconformably on the Knight and older rocks, but this relation is generally concealed because it is dropped down into long, narrow depressions by faults of the Basin and Range system. Without the Fowkes to separate the Almy and Knight, the Almy now appears to be a basal, and, perhaps, local unit of the Knight formation.

The igneous history of the rest of Utah is varied and complicated (see map, Figure 9). The most voluminous extrusive rocks are quartz latites, and most of these were probably erupted in late Eocene and Oligocene time. Some of the flows are ignimbrites, especially in southwestern Utah, and are part of a large volcanic province extending over eastern Nevada, generally called the ignimbrite subprovince. Younger flows and cinder cones of Pleistocene and Recent age occur and are basaltic.

The intrusive rocks in the Basin and Range province are in the form of stocks and are mostly quartz monzonites. They are the same in composition as the extrusive quartz latites, and probably were derived from the same magma. The stocks post-date the Laramide folds and thrusts and, according to a few isotope age determinations, are Eocene and Miocene in age.

The laccolithic groups of the Colorado Plateau are acidic alkalic rocks and belong to an entirely different igneous province than the quartz monzonites and quartz latites. They are probably fractionation products of an olivine basalt magma which had assimilated considerable amounts of alkali-rich Precambrian basement gneisses and schists.

BASIN AND RANGE FAULTING

Following the Laramide orogenies and the early Oligocene volcanic activity, the crust was broken by numerous high-angle faults, the approximate distribution of which is shown on the lower left map of Figure 9. The fault system trends generally northward, but cuts the older structures discordantly in many places. Horsts, grabens, and tilted blocks are characteristic. Some of the faults, undoubtedly, facilitated the rise of the large late Laramide folds, and therefore had an inception in late Eocene or Oligocene time.

Major faults are localized somewhat in a central belt, and have produced there a zone of trenches and elongated plateaus and ranges, the High Plateaus of Utah. The fault system as a whole is responsible for the internal drainage of the Great Basin. In Utah the faults continued active during Pliocene and early Pleistocene time, and the zone is one of special seismic activity even today.

Gravity surveys by Professors Cook, Berg, and students have demonstrated the presence of buried fault scarps beneath the valley alluvium, and the existence of several deep grabens and cross-trending faults. The vertical displacement of the zone of faults along the Wasatch Mountains may be over 10,000 feet.

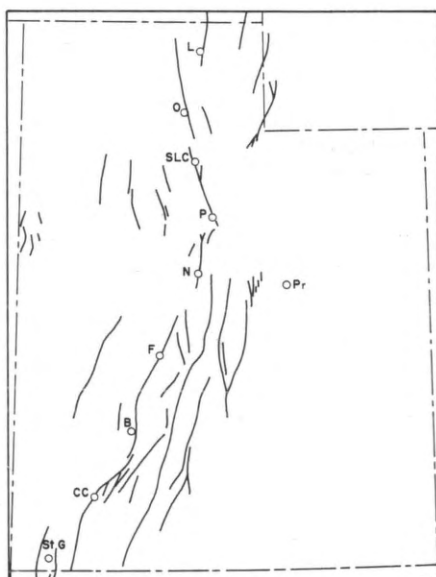


Figure 9a. Basin and Range Fault System, Late Tertiary and Quaternary. L, Logan; O, Ogden; SLC, Salt Lake City; P, Provo; N, Nephi; Pr, Price; F, Fillmore; B, Beaver; CC, Cedar City; St.G, St. George.

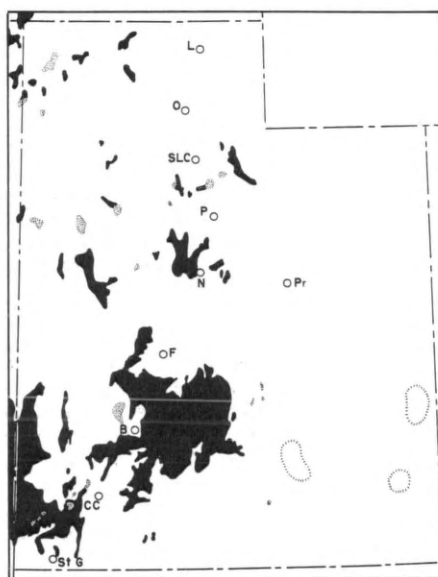


Figure 9b. Igneous rocks. Black, Cenozoic extrusives; stippled, Early and Mid-Tertiary intrusives; hachured, laccolithic groups.

UPLIFT OF COLORADO PLATEAU

The Colorado Plateau was uplifted from about 1,000 feet to about 8,000 feet above sea level in mid-Tertiary time. The major drainage pattern had been established before the uplift, and thereafter the streams entrenched themselves in deep gorges through the resistant sandstones and limestones. The tributaries removed extensive covers of shale and siltstone from the Plateau province. The great flexures that bound the several separate uplifts of the Plateau were formed during Laramide times, and the major streams, either by antecedency or superposition, flow across these structures.

The laccolithic mountains are drained radially, however, and are exceptions to the major drainage pattern. They therefore have been judged to be late Tertiary in origin.

CITED REFERENCES

(All geologic works up to 1939 on the Great Basin and the fringing mountains on the east in Utah are listed in the bibliography in T. B. Nolan's U.S. Geological Survey Prof. Paper 197-D).

Barrett, D. W., 1953, Micropaleontology of the Evanston formation, southwestern Wyoming: Univ. of Utah, M.S. thesis.

Eardley, A. J., 1951, Structural Geology of North America: New York, Harper and Brothers, publishers.

_____, 1959, Review of the geology of northeastern Utah and southwestern Wyoming: Intermountain Assoc. Petroleum Geologists Guidebook 10th Ann. Field Conf., p. 166-171.

Hewett, D. F., 1941, New formation names to be used in the Kingston Range, Ivanpah quadrangle, California: Wash. Acad. Sci. Jour., v. 30, p. 239-240.

Longwell, C. R., 1928, Geology of the Muddy Mountains, Nevada, with a section through the Virgin Range to the Grand Wash Cliffs, Arizona: U.S. Geol. Survey Bull. 798, p. 1-152.

Mackin, J. H., 1947, Some structural features of the intrusions in the Iron Springs district: Utah Geol. Soc. Guidebook, no. 2.

Mansfield, G. R., 1927, Geography, geology and mineral resources of part of southeastern Idaho: U.S. Geol. Survey Prof. Paper 152, p. 1-453.

Nolan, T. B., 1943, Basin and Range province in Utah, Nevada, and California: U.S. Geol. Survey Prof. Paper 197-D.

Spieker, E. M., 1946, Late Mesozoic and early Cenozoic history of central Utah: U.S. Geol. Survey Prof. Paper 205-D.

Tracy, J. I., Jr., and Oriel, S. S., 1949, Uppermost Cretaceous and Lower Tertiary rocks of Fossil Basin: Intermountain Assoc. Petroleum Geologists, Guidebook to the geology of the Wasatch and Uinta Mountains, p. 126-130.

Veatch, A. C., 1907, Geography and geology of a portion of southwestern Wyoming: U.S. Geol. Survey Prof. Paper 56.

Walton, P. T., 1944, Geology of the Cretaceous of the Uinta Basin: Geol. Soc. America Bull., v. 55, p. 91-130.

Williams, N. C., and Madsen, J. H., Manuscript on Echo Canyon conglomerate and Wanship formation (in preparation).

PART II

STRATIGRAPHIC SETTING

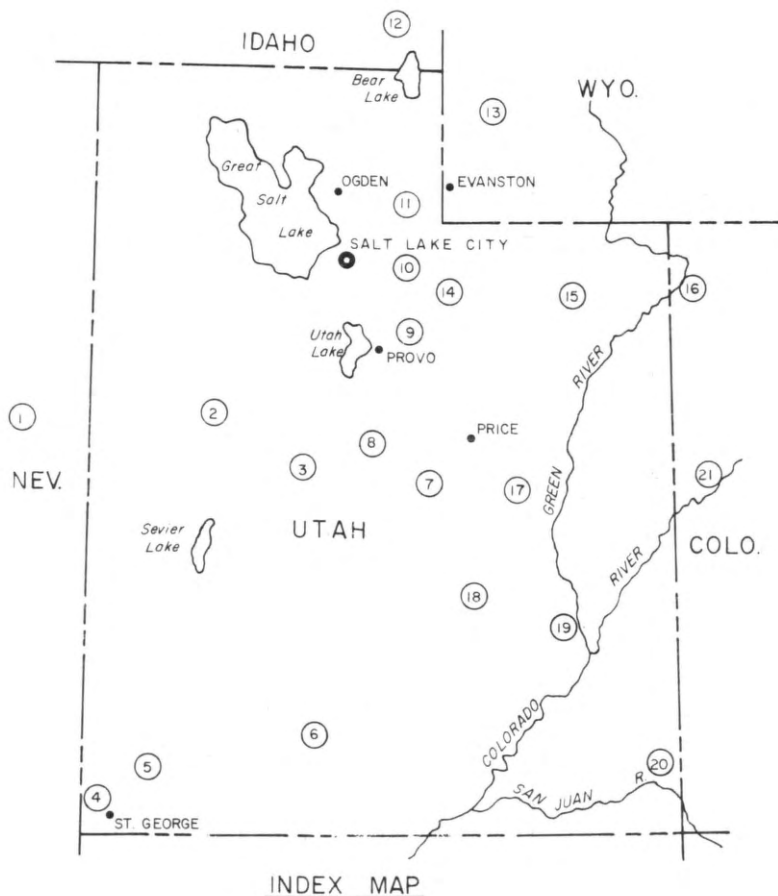
-INDEX TO PART II-

<u>Paper</u>		<u>Page</u>
4	STRATIGRAPHIC CORRELATION CHART, by F. Neighbor, L. Wells, G. Elias.....	33
5	PRECAMBRIAN ROCKS OF UTAH, by E. Blackwelder, A. Granger, R. Cohenour.....	39
	General.....	39
	The Metamorphic Complex.....	39
	Younger Precambrian System.....	42
	Cited References.....	43
6	CAMBRIAN ROCKS OF UTAH, by F. W. Christiansen.....	45
	Introduction.....	45
	Paleogeography.....	45
	Paleotectonic History.....	49
7	SUMMARY OF ORDOVICIAN STRATIGRAPHY OF UTAH, by L. F. Hintze.....	51
	Regional Relations.....	51
	Miogeosynclinal Ordovician of Northern Utah Basin.....	51
	Garden City Formation.....	52
	Swan Peak Formation.....	53
	Fish Haven Dolomite.....	53
	Ordovician Erosion on the Tooele Arch.....	53
	Miogeosynclinal Ordovician of Ibex Basin.....	56
	Pogonip Group.....	56
	Middle Ordovician Quartzites.....	56
	Upper Ordovician Dolomites.....	57
	Ordovician of Eastern Utah Craton.....	57
	Correlation of Utah Ordovician with Other Areas.....	57
	Cited References.....	60
8	SILURIAN STRATA IN UTAH, by R. W. Rush.....	63
	Regional Distribution.....	63
	Stratigraphy.....	67
	Roberts Mountain Formation.....	67
	Jack Valley Formation.....	71
	Decathon Dolomite.....	72
	Cited References.....	72

9	DEVONIAN SYSTEM OF UTAH, by J. K. Rigby	75
	Introduction	75
	Northeastern Utah Basin	76
	Northwestern Utah Basin	77
	Southwestern Utah Basin	81
	Basin Margin Transition	82
	Southeastern Utah Shelf	83
	Northern Utah Shelf	85
	Summary of the Devonian System of Utah	86
	Cited References	86
10	CARBONIFEROUS AND PERMIAN ROCKS OF UTAH, by J. S. Williams	89
	Mississippian System	89
	General Statement	89
	The Madison Limestone and Its Equivalents	90
	Meramecian and Chesterian Rocks	91
	Pennsylvanian System	93
	General Statement	93
	Oquirrh Basin Facies	93
	Morgan-Weber Facies	95
	Pennsylvanian of the Paradox Basin	96
	Pennsylvanian of the Southeastern Area	100
	Permian System	100
	General Statement	100
	Terrestrial Formations of Southeastern Utah	100
	Kaibab Limestone and Associated Formations	102
	Park City Formation and Correlatives	103
	Conclusion	105
	Cited References	106
11	TRIASSIC AND JURASSIC PERIODS IN UTAH, by W. L. Stokes	109
	Introduction	109
	Triassic	109
	Stratigraphic Limits	109
	Major Divisions	109
	Individual Formations	110
	Triassic of the Great Basin	113
	Problems of Correlation	113
	Triassic Paleogeography	115
	Jurassic	115
	Stratigraphic Limits	115
	Major Divisions	116
	Individual Formations	116
	Problems of Correlation	118
	Jurassic Paleogeography	119
	Cited References	121
12	THE CRETACEOUS SYSTEM OF UTAH, by J. A. Burger	123
	Introduction	123
	Discussion by Areas	125
	North Flank of Uinta Mountains	125
	Wasatch Mountains and Western Uinta Mountains	127
	South Flank of Uinta Mountains	128
	Wasatch Plateau and Adjacent Areas	130
	Henry Mountains	132
	Southeastern Utah	133
	Book Cliffs	135
	Southern Utah Plateaus	136
	Cited References	138
13	TERTIARY STRATIGRAPHY OF UTAH, by C. T. Hardy	141
	Introduction	141
	Northern Utah	141
	Uinta Basin	143
	Central Utah	143
	Southern Utah	144
	Cited References	145
14	THE QUATERNARY SYSTEM IN UTAH, by R. E. Marsell	147
	Introduction	147
	Sedimentary Rocks	149
	Detrital Deposits	149
	Cited References	153
15	IGNEOUS ROCKS OF UTAH, by P. D. Proctor, and K. C. Bullock	155
	Intrusive Igneous Rocks	155
	Distribution	155
	Structural Relations of Intrusive Rocks	155
	Composition of Intrusive Rocks	158
	Extrusive Rocks	158
	General Distribution	158
	Origin, Composition, and Character of Extrusive Rocks	158
	Extrusive Rocks of Specific Areas	159
	Age of Igneous Rocks of Utah	167
	Possible Relation to Oil Accumulations	168
	Cited References	169

Paper 4 STRATIGRAPHIC CORRELATION CHART

by Frank Neighbor¹, Louis F. Wells²,
and Gregory Elias³



1. Division Geologist, Sun Oil Company, Denver, Colorado
2. Consultant, Salt Lake City, Utah, formerly Geologist, Sun Oil Company.
3. Geologist, Public Service Company, Durango, Colorado

AREAS		S E IDAHO	S.W. WYOMING	UINTA MOUNTAINS-SOUTH FLANK			SAN RAFAEL	HENRY MTNS.	PARADOX BASIN		WEST CENTRAL COLORADO
DISTRICTS		(2)	(3)	(4) WESTERN	(5) CENTRAL AND UINTA BASIN	(6) EASTERN	(7)	(8)	(9) NORTHERN	(10) SOUTHERN	(11)
SOURCE OF INFORMATION		1 A PG GUIDE BODY TO 4TH ANNUAL FIELD CONFERENCE	SAME AS S.E. IDAHO	UTAH GEOLOGICAL SOC GUIDE BOOK NO 8, 1952	1 A PG GUIDE BOOK NO 5, 1950	TEXAS-UTAH PACIFIC NO 70-32 UNIT	STD. OIL OF CALIF NO 2 SAN RAFAEL WELL	GEOLOGY OF HENRY MTNS REGIONAL HUNT. PROF PAPER NO. 228	PHILLIPS PET NO 1 BARRIER CREEK WELL	1 A PG GUIDE BOOK NO 9, 1958	GENERAL PET NO 1 SHUTE
CENOZOIC	QUATERNARY	Recent									
		UNDIFFERENTIATED	UNDIFFERENTIATED	MORAINES TERRACE GRAVELS	GLACIAL DRIFT						
	TERTIARY	OLIGOCENE	WHITE RIVER		BROWNS PARK BISHOP CONGLOM. DUCHESNE RIVER						
		EDCENE	BRIDGER GREEN RIVER WASATCH KNIGHT		UINTA GREEN RIVER WASATCH						
		PALEOCENE	FOWKES ALMY CONGL.								
	CRETACEOUS	UPPER	EVANSTON		CURRENT CREEK						
			ADAVILLE HILLIARD		MESAVERDE MANCOS	MESAVERDE MANCOS		MESAVERDE MANCOS GROUP Mosak member Emery ss Bluegale ss Ferron ss Tununk shale	MESAVERDE MANCOS		MESAVERDE MANCOS
			FRONTIER ASPEN SHALE		FRONTIER MOWRY - DAKOTA SS	FRONTIER MOWRY DAKOTA SS		DAKOTA SS	DAKOTA SS	DAKOTA SS	DAKOTA SS
		LOWER	WAYAN GANNET GROUP Tyee shale Draney ss Bechler congl Peterson ss Ephraim	BEAR RIVER	CEDAR MTN		CEDAR MTN Buckhorn		BURRO CANYON	BURRO CANYON	
MESOZOIC	JURASSIC	UPPER	BECKWITH		MORRISON	MORRISON	MORRISON Brushy Basin Salt Wash	MORRISON	MORRISON Brushy Basin Salt Wash	MORRISON Brushy Basin Westwater Recapture Salt Wash	MORRISON
			STUMP SS PREUSS SS TWIN CREEK	PREUSS SS TWIN CREEK	TWIN CREEK	CURTIS ENTRADA TWIN CREEK	CURTIS ENTRADA CARMEL	SUMMERVILLE CURTIS ENTRADA CARMEL	SUMMERVILLE CURTIS ENTRADA CARMEL	SUMMERVILLE ENTRADA CARMEL	CURTIS ENTRADA
			NUGGET SS	NUGGET SS	NUGGET SS	NAVAJO SS	NAVAJO SS	NAVAJO SS KAYENTA	NAVAJO SS KAYENTA	NAVAJO SS KAYENTA	NAVAJO SS
	TRIASSIC		WOOD SHALE		CHINLE	CHINLE	WINGATE CHINLE	WINGATE CHINLE	WINGATE CHINLE Owl Creek Mesa Rock Monitor Butte	WINGATE CHINLE	CHINLE
			DEADMAN LS HIGHAM GRIT THAYNES WOODSIDE DINWOODY	ANKAREH THAYNES WOODSIDE	ANKAREH THAYNES WOODSIDE	SHINARUMP ANKAREH THAYNES WOODSIDE MOENKOPI	SHINARUMP MOENKOPI Simbad	SHINARUMP MOENKOPI	SHINARUMP MOENKOPI	SHINARUMP MOENKOPI	

AREAS			S.E. IDAHO	S.W. WYOMING	UINTA MOUNTAINS-SOUTH FLANK			SAN RAFAEL	HENRY MTNS.	PARADOX BASIN		WEST CENTRAL COLORADO
DISTRICTS			(12)	(13)	(14) WESTERN	(15) CENTRAL AND UINTA BASIN	(16) EASTERN	(17)	(18)	(19) NORTHERN	(20) SOUTHERN	(21)
SOURCE OF INFORMATION			I.A.P.G. GUIDE BOOK TO 4TH ANNUAL FIELD CONFERENCE	SAME AS SE IDAHO	UTAH GEOLOGICAL SOC. GUIDE BOOK NO. 8, 1950	I.A.P.G. GUIDEBOOK NO. 5, 1950	TEXAS-UNION PACIFIC NO. 70-32 UNIT	STD. OIL OF CALIF. NO. 2 SAN RAFAEL WELL	GEOLOGY OF HENRY MTNS REGION, HUNT, PROF. PAPER NO. 228	PHILLIPS PET. NO. 1 BARRIER CREEK WELL	I.A.P.G. GUIDE BOOK NO. 9, 1958	GENERAL PET. NO. 1 SHULTE
PALEOZOIC	PERMIAN		PHOSPHORIA Rex chert mbr.	PHOSPHORIA	PARK CITY	PARK CITY	PHOSPHORIA	KAIBAB COCONINO	WESTERN EASTERN KAIBAB CUTLER GP. COCONINO White Rim Organ Rock Cedar Mesa Holgaito LOWER	CUTLER	CUTLER De Chelly ss Organ Rock Cedar Mesa	MAROON
	PENNSYLVANIAN		WELLS	WELLS	WEBER MORGAN	WEBER MORGAN	WEBER MORGAN	HERMOSA	HERMOSA	HERMOSA PARADOX	HONAKER TRAIL PARADOX Ismay Desert Creek Akoh Barker Creek PINKERTON TRAIL MOLAS	MORGAN MOLAS
	MISS.		BRAZER LS. MADISON	BRAZER LS. MADISON	MADISON	BLACK SHALE HUMBUG DESERT MADISON	MADISON	MADISON RED WALL		LEADVILLE MADISON	LEADVILLE	LEADVILLE
	DEVONIAN		THREE FORKS JEFFERSON DOLO.	THREE FORKS	PINYON PEAK		CHAFFEE	ELBERT		OURAY ELBERT Upper Elbert Mc Cracken	OURAY ELBERT Upper Elbert Mc Cracken	DYER
	SIL.		LAKETOWN	LAKETOWN						ANETH	ANETH	
	ORD.		FISH HAVEN SWAN PEAK GARDEN CITY									MANITOU
	CAMBRIAN		ST CHARLES NOUNAN LS. BLOOMINGTON BLACKSMITH UTE LS. LANGSTON SH. BRIGHAM QTZITE			OPHIR SH. TINTIC QTZITE.	PINE VALLEY QTZITE. OPHIR SH.	LODORE SAWATCH	Dolomite & Limestone Upper Middle OPHIR SH. TINTIC QTZITE		LYNCH DOLOMITE BOWMAN LS. HARTMANN OPHIR SH. IGNACIO	PEERLESS SAWATCH
	PRECAMBRIAN				RED PINE SH MUTUAL QTZITE	UINTA MTN. GP	UINTA MTN. GP	BIOTITE GRANITE			PRESENT	

LATE PALEOZOIC PRESENT

AREAS		BASIN AND RANGE PROVINCE			SOUTHWEST UTAH		WASATCH PLATEAU			WASATCH MOUNTAINS		
DISTRICTS		① ELY, NEVADA	② CONFUSION, HOUSE RANGE	③ CANYON RANGE	④ BEAVER DAM MTNS.	⑤ PINE VALLEY AREA	⑥ SOUTHERN	⑦ CENTRAL	⑧ WESTERN	⑨ SOUTHERN	⑩ CENTRAL	⑪ NORTHERN
SOURCE OF INFORMATION		A & P.G. VOL. 37, NO. 1, EASTERN NEVADA GEOL. ASSOC., STRAT. COMM.	A & P.G. GUIDE BOOK NO. 8, 1951	A & P.G. GUIDE BOOK NO. 6, 1951	A & P.G. GUIDE BOOK NO. 7, 1952	A & P.G. GUIDE BOOK NO. 7, CALIF. CO. NO. 1 PICKETT WELL.	CALIF. CO. NO. 1 UPPER VALLEY WELL.	SPIEKER, UTAH GEOL. SOCIETY GUIDE BOOK NO. 4, AND PHILLIPS NO. 1 HUNTINGTON WELL.	SPIEKER, UTAH GEOL. SOCIETY GUIDE BOOK NO. 4, 1949	BAKER, A. A., STRATIGRAPHY OF WASATCH MTNS., PREL. CHART NO. 7	UTAH GEOL. SOCIETY GUIDE BOOK NO. 8, 1952	A. J. EARDLEY, G. S. A. BULL. VOL. 55, 1944
PALEOZOIC	PERMIAN	ARCTURUS FM. RIB HILL SS	PHOSPHORIA LS. KAIBAB LS. SUPAI SS		KAIBAB COCONINO SUPAI UPPER CALLVILLE LS.	KAIBAB COCONINO HERMIT PAKOON	KAIBAB COCONINO RICO	KAIBAB COCONINO		PARK CITY DIAMOND CREEK SS KIRKMAN LS.	PARK CITY	PHOSPHORIA
	PENNSYLVANIAN	ELY FM.	BIRD SPRINGS LS.		LOWER CALLVILLE LS.	LOWER CALLVILLE LS.	HERMOSA	HERMOSA		OQUIRH	WEBER QUARTZITE MORGAN	WELLS
	MISSISSIPPIAN	WHITE PINE SH. GP. Johanna ls.	CHAINMAN SHALE Johanna ls.		REDWALL LS.	BLUE POINT REDWALL	REDWALL	BRAZER MADISON		MANNING CANYON SH. GREAT BLUE LS. HUMBUG DESERET LS. MADISON LS.	DOUGHNUT DESERET LS. MADISON BASAL DOLOMITE CITY CREEK	BRAZER MADISON
	DEVONIAN	PILOT SHALE NEVADA LS.	PILOT SHALE GUILMETTE FM. SIMONSON DOLO. SEVY DOLOMITE		MUDDY PEAK LS.	MARTIN				JEFFERSON DOLO.		JEFFERSON
	SILURIAN	LONE MTN. FM.	LAKETOWN DOLO.									LAKETOWN
	ORDOVICIAN	ELY SPRINGS DOLO. EUREKA QTZITE POGONIP	FISH HAVEN DOLO. EUREKA QTZITE. POGONIP CHOKECHERRY DOLO.		Unnamed Dolomitic Ls.						SWAN PEAK	FISH HAVEN SWAN PEAK GARDEN CITY
	CAMBRIAN	Upper B Middle Limestone, Dolomite and Shales, Undivided	NOTCH PEAK ORR-WEEKS FM. MARJUM LS. WHEELER FM. SWASEY LS. DOME LS. BURNT CANYON LS. BURROWS LS. MILLARD LS. BUSBY QUARTZITE PIOCHE SH. PROSPECT MTN.	Upper Ls. and Dolo. Middle Ls.	PEASLEY LS. CHISHOLM SH. LYNDON LS. PIOCHE SH. PROSPECT MTN. Qtzite		Limestones and Dolomites present			LYNCH DOLOMITE BOWMAN LS. HARTMANN MAXFIELD LS. OPHIR SH. TINTIC QTZITE	MAXFIELD LS. OPHIR SH. TINTIC QTZITE	ST CHARLES NOUNAN LS. BLOOMINGTON BLACKSMITH LS. UTE LS. LANGSTON SH. BRIGHAM QTZITE
PRECAMBRIAN				PROTEROZOIC ROCKS						TILLITE BIG COTTONWOOD SERIES	MUTUAL TILLITE BIG COTTONWOOD SERIES	PRESENT

AREAS		BASIN AND RANGE PROVINCE			SOUTHWEST UTAH		WASATCH PLATEAU			WASATCH MOUNTAINS		
DISTRICTS		① ELY, NEVADA	② CONFUSION, HOUSE RANGE	③ CANYON RANGE	④ BEAVER DAM MTNS.	⑤ PINE VALLEY AREA	⑥ SOUTHERN	⑦ CENTRAL	⑧ WESTERN	⑨ SOUTHERN	⑩ CENTRAL	⑪ NORTHERN
SOURCE OF INFORMATION		A.A.P.G. VOL. 37 NO. 1, EASTERN NEVADA GEOL. ASSOC., STRAT. COMM.	A.A.P.G. GUIDE BOOK NO. 6, 1951	A.A.P.G. GUIDE BOOK NO. 6, 1951	A.A.P.G. GUIDE BOOK NO. 7, 1952	A.A.P.G. GUIDE BOOK NO. 7, CALIF. CO. NO. 1 PROCKET WELL	CALIF. CO. NO. 1 UPPER VALLEY WELL	SPIEDER, UTAH GEOL. SOCIETY GUIDE BOOK NO. 4, HUNTINGTON WELL	SPIEDER, UTAH GEOL. SOCIETY GUIDE BOOK NO. 4, 1949	BAKER, A.A., STRATIGRAPHY OF MOUNTAIN MTNS., PREL. CHART NO. 7	UTAH GEOL. SOCIETY GUIDE BOOK NO. 8, 1952	A.J. EARDLEY, G.S.A. BULL. VOL. 55, 1944
CENOZOIC	QUATERNARY	Recent	VOLCANICS	TERRACE GRAVELS	ALLUVIUM	PYROCLASTICS					ALLUVIUM	ALLUVIUM
			UNDIFFERENTIATED	UNDIFFERENTIATED	LACUSTRINE CLAYS TERRACE SANDS GRAVELS	LANDSLIDE BRECCIA TALUS	LACUSTRINE DEPOS.	MUD FLOWS TERRACE GRAVELS	MUD FLOWS TERRACE GRAVELS	TERRACE GRAVELS	LAKE DEPOSITS	UNDIFFERENTIATED
	TERTIARY	OLIGOCENE			FOOL CREEK CONGL.		BRIAN HEAD		GRAY GULCH CRAZY HOLLOW			SALT LAKE GROUP: Cache Valley West Springs Collingston congl. Norwood tuff
		Eocene	PANACA HULAPAI MUDDY CREEK			CLARON	WASATCH	GREEN RIVER COLTON	GREEN RIVER COLTON	UINTA GREEN RIVER		WASATCH GROUP: KNIGHT
	PALEOGENE		FLOWS-PYROCLASTICS			CEDAR BREAKS		FLAGSTAFF	FLAGSTAFF LS	FLAGSTAFF	KNIGHT ANDESITE	FOWKES ALMY CONGL.
MESOZOIC												
CRETACEOUS	UPPER	LACUSTRINE BEDS		NORTH HORN		PANOWAN GAP	KAIPAROWITS WAWHEAP SS STRAIGHT CLIFF SS TROPIC SHALE	NORTH HORN MESAVERTIDE GROUP PRICE RIVER SOUTH FLAT	NORTH HORN FM. PRICE RIVER SOUTH FLAT	NORTH HORN PRICE RIVER	WANSHIP	HENEFER
JURASSIC	LOWER						DAKOTA SS.	DAKOTA SS.	DAKOTA SS.			
TRIASSIC	UPPER						WINSOR	WINSOR	MORRISON	MORRISON	MORRISON	MORRISON

Paper 5 PRECAMBRIAN ROCKS OF UTAH

by Eliot Blackwelder¹, Arthur Granger¹,
and Robert C. Cohenour²

GENERAL

Although Precambrian formations must underlie the entire state of Utah, they are exposed only here and there in some of the mountain ranges. In most of these localities they have been little more than reconnoitered, and, except for the area near Farmington (Bell, 1952), and Antelope Island in Great Salt Lake (Larsen, 1957), it can hardly be said that they have been thoroughly studied anywhere in the state. Like the Precambrian rocks of other regions, they are in part so metamorphosed and so complexly folded that they are difficult to study, but some of them are altered little more than are some of the Paleozoic formations.

The accompanying sketch-map (Figure 10) shows most of the localities where Precambrian rocks have been recognized in Utah. Of these, the best known are in the Wasatch Range from Brigham City to Santaquin. Other extensive outcrops occur in the Uinta Mountains and in the mountains of the extreme north-western corner of the state. Also there is a less extensive area in the south-west corner of Utah.

In the past, some difficulty has been experienced in distinguishing Precambrian rocks from Cambrian, but more recently definite unconformities have been identified which seem to mark the base of the Paleozoic sequence. On the basis of rather scanty fossils, the overlying beds are referred variously to the Lower and Middle Cambrian series.

The Precambrian formations seem to be readily divisible into two main groups, the older of which is strongly metamorphosed, whereas the younger one is but slightly altered. It may be possible to subdivide the older complex after more detailed study. Thus far, the Utah Precambrian formations have not been correlated successfully with those of other states, although plausible relationships have been suggested. No attempt will be made here to classify any of the rocks in Utah as either Archean or Algonkian, especially as there is much disagreement among geologists as to the exact meaning of those terms.

THE METAMORPHIC COMPLEX

Under this heading are included rocks which are for the most part highly folded and sheared and almost completely recrystallized. They include various kinds of schists and gneisses as well as metamorphic quartzites. Marble has not been observed among them, although it appears in a similar complex on the southern border of Idaho and occurs as pebbles in the Precambrian tillite near Provo.

1. Professor Emeritus and former Head, Department of Geology, Stanford University, Palo Alto, California

2. Geologists, U.S. Atomic Energy Commission.

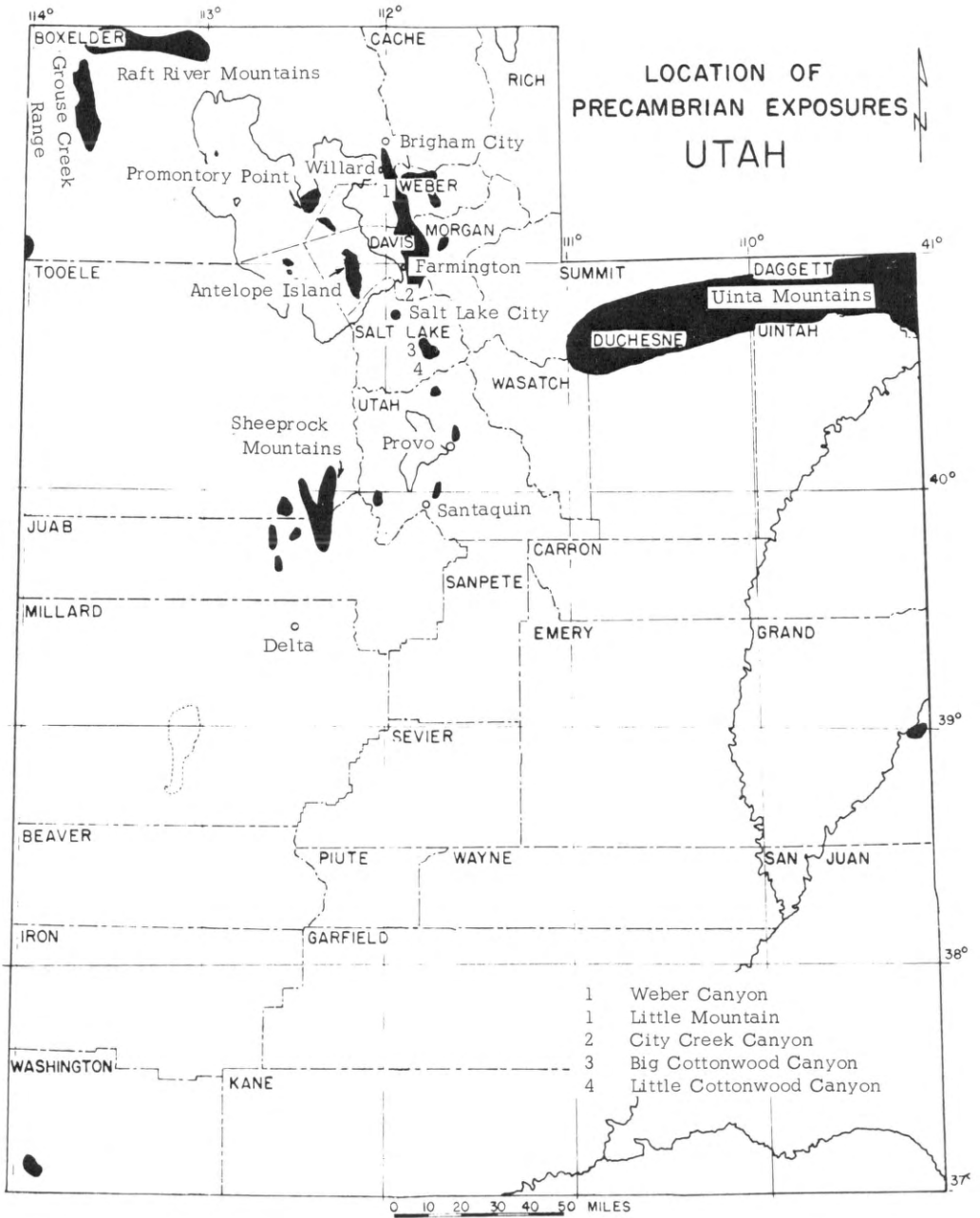


Figure 10.

This ancient complex has been intruded by small masses of granite with attendant dikes and veins. Some of these intrusions have themselves been rendered gneissic, but others remain relatively unaltered, a fact which suggests a marked difference in age among them. This metamorphic complex is best known in the Farmington section of the Wasatch Range, where Crawford (1935), Redden (1935), and Eardley (1940) have examined it, and Bell (1952) has mapped it in detail. Identical rocks on Antelope Island have been mapped and described by Larsen (1957).

The most problematical and perhaps the oldest of these ancient rocks in Utah are the contorted biotite schists, hornblende gneisses, and injection-gneisses which are particularly well displayed in Weber Canyon, on Antelope Island, and in the Farmington section of the Wasatch Range. As reported by Bell, the rocks of the Farmington complex are mostly metamorphosed sedimentaries, with some interlayered metamorphosed igneous rocks, the entire complex being cut by pegmatite dikes. He lists four metamorphic facies: greenschist, amphibolite, migmatite, and granulite, plus hornblende-biotite granite, and pegmatite dikes, as middle Precambrian in age, and a quartz schist as being of late Precambrian age. Recent work by Odekirk (1962) indicates an age of 1,582 million years (plus or minus 16 million years) as the absolute age for the formation of zircon crystals (lead-alpha method) in a granite gneiss of the Farmington complex from Ogden Canyon. Whether or not this age dates the period of metamorphism or is the true age of the rock cannot be stated with certainty; therefore, the Farmington complex is tentatively considered to be middle Precambrian in age. Their age relationship to the Red Creek series, next to be described, is not clear, although outcrops near City Creek Canyon at the extreme southern end of the Farmington complex (Granger, 1954) indicate that the quartz schists of the Farmington complex are older.

A more readily interpreted part of the ancient complex is a series of highly metamorphosed sedimentary rocks which occur in at least five localities widely scattered over the state. They were noted by Powell (1876) in Red Creek Canyon near the Wyoming boundary in the northeastern corner of Utah and called by him the "Red Creek series." Similar rocks occur in the northwestern corner of the state as well as in the Wasatch Range east of Willard, east of Farmington, and southeast of Salt Lake City. The prevailing rocks in this series are silvery muscovite and dark gray biotite schists, some of which contain abundant chlorite, kyanite, garnet, hornblende, and staurolite. With these are associated white, gray, and even clear green metaquartzites which are more or less schistose and entirely recrystallized. Basic igneous rocks which were intruded into the sedimentary strata as dikes and sills have since been intensely deformed and altered to hornblende-schist.

These strata are so complexly folded that no one has yet attempted to work out their stratigraphy, although sections up to 3,000 feet thick have been measured in a few places. Granitic intrusions, with associated dikes of pegmatite and quartz which have invaded them in Dry Mountain southeast of Santaquin and in other localities, seem not to have been intensely deformed in any subsequent orogeny.

The Red Creek system resembles some of the older rocks in the Cherry Creek region in southwestern Montana, the Harrison system in extreme southern Idaho, and especially the metamorphic system in the Medicine Bow Range and the Sierra Madre in southern Wyoming.

North of Little Cottonwood Canyon, east of Salt Lake City, Crittenden, Sharp, and Calkins (1952) assigned the name Little Willow series to a section of strongly folded gneissic quartzites, schists and stretched-pebble schists, intruded by basic igneous rocks (amphibolites). The metamorphism, though intense, was not so pronounced as that which affected the Farmington Canyon complex, nor was it as slight as that which acted upon the overlying Cottonwood series.

The Raft River Mountains and adjacent ranges in northwestern Utah and southern Idaho (Felix, 1956) reveal a thick sequence of similar rocks among which are massive to platy white, gray, and even bright-green metaquartzites; silvery muscovite schists and dark chlorite and biotite schists are also prominent. Some of the layers of schist contain much kyanite. In addition to the sedimentary strata there are bodies of gneissic granite which are probably intrusive into them. A layer of schistose conglomerate in the Grouse Creek Range contains white metaquartzite pebbles resembling beds in the same system, suggesting that there may be an unconformity in this sequence. In the mountains of southern Idaho, just north of the Grouse Creek Range, Anderson (1931) found a thick series of similar rocks, which also includes marble and garnet schist.

YOUNGER PRECAMBRIAN SYSTEM

The best known section of the younger Precambrian rocks is exposed in the lower part of Big Cottonwood Canyon, southeast of Salt Lake City. There are other good exposures north of Ogden and to the east along the axis of the Uinta Mountains. A section by Eardley and Hatch (1940) shows a total thickness of more than 16,000 feet. The whole sequence is so little altered that the geologists of the 40th Parallel Survey originally supposed that they were of Paleozoic age.

The Big Cottonwood series is a 16,000-foot sequence (Crittenden, Sharp, and Calkins, 1952) of quartzites and shales of varying colors and containing ripple marks, cross-bedding, and mud cracks. Above these rocks are from 1,000 to 3,000 feet of Mineral Fork tillite, and above the tillite are up to 1,200 feet of quartzites, shales, and conglomerate designated as the Mutual formation, which contains the youngest Precambrian rocks in the Big Cottonwood area.

In several localities in the Wasatch Mountains and the islands of Great Salt Lake, this upper part of the system includes one or more beds of dark, bouldery slate, or tillite, which is almost surely of glacial origin. Some of these strata are at least 250 feet thick. The gray slates associated with the tillites are finely laminated and contain scattered pebbles. They are interpreted as varved deposits made in glacial lakes. This part of the system is well exposed in Promontory Point, Little Mountain, the adjacent islands of the lake, in the Wasatch Range (near Brigham City and Salt Lake City), and in the Sheeprock Mountains (north of Delta).

In the Sheeprock Mountains, nearly 8,000 feet of metasediments, largely slates, quartzites, and a tillite similar to the Mineral Fork tillite of the Wasatch Range, were mapped and designated the Sheeprock series (Cohenour, 1957). The Sheeprock series, because of the absence of unconformities above or below the lensing tillite unit, probably represents an interval of Precambrian deposition heretofore unrecognized in Utah. Similarly, the source of algal limestone boulders in the tillites of the Wasatch and Sheeprock ranges is unknown; these boulders suggest the presence of hidden Beltian carbonate rocks in the vicinity.

Though tillite is the term many investigators have used for the extremely coarse, poorly sorted, clay-cemented strata, it is possible that not all the material is of glacial origin, and some occurrences may have resulted from ancient mud-rock flows. The rapid facies changes and the absence of chemically precipitated sediments indicates a prevalence of "restricted" continental-type sedimentation which further connotes a region of considerable relief, especially the regions containing tillite or tillite-like rocks.

At the base of the system in Red Creek Canyon (Uinta Mountain area), quartzitic brown sandstone with many beds of fluvial conglomerate rests unconformably on strongly folded beds of the metamorphic complex. The upper limit of the slate and quartzite system is marked by an obscure unconformity beneath the Brigham City (Tintic) quartzite, which is probably of Early or Middle Cambrian age.

As various local sections of the system do not agree closely in detail, it is evident that the formations vary considerably from place to place. A detailed section measured by Powell (1876) near the east end of the Uinta Mountains indicates a great predominance of sandstones or quartzites over shales and the presence of much conglomerate, especially in the lower part. Moreover, the red, brown, and purple beds seem to predominate over the gray.

The Precambrian age of this great thickness of quartzite and slate seems to be adequately established by the fact that it lies unconformably below a thick formation which contains Lower Cambrian fossils in several localities. As long ago noted by Walcott, Powell, and others, many of the shales look promising for fossils, but thus far nothing more than a few indistinct and problematical trails and markings have been found. In the Promontory Range (Olson, 1956) and the Sheeprock Range (Cohenour, 1957), it has been noted that there is an absence of an unconformity between the youngest Precambrian (Mutual formation) and the overlying basal Cambrian quartzites.

There is some difference of opinion regarding the correlation of these younger Precambrian rocks with those of other parts of western United States. Most students of the subject are impressed with their general similarity to the late Precambrian Grand Canyon system of Arizona and the Belt system of western Montana. In all these localities the formations underlie Middle or Lower Cambrian rocks with an unconformity which is locally obscure. They resemble each other in consisting largely of sandy and shaly beds of continental origin and in having been little more severely metamorphosed than the associated Paleozoic strata. On the other hand, Hinds (1936) notes that the Cottonwood system contains little or no limestone and also differs from the beds in Arizona and Montana in having glacial deposits. Because of these and other discrepancies, he argues that they probably belong to an older system which he calls the Uncompahgran.

CITED REFERENCES

- Anderson, A. L., 1931, Geology and mineral resources of eastern Cassia County, Idaho: Idaho Bur. of Mines and Geology, Bulletin 14.
- Bell, G. L., 1952, Geology of the central Wasatch Mountains: Utah Geol. Soc. Guidebook, no. 8, p. 38-43.
- Blackwelder, Eliot, 1935, Summary of the Precambrian rocks of Utah and Wyoming: Utah Acad. Sci., Arts, and Letters Proc., v. 12, p. 153-157.
- Cohenour, R. E., 1957, Geology of the Sheeprock Mountains, Utah: Univ. of Utah, Ph.D. thesis. Published version--1959, Geology of the Sheeprock Mountains, Tooele and Juab Counties, Utah: Utah Geol. and Mineralog. Survey Bull., 63, p. 17-25.
- Crawford, A. L., 1935, Archean (?) metaquartzites east of Bountiful, Utah: Utah Acad. Sci., Arts, and Letters Proc.
- Crittenden, M. D., Sharp, B. J., and Calkins, F. D., 1952, Geology of the central Wasatch Mountains: Utah Geol. Soc. Guidebook, no. 8, p. 2-5.
- Bardeley, A. J., 1940, Precambrian crystalline rocks of north-central Utah: Jour Geol., v. 48, p. 48-72.

- Eardley, A. J., and Hatch, R. A., 1940, Proterozoic (?) rocks in Utah: Geol. Soc. America Bull., v. 51, p. 820.
- Felix, F. E., 1956, Geology of the eastern part of the Raft River Range, Box Elder County, Utah: Utah Geol. Soc. Guidebook, no. 11, p. 78-82.
- Granger, A. E., 1954, Stratigraphy of the Wasatch Range near Salt Lake City, Utah: U.S. Geol. Survey Circ. 296.
- Hinds, N. E. A., 1936, Uncompahgran and Beltian deposits in western North America: Carnegie Inst. of Washington Publication 463.
- Larsen, W. N., 1957, Petrology and structure of Antelope Island, Davis County, Utah: Univ. of Utah Ph.D. thesis.
- Odekirk, J. R., 1962, Lead-Alpha age determinations of five Utah rocks: Univ. of Utah, M.S. thesis, p. 12-27.
- Olson, R. H., 1956, Geology of Promontory Range: Utah Geol. Soc. Guidebook, no. 11, p. 42-44.
- Powell, J. W., 1876, Report on the geology of the eastern portion of the Uinta Mountains: U.S. Geol. and Geog. Survey of the Territories, p. 143.
- Redden, R. E., and Crawford, A. L., 1935, Two basal Cambrian sections west of Morgan, Utah: Utah Acad. Sci., Arts, and Letters Proc., v. 12, p. 169.



Paper 6 CAMBRIAN ROCKS OF UTAH

by F. W. Christiansen

INTRODUCTION

Cambrian rocks crop out in numerous localities in Utah. The most extensive outcrops are located in the ranges of the Great Basin of western Utah and in the Wasatch and Uinta Mountains. Considerable interest is centered around the thick (more than 10,000 feet) and relatively complete section exposed in the House Range and vicinity, located in west-central Utah. This section may prove to be the most complete in North America.

The rocks of this system are locally yielding ores of the base and precious metals, notably in the Tintic mining district; and the limestone consumed in the Geneva Steel Plant is being quarried in central Utah from rocks of Middle Cambrian age. In these and several other areas considerable stratigraphic work has been done, and the results have been published; however, a large amount of general and detailed work, including regional mapping, remains to be done before many of the stratigraphic and paleogeographic problems will be solved.

The Cambrian system of Utah consists predominantly of marine clastic and chemical sediments that developed in and at the margins of an encroaching arm of the sea. In the deepest basins, where deposition was apparently continuous from Upper Precambrian time into the Cambrian, the rocks of Early Cambrian age are chiefly clastics, quartzites and some conglomerates. These relatively coarse clastics grade upward in the section into finer clastics, chiefly shale, and into some chemical sediments, limestones and dolomites, which make up the bulk of the Middle Cambrian section. Chemical sediments, limestones and dolomites, are the predominant types in the Late Cambrian.

PALEOGEOGRAPHY

The lithologic features and general distribution of the Cambrian system suggests a comparatively simple interpretation of Cambrian paleogeography. Marine waters invaded Utah from the southwest, following essentially the old trough that had developed in west-central Utah during late Precambrian time. (Compare Figure 11 with Figure 12.) The Early Cambrian sea was restricted to a relatively irregular trough that extended in a northeasterly direction across western and northern Utah into southeastern Idaho. It was narrow in the present area of Great Salt Lake and to the northeast but broadened to the southwest (Figure 13). Although most of western and northern Utah slowly subsided during Early Cambrian time, the border lands and some small areas within the trough remained relatively high and consequently were the source of quantities of relatively coarse sediments which were shed into the sea and along its margins (Prospect Mountain, Tintic, and Bingham quartzites). Subsidence continued over most of Utah, and Middle Cambrian marine waters spread over most of the state (Figure 12). The highlands were reduced, and by the close of Middle Cambrian time they had been almost completely leveled off. The finer clastics, predominantly shale, which developed mainly during the early part of this epoch, gave way to the development of chiefly chemical sediments.

1. Professor of Geology, University of Utah, Salt Lake City, Utah.

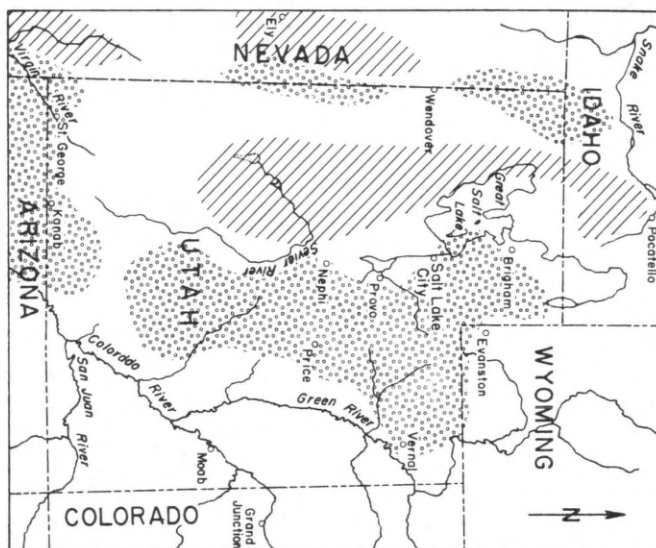


Figure 11. Map showing some of the areas that were uplifted in Late Precambrian times (circles), and areas of thick deposition continuous through to Cambrian time (cross-lined).

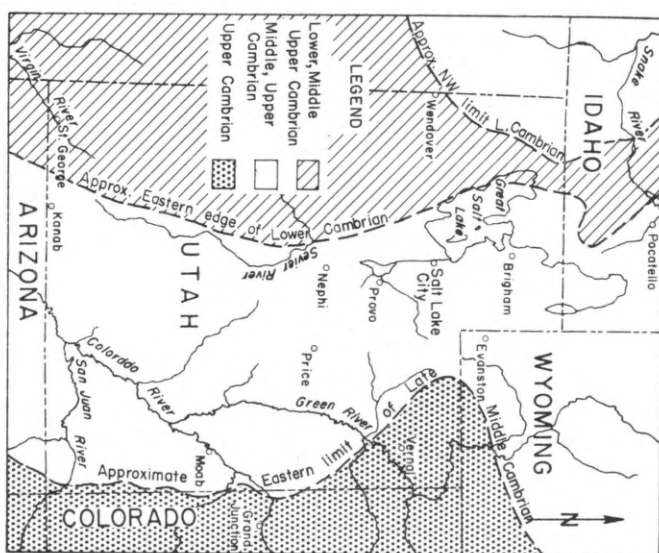


Figure 12. Map showing the distribution of the Cambrian system in Utah.

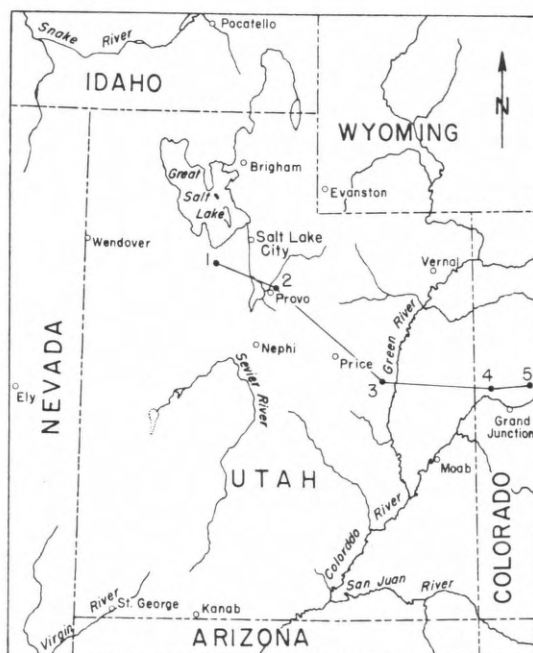
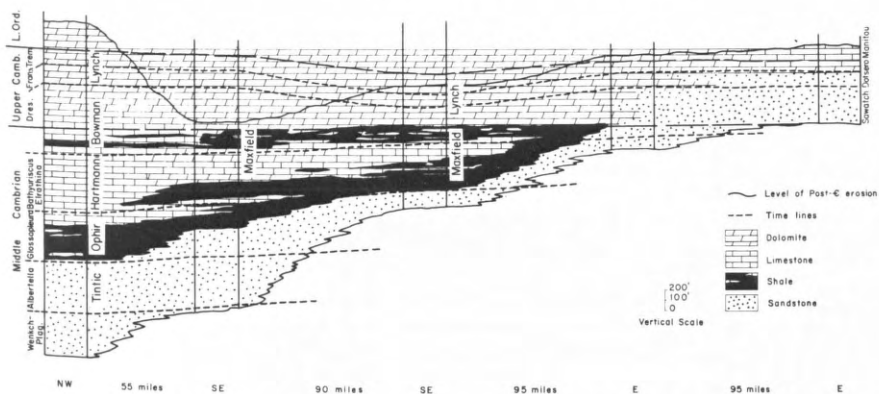


Figure 13. Index map showing location of section illustrated in Figure 14.

1. Quirrh Mountains, Utah 2. So. Wasatch Range, Utah 3. El Paso Natural Gas Co. Packsaddle #1, Utah 4. General Petroleum Co. Schulte #1, Colo. 5. White River Plateau, Colo.



Section from North-Central Utah to Western Colorado, after Christina Lochman Balk, 1956.

Figure 14.

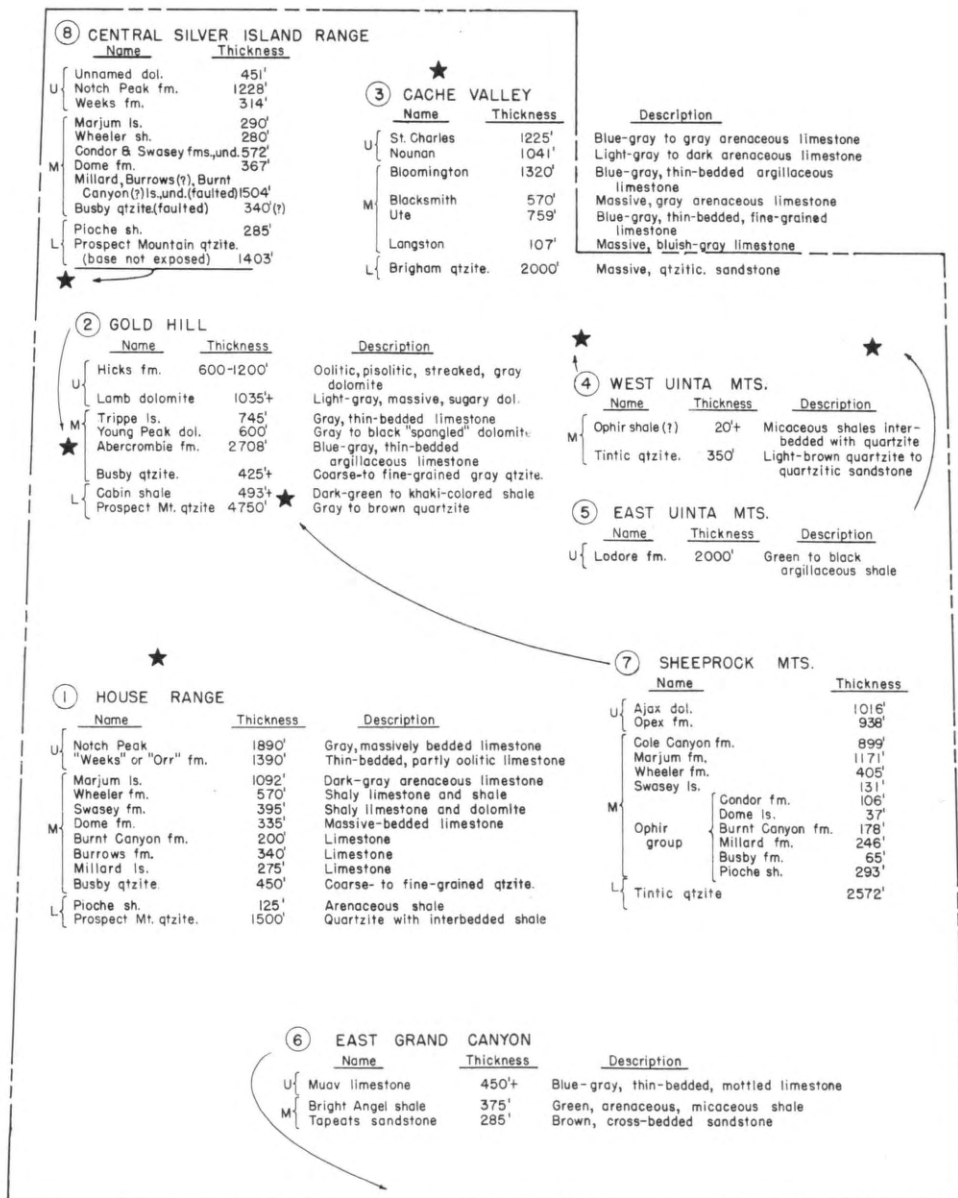


Figure 15. Selected Sections of the Cambrian System of Utah.

With further subsidence the Late Cambrian seas spread eastward into Colorado and westward into Nevada and eventually covered most of the West. Land masses existing in western Nevada and eastern Colorado during Late Cambrian time restricted the lateral extent of the sea. As in most sections of the world, the Upper Cambrian strata of Utah are composed chiefly of chemical sediments, limestones and dolomites. The general condition of slow subsidence that dominated the Late Cambrian of Utah continued without interruption into the early part of the Ordovician.

Sedimentary units that develop under the general conditions of an expanding sea, such as described above, will transcend time lines, as do the Tintic and Ophir formations. The east-west section of Figure 14 illustrates this relationship.

PALEOTECTONIC HISTORY

At the close of Precambrian time, block faulting and local upwarping deformed the late Precambrian rocks in areas such as the Colorado Plateau, Wasatch and Uinta Mountains, Raft River Range, and the Snake Range in east-central Nevada (Figure 3, 11). Prior to and also contemporaneous with this disturbance, several relatively deep troughs in which thick sequences of continental and marine sediments accumulated continued to develop. The thick sequences of sedimentary rocks deposited in these basins thin abruptly toward the uplifted source areas and near them have unconformable relations beneath the Cambrian rocks. In the central and deeper parts of the sites of sedimentary accumulation, as exemplified by the relatively thick sections of the islands of Great Salt Lake, Canyon Range, and Tintic district, there is no evidence of a physical break between late Precambrian and Cambrian rocks. Thus it appears that, locally, deposition was continuous from the Precambrian into Cambrian time (Figure 11).

The great differences in thickness of the Cambrian strata and their lateral variance in lithology and age serve to emphasize the important phases of Cambrian paleotectonic history. Downwarping and the development of a pronounced, relatively narrow trough in western and northwestern Utah and southeastern Nevada continued through most of Early Cambrian time. The centers of maximum subsidence coincide, in general, with the areas where deposition was continuous from the Precambrian into the Cambrian. This would indicate that perhaps the salient features of the trough were inherited from the Precambrian and were in part products of the Late Precambrian orogeny.

During Middle and Late Cambrian time, movement was chiefly vertical and of an epeirogenic nature. Slow, continued regional subsidence by the close of Late Cambrian time had depressed most of the western United States below sea level.

The differences in thickness and age relationships inferred from the foregoing are illustrated and further emphasized by the geologic sections given in Figure 15.



Paper 7 SUMMARY OF ORDOVICIAN STATIGRAPHY OF UTAH

by *Lehi F. Hintze*¹

REGIONAL RELATIONS

A line drawn from the southwest corner of Wyoming to the southwest corner of Utah roughly divides two areas of contrasting Ordovician stratigraphy. East of such a line Ordovician rocks are relatively thin, a few hundred feet thick at most in Wyoming, Colorado, and eastern Utah. West of such a line Ordovician strata thicken to as much as 4,500 feet in western Utah and Nevada. Although Ordovician rock types are much the same in the two areas, principally carbonates and sandstone, the contrast in thickness has enabled recognition that the eastern area was one of little subsidence, hence a stable shelf, or craton; the western area, on the other hand, was one of great subsidence, and, lacking volcanics, has been termed a miogeosyncline (Kay, 1947, 1951). Still farther to the west, Ordovician strata include volcanic rocks and thus are called eugeosynclinal. The relationship of these three belts is shown on Figure 16. Thicknesses of Ordovician strata over the eugeosyncline, miogeosyncline, and craton may be compared by reference to thickness figures given on the correlation chart, Figure 18, where it will also be seen that erosion or nondeposition occupied a much greater part of Ordovician time on the cratonal area than it did in geosynclinal areas.

The line of division between the major Ordovician structural elements in Utah, the craton and the miogeosyncline, coincides roughly with the division between major present-day structural and geomorphic units in Utah.

Thus, the miogeosynclinal Ordovician, confined mostly within the Basin and Range province, is well exposed in the fault block ranges there; but the cratonal Ordovician, under the Colorado Plateaus area, is not exposed at the surface and is not yet certainly identified from well logs.

Within the miogeosynclinal belt Ordovician rocks were deposited in two basins: the Ibex basin and the northern Utah basin. These were separated by the Tooele arch, a positive feature which shows most obviously on the isopach map of Middle Ordovician quartzites, but which shows also on isopach maps of several other Paleozoic intervals from Cambrian to Devonian times (Hintze, 1959).

MIOGEOSYNCLINAL ORDOVICIAN OF NORTHERN UTAH BASIN

Three Ordovician formations are recognized in northeastern Utah and southeastern Idaho. In ascending order these are the Garden City formation, the Swan Peak formation, and the Fish Haven dolomite. These formations have been mapped in the Logan Quadrangle (Williams, 1948) and in the Randolph quadrangle (Mansfield, 1927), and their distribution in these and adjoining areas is shown on Plates I and II of the Intermountain Assoc. Petroleum Geologists Guidebook for 1953.

1. Professor of Geology, Brigham Young University, Provo, Utah.

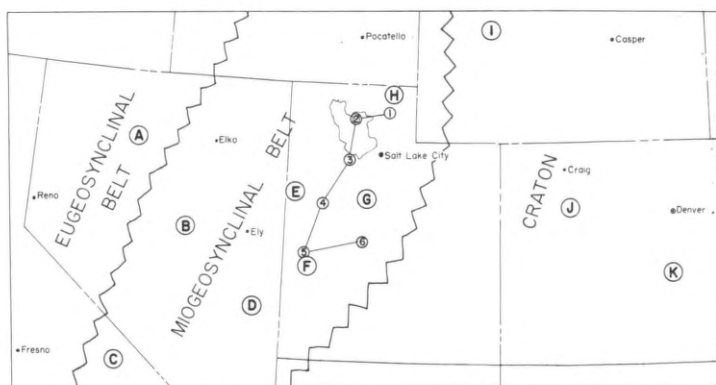


Figure 16. Index map of Ordovician localities shown on Figures 17 and 18, showing their relationship to geosynclinal belts.

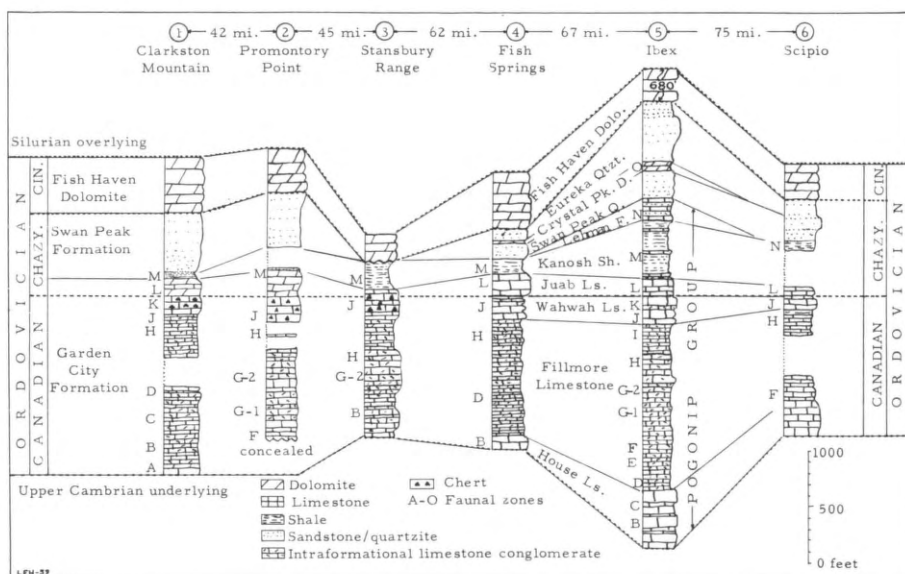


Figure 17. Correlation of Utah Ordovician sections of the miogeosyncline.

Garden City Formation

Two members are recognized in the Garden City formation. The lower member comprises two-thirds of the total thickness in most places and is an interbedded complex of intraformational flat-pebble conglomerate, shaly limestone, and crystalline limestone. The upper member of the Garden City formation is characterized by nodules and stringers of chert within fine-grained limestone and dolomites. The stratigraphy and trilobite faunas of the Garden City and Swan Peak formations have been the subject of detailed studies by R. J. Ross (1949, 1951).

The Garden City formation ranges in age from earliest Ordovician to early Chazyan and is believed to have been deposited mostly in shallow waters of an almost tidal-flat nature.

Swan Peak Formation

Recent mapping and stratigraphic studies have defined two members in the Swan Peak formation of northeastern Utah. The lower member, usually less than 200 feet thick, is composed of nonresistant slope-forming interbeds of shale, thin-bedded sandstones, limestone, and dolomites. This member is lithologically and faunally similar to the Kanosh shale of the Ibex basin, and this name has been appropriately extended into the northern Utah basin by recent mapping in the ranges northeast of Wendover. On the isopach maps which accompany this paper, the shaly member of the Swan Peak formation is included within the Pogonip-Garden City interval rather than with the Ordovician quartzites. The upper Swan Peak member, attaining a thickness of over 500 feet, is a conspicuous, light-colored, cliff-forming quartzite with associated quartz sandstones. Ross (1949, 1951, 1953) and others have identified or described trilobites, brachiopods, ostracods, and graptolites from the lower member of the Swan Peak formation and have dated it as early Chazyan. Robert C. Bright (personal communication) has recently discovered large, simple-cone conodonts in the reddish-brown sandstones at the base of the upper quartzite; he reports that this conodont fauna most closely resembles that found in the middle Chazyan Dutchtown formation of Missouri. The massive quartzites of the upper Swan Peak formation have not yielded fossils.

Fish Haven Dolomite

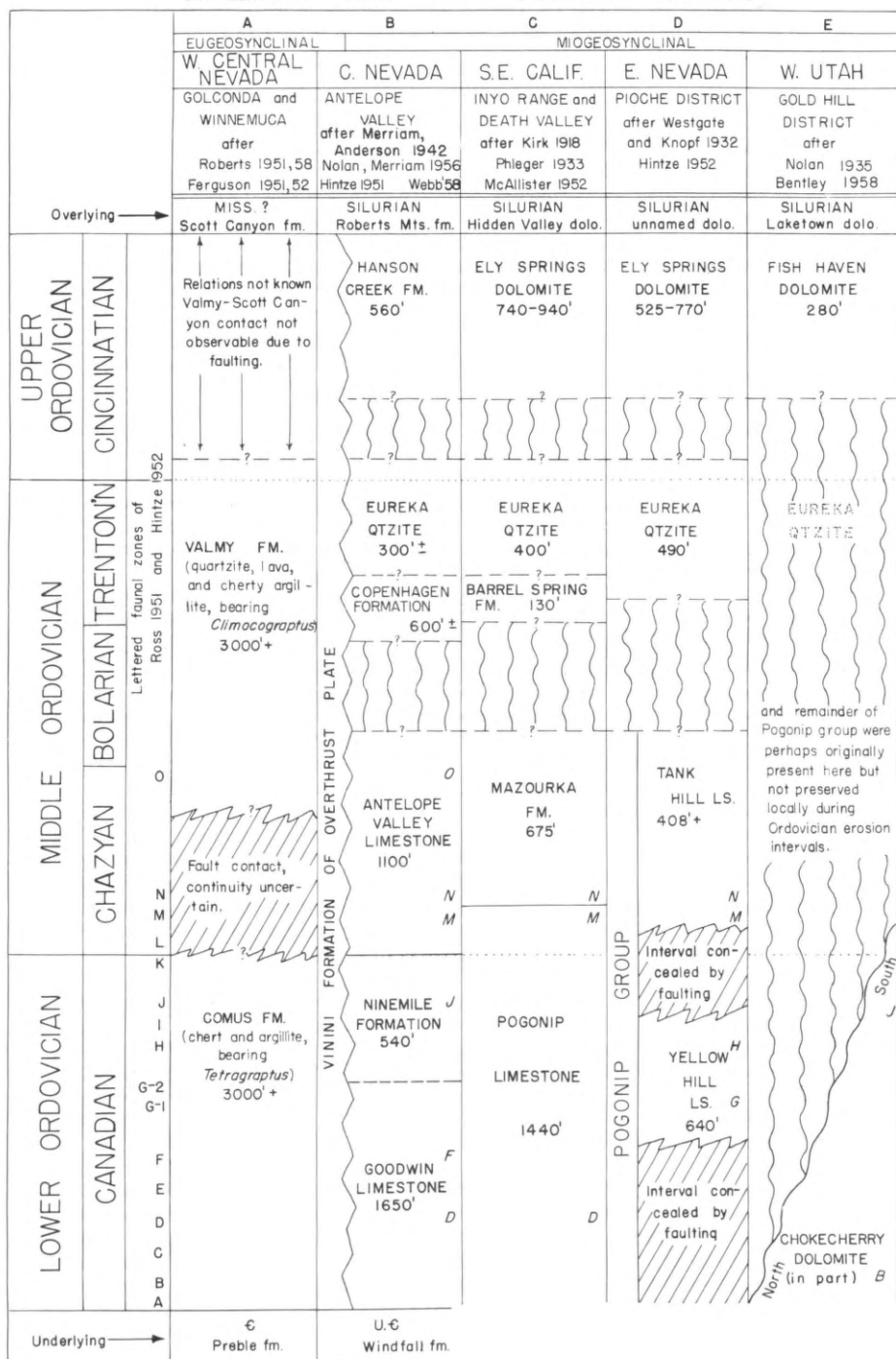
Perhaps the most widespread and most uniform, in thickness and lithology, of all Ordovician formations in Utah, the Fish Haven dolomite has been the subject of the least study. On the basis of its coral and brachiopod fauna, it has been correlated with Upper Ordovician dolomites on the craton to the east and in the geosyncline to the west. In contrast to Lower Ordovician carbonates, which vary so markedly in thickness from craton to geosyncline, the Upper Ordovician dolomites are more uniformly distributed, are present over several places on the craton where other Ordovician is lacking, and do not exceed eight hundred feet in thickness even over the geosynclinal area (Figure 18). Where Silurian dolomite is present, the Upper Ordovician is often difficult to separate from it; hence, published thickness figures for the Upper Ordovician may include some Silurian and vice versa. Data published in the last decade has made it possible to present an isopach map for this unit (also see Hintze, 1960).

Upper Ordovician deposits represent the most widespread invasion of any Paleozoic sea in North America; the marine carbonate sheet deposited at that time sealed off the underlying Ordovician and Cambrian sands as well as some of the Precambrian crystalline areas from thenceforth being sources of quartz detritus.

ORDOVICIAN EROSION ON THE TOOELE ARCH

The absence of Ordovician strata in central Utah is shown graphically on the accompanying isopach maps, where it may be seen that only part of the normal Ordovician sequence is present in the Stansbury Mountains, Lakeside Mountains, and in the Tintic and Gold Hill mining districts. In these areas Upper Ordovician dolomites directly overlie various parts of the Lower Ordovician, and the Middle Ordovician sandstones are conspicuous by their absence (Webb, 1958).

CORRELATION CHART FOR ORDOVICIAN FORMATIONS



OF WESTERN UNITED STATES

F	G	H	I	J	K
MIOGEOSYNCLINAL			CRATON		
W UTAH	C. UTAH	N.E. UTAH S.E. IDAHO	C. WYO	N.W. COLO.	C. COLO.
IBEX AREA after Hintze 1951, 1952, Webb 1953, 1958.	TINTIC DISTRICT after Lovering 1949, Hintze 1951 Morris 1957	after Ross 1951, 53	WIND RIVER MOUNTAINS after Miller 1930 Baker 1946	WHITE RIVER PLATEAU after Bass and Northrop 1953	ROCKY MTN. FRONT after Cloud, Barnes 1948, Maher 1950, Flower 1952, Berg 1958 Frederickson, Pollack 1952, Sweet 1954
SILURIAN Laketown dolo.	SILURIAN Bluebell dolo.	SILURIAN Laketown dolo.	DEVONIAN Darby fm.	DEVONIAN Chaffee fm.	MISS.(?) Williams Canyon ls.
FISH HAVEN DOLOMITITE 630'	FISH HAVEN DOLOMITITE 275 - 350'	FISH HAVEN DOLOMITITE 140-500'	BIGHORN DOLOMITITE 300-600'		DOLO. Priest Canyon member 0-211'
			Lander ss. member, 2-4'		MASSIVE member 0-208'
? ?	?	?			?
EUREKA QTZITE 540'					
?					?
CRYSTAL PEAK DOLOMITITE 85' O					
SWAN PEAK QTZITE 250'		SWAN PEAK FM. Qtzite member 0-500'			
LEHMAN FM. 200' N		Shaly memb. 0-270' M			
KANOSH SH 550' N					
JUAB LS. 140' L		Cherty and dolomitic ls. member 200-425' K			
WAHWAH LS. 230' J					
FILLMORE LS. CG. G-2 G-1 1540'		LS. and LS. cg. member 960-1340' F			
OPOHONGA LS. 400-1000' F					
HOUSE LS. 475' B		GARDEN CITY FORMATION E D C B A		MANITOU FM. Tie Gulch dolo. 47-66' Dead Horse int. ls. cg. B 47-108'	MANITOU FORMATION 0-187' E D C B
				U.C. Dotsero fm.	U.C? Ute Pass dolo.

L. F. Hintze - 1959

formations with surrounding areas.

This relationship is especially well shown on the geologic map of the Stansbury Range (Rigby, 1958a) where the Fish Haven dolomite rests on successively lower members of the Garden City formation toward the north in the map area.

MIOGEOSYNCLINAL ORDOVICIAN OF IBEX BASIN

A broad threefold division of Ordovician strata, somewhat similar to that of northern Utah, may be recognized in western Utah. The lowest unit, the Pogonip group, is dominantly of clastic limestones; above this are Middle Ordovician sandstones and quartzites; the Upper Ordovician is dolomitic.

The distribution of Ordovician outcrops is best shown on the new 1:250,000 State Geologic Map of Utah 1962. The best reference section for Ordovician rocks in the western United States is that at Ibex in Millard County (Hintze, 1951, 1952).

Pogonip Group

Six formations have been defined by Hintze (1951) in the Pogonip group of western Utah (Figure 18). The lowest two formations, the House limestone and Fillmore intraformational limestone conglomerate, correspond in lithology and age with the lower member of the Garden City formation. The middle formations, the Wahwah and Juab limestones, correlate faunally with the upper Garden City formation, but differ from it in lithology as they lack chert and dolomite. The next higher formation, the Kanosh shale, contains fossils like those in the shaly lower member of the Swan Peak formation of northern Utah. The highest Pogonip, the Lehman formation, contains fossils younger than any so far reported from the Middle Ordovician of northeastern Utah. The Pogonip group attains a maximum thickness in Utah of 3,100 feet in the Ibex area. Fossils ranging in age from earliest Ordovician to middle Chazyan have been identified or described from the Pogonip group by Hintze (1952).

Middle Ordovician Quartzites

In the Ibex area of western Utah and in the ranges of the Great Salt Lake desert northeast of Wendover (Paddock, 1956), several hundred feet of Middle Ordovician quartzite beds are divided into two unequal units by a dolomite bed. Webb (1953, 1958) has assigned the lower, thinner quartzite unit to the Swan Peak formation and the upper quartzite to the Eureka quartzite. Elsewhere in western and central Utah where the intervening dolomite beds are lacking, it has been difficult to determine whether the Middle Ordovician quartzite should be assigned to the Eureka or to the Swan Peak. Ross (1953, p. 24) has suggested that perhaps the Eureka and the Swan Peak quartzites are equivalent and are part of a single quartzite unit which overlies progressively younger Ordovician beds as it extends westward into central Nevada.

The Middle Ordovician quartzites of the Great Basin have been the subject of detailed study by Webb (1953, 1958) who believes that the Swan Peak-Eureka deposition is more complex than heretofore suspected, consisting of both regressive and transgressive phases. These quartzites are of interest as possible reservoir beds for petroleum.

Upper Ordovician Dolomites

To date the Upper Ordovician dolomites have received no special study in the Great Basin, and little can be added to the information shown on the correlation chart and isopach map and discussed above under the Fish Haven dolomite.

ORDOVICIAN OF EASTERN UTAH CRATON

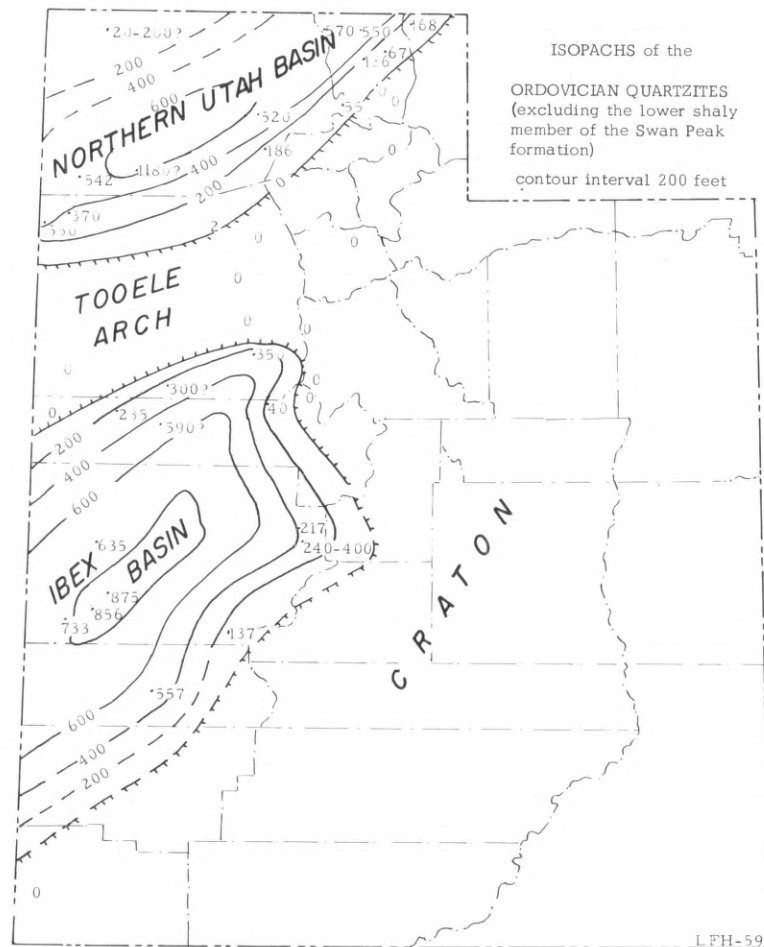
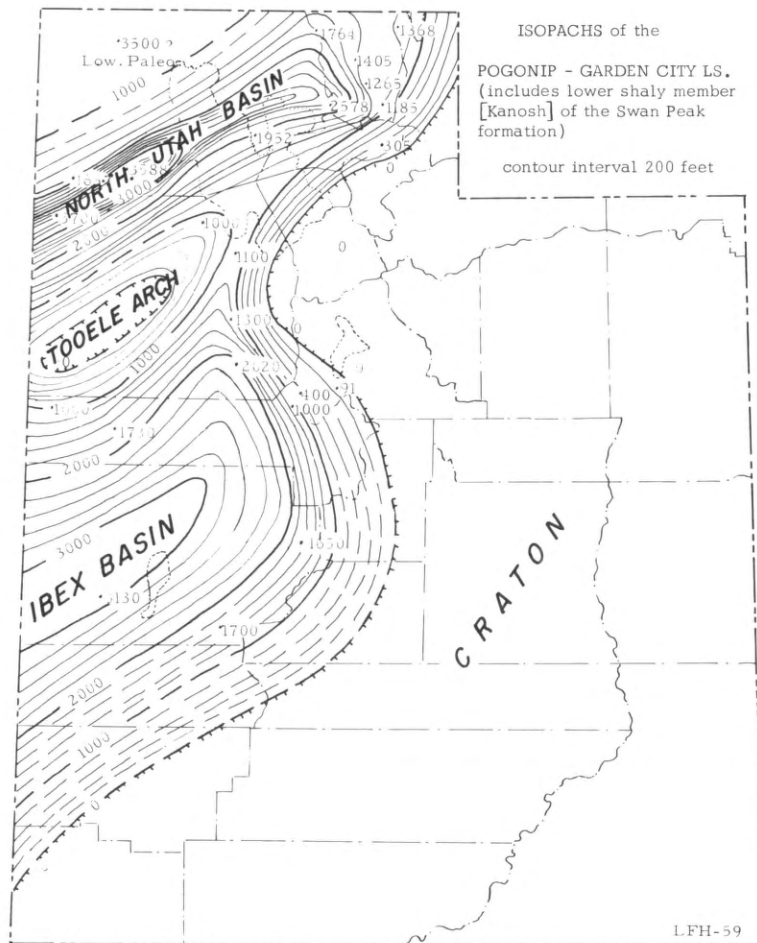
Eastern Utah has long been favored over the rest of the state for oil exploration. A great many more wells have been drilled there than elsewhere, and to date it is the only part of the state yielding commercial production. Recently, Weirich (1953) has advanced a stratigraphic reason as to why oil is more likely to occur in eastern than in western Utah. This is the principle, based on empirical observation, that oil is much more likely to originate, migrate, and accumulate over shelf areas along the margins of the craton than it is in the adjacent geosynclinal areas. Although the Ordovician is low in the stratigraphic column, its position need not cause it to be ignored, for commercial production comes from analogous lower Paleozoic "shelf" beds in Wyoming. Stratigraphically and structurally the Ordovician of eastern Utah should be of interest to petroleum geologists.

Perhaps the most obvious thing which the published records show is that the Ordovician is thin or absent over all of eastern Utah. The lower Paleozoic beds are exposed around the flanks of the Uinta Mountains, but Ordovician beds are entirely lacking, not only in that area but also westward from there at least to the Provo vicinity and probably farther westward.

In southeastern Utah a number of wells have been drilled, but relatively few of these have penetrated the lower Paleozoic. Accurate faunal control of the lower Paleozoic sequence is apparently lacking in the few published well logs, for most of them show these strata as "Undifferentiated Paleozoic" or as "Cambrian (?) - Devonian" with an erosional interval between. Recent Intermountain Association of Petroleum Geologists Guidebooks discuss the Cambrian and Devonian rocks of eastern Utah in some detail; Ordovician strata, if present in the subsurface, seem to be limited to the area west of the San Rafael and South Last Chance fields in Emery County. Dolomites less than 100 feet thick at the top of the Cambrian in these fields may be Ordovician. In adjacent northwestern Colorado, Bass and Northrop (1953) have recently differentiated the Lower Ordovician Manitou formation from limestones and dolomites formerly believed to be entirely Upper Cambrian, so possibly the apparent lack of Ordovician limestone in published well logs from eastern Utah may be due in part to lack of recognition. However, Silurian and Devonian erosion is a more likely explanation. It is hoped that future drilling will clarify this problem. At any rate, we know that the entire lower Paleozoic sequence is comparatively thin in eastern Utah, and that the Ordovician, if present, certainly cannot exceed more than a few hundred feet in thickness there. No production is yet reported from Ordovician horizons in eastern Utah.

CORRELATION OF UTAH ORDOVICIAN WITH OTHER AREAS

Recent studies by Ross (1951) and Hintze (1952) have defined fifteen faunal zones in the Lower and early Middle Ordovician of Utah. These are indicated on the columnar sections (Figure 17) and the correlation chart (Figure 18) by letters. The zones are based principally on a succession of trilobites which are now better known from this part of the stratigraphic column in Utah than



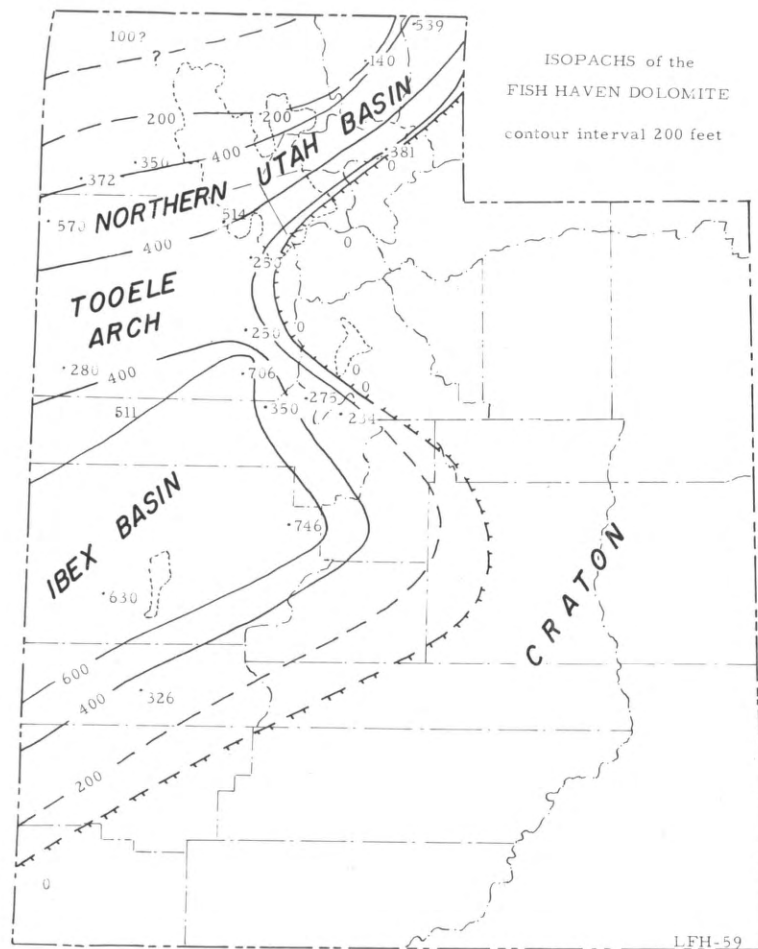


Figure 21.

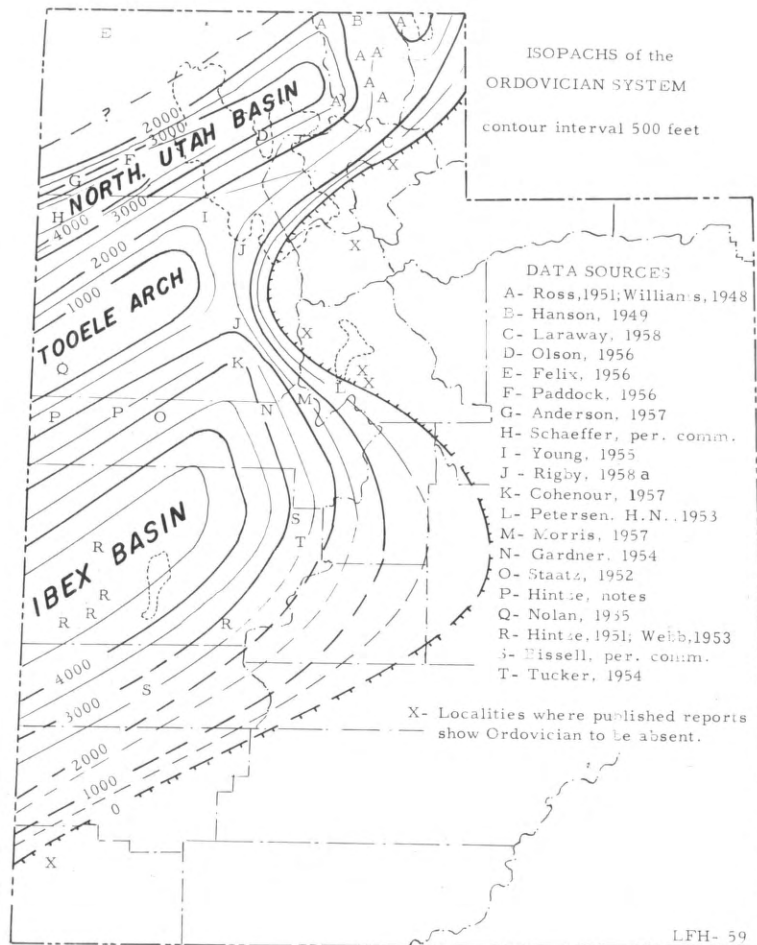


Figure 22.

they are from any place else in the world. Rigby (1958b) has listed the graptolites from these zones. Despite this zoning it is difficult to establish detailed correlations with rocks of other areas bearing non-trilobite faunas, for example, the Lower Ordovician of Missouri, Oklahoma, and Texas. In these states the Lower Ordovician is dolomitic and cherty, and bears a molluscan fauna dominated by gastropods and cephalopods. On the basis of the very few fossils which the Utah Ordovician shares in common with the mid-continent region, we may say that the Garden City-Pogonip faunal zones "A" through "J" are approximately equivalent to faunas found in the El Paso and Ellenburger formations of Texas, the upper Arbuckle group of Oklahoma, and in the Lower Ordovician formations, Gasconade through Black Rock, of the Ozark region, Missouri. Equivalents of Utah Chazy zones "L" through "N" are apparently represented in the lower Simpson group (Joins and Oil Creek) of Oklahoma.

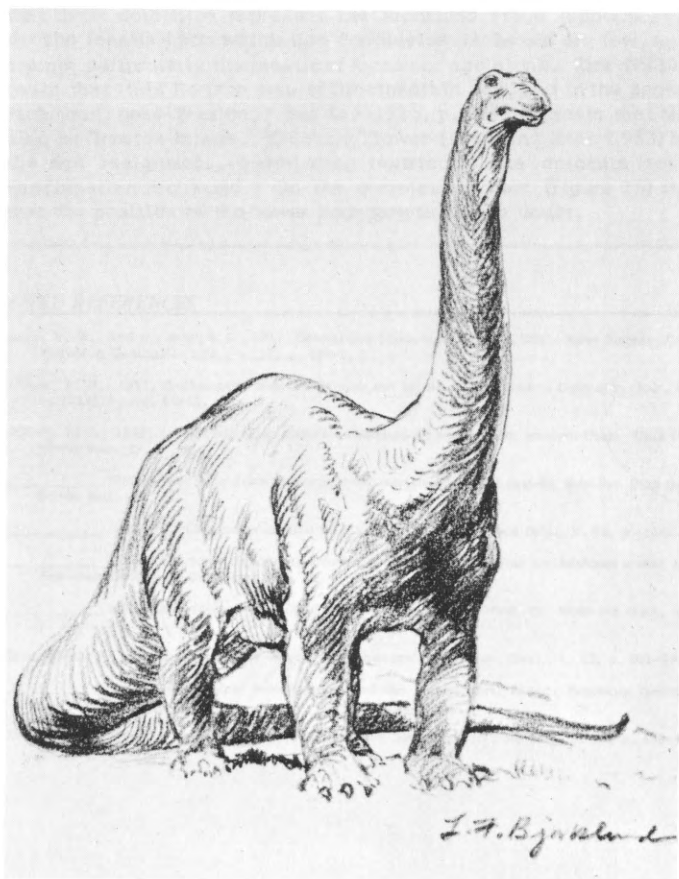
Middle Ordovician quartzites, lacking fossils except at the base, are difficult to date. On the basis of a regional study, Webb (1953, 1958) assigned the Swan Peak quartzite to the Chazy and the bulk of the Eureka quartzite to the Trentonian.

Although the faunas of the Upper Ordovician dolomites of the West are well known, there is little agreement among authorities as to exactly how much of Late Ordovician time is represented by the dolomite. It is generally supposed that these dolomites represent the Richmond stage (uppermost Cincinnati), but the fossils upon which this conclusion is based are few, and most of them are not particularly diagnostic of Richmond age alone. Kirk (1930, p. 464) suggests that "this horizon was of Cincinnati age, and in the sense of being pre-Richmond, post-Trenton." But Kay (1935, p. 589) suggests that these rocks may also be Trenton in age. Recently Flower (1952) and Ross (1953) have discussed the age assignment, questioning restricting the dolomite to the uppermost Cincinnati Richmond. On the correlation chart (Figure 18) it will be noted that the position of the lower boundary is left in doubt.

CITED REFERENCES

- Bass, N. W., and Northrop, S. A., 1953, Dotsero and Manitou formations, White River Plateau, Colorado: *Am. Assoc. Petroleum Geologists Bull.*, v. 37, p. 889-912.
- Flower, R. H., 1952, Cephalopods from the Harding and Manitou formations of Colorado: *Jour. Paleontology*, v. 26, p. 505-518, pls. 60-61.
- Hintze, L. F., 1951, Lower Ordovician detailed stratigraphic sections for western Utah: *Utah Geol. and Mineralog. Survey Bull.* 39.
- _____, 1952, Lower Ordovician trilobites from western Utah and eastern Nevada: *Utah Geol. and Mineralog. Survey Bull.* 48.
- _____, 1954, Mid-Ordovician erosion in Utah: *Geol. Soc. America Bull.*, v. 65, p. 1343.
- _____, 1959, Ordovician regional relationships in north-central Utah and adjacent areas: *Intermountain Assoc. Petroleum Geologists Guidebook*, no. 10, p. 46-53.
- _____, 1960, Ordovician tectonics of western Wyoming and vicinity: *Wyoming Geol. Assoc. Guidebook* 15, p. 111-115.
- Kay, Marshall, 1935, Ordovician Stewartville-Dubuque problems: *Jour. Geol.*, v. 43, p. 561-590.
- _____, 1947, Geosynclinal nomenclature and the craton: *Am. Assoc. Petroleum Geologists Bull.*, v. 31, p. 1289-1293.
- Kirk, Edwin, 1930, The Harding sandstone of Colorado: *Am. Jour. Sci.*, 5th ser., v. 20, p. 456-466.

- Paddock, R. E., 1956, Geology of the Newfoundland Mountains, Box Elder County, Utah: Univ. of Utah M.S. thesis.
- Rigby, J. K., 1958a, Geology of the Stansbury Mountains, Tooele County, Utah: Utah Geol. Soc. Guidebook, no. 13.
- _____, 1958b, Lower Ordovician graptolite faunas of western Utah: Jour. Paleontology, v. 32, p. 907-917.
- Ross, R. J., Jr., 1949, Stratigraphy and trilobite faunal zones of the Garden City formation, northeastern Utah: Am. Jour. Sci., v. 247, p. 472-491.
- _____, 1951, Stratigraphy of the Garden City formation in northeastern Utah, and its trilobite faunas: Yale Peabody Mus. Nat. Hist. Bull. 6.
- _____, 1953, Ordovician system in northeastern Utah and southeastern Idaho: Intermountain Assoc. Petroleum Geologists Guidebook 4th Ann. Field Conference.
- Webb, G. W., 1953, Middle Ordovician stratigraphy in eastern Nevada and western Utah: Columbia Univ., Ph.D. thesis. Published version--1956, Middle Ordovician detailed stratigraphic sections for western Utah and eastern Nevada: Utah Geol. and Mineralog. Survey Bull. 57.
- _____, 1958, Middle Ordovician stratigraphy in eastern Nevada and western Utah: Am. Assoc. Petroleum Geologists Bull., v. 42, p. 2335-2377.
- Weirich, T. E., 1953, Shelf principle of oil origin, migration and accumulation: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 2027-2045.



Paper 8 SILURIAN STRATA IN UTAH

by Richard W. Rush²

The Silurian system is a relatively thin but important part of the stratigraphic column in western Utah and eastern Nevada. In Utah it has been recognized west of the Wasatch line within two broad shallow basins of the geosyncline (Figure 23). Throughout much of the area the Silurian rocks average approximately 1,000 feet thick. The eastern outcrops consist of asphaltic dolomite. Near the Utah-Nevada border the system is less asphaltic and more fossiliferous. A regional summary of the system was made by McFarlane (1955). Several local papers have since described additional Silurian sections.

Most Silurian rocks within the state have been assigned to the medial Silurian Niagaran series, largely because of their relatively unfossiliferous character. Recently, a Late Silurian brachiopod fauna from western Utah and Nevada has been described by Waite (1956). Silurian rocks lie conformably between Upper Ordovician dolomite and Devonian dolomite, suggesting essential continuity of deposition in the Great Basin area.

REGIONAL DISTRIBUTION

In the Utah-Nevada area Silurian rocks were first recognized and described by Hague (1883) in the Eureka district, Nevada. He named the Lone Mountain formation, which includes beds with a "Trenton" and a Niagaran fauna. Merriam (1940) subdivided similar beds in the Roberts Mountains, near Eureka, into three formations: Hansen Creek (Upper Ordovician), Roberts Mountain (Niagaran with a pentamerid fauna), and Lone Mountain (restricted) (questionable Silurian but non-fossiliferous).

Kindle (1908) first described Silurian rocks in Utah in outcrops near Logan Canyon. He reported Halysites sp. above Silurian rocks in association with what he interpreted as a Devonian fauna. Later Blackwelder (1910) reported Silurian beds near Mantua, Utah; and F. F. Hintze (1913) reported Silurian quartzite, now believed Devonian, in the Wasatch Mountains south of Salt Lake City.

Richardson (1913) described and named the Fish Haven (Upper Ordovician) and the Laketown (Silurian) dolomites from the Bear River Range near the Idaho-Utah border; reported that the type Laketown dolomite contains Pentamerus cf. P. oblongus Sowerby, Halysites catenulatus ? Linne, Favosites sp., and Cyathophyllum sp.; thought the fossils could be Richmond (Upper Ordovician); but provisionally interpreted the Laketown dolomite as Silurian. Mansfield (1927) followed Richardson's interpretation of the Laketown dolomite.

Williams (1948), in the Wasatch Range, measured 1,510 feet of Silurian rocks with Pentamerus sp. and Halysites sp. and applied Richardson's term Laketown dolomite to the sequence.

-
1. Portions of this paper taken from Utah Geol. and Mineralog. Survey Bull. 53, "Silurian Rocks of Western Millard County, by R. W. Rush, 1956.
 2. Consultant, Iowa City, Iowa.

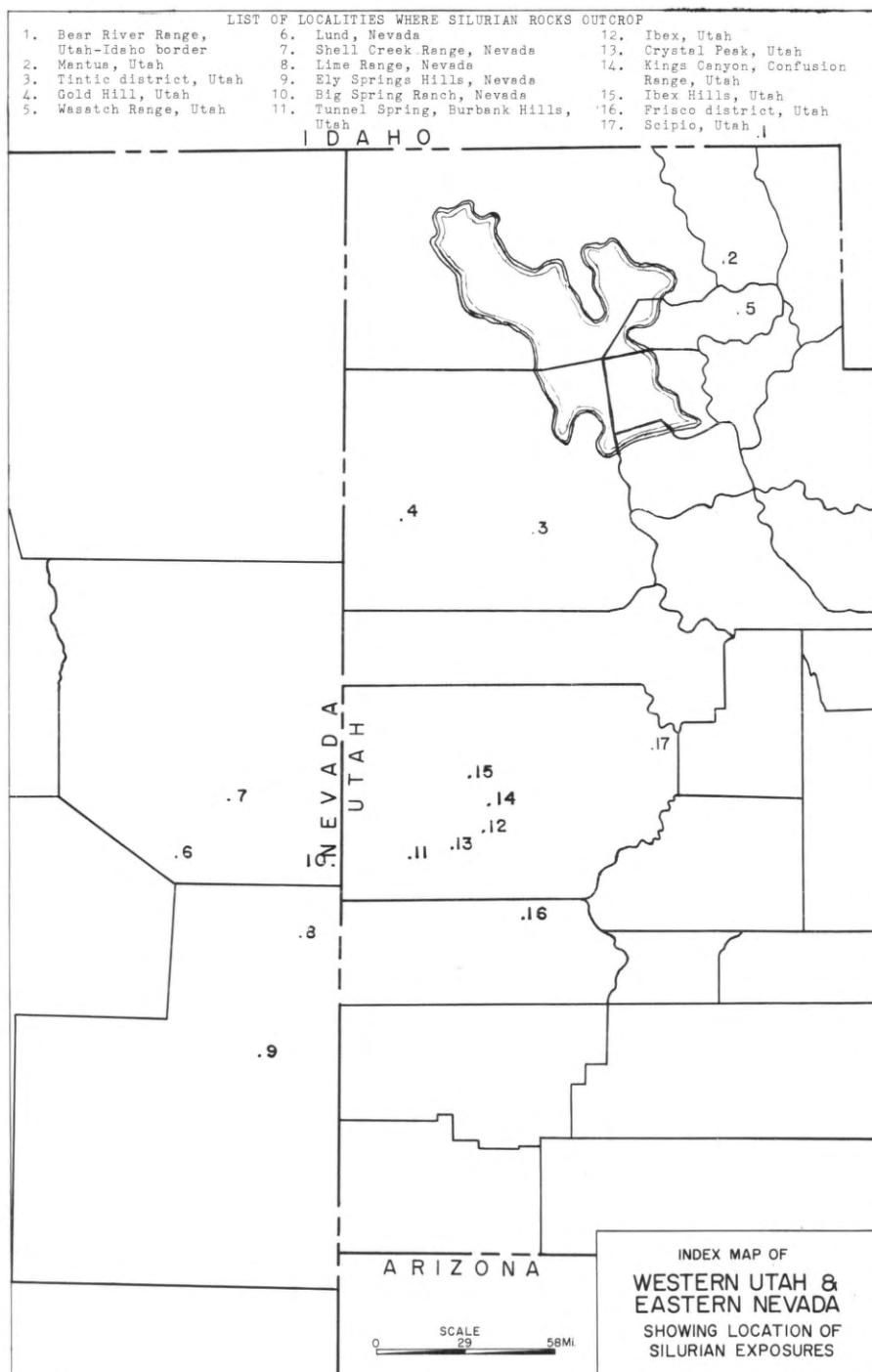


Figure 23.

UPPER ORDOVICIAN.		SILURIAN		DEVONIAN	
	Lone Mountain				Hague 1883 1892
	Morehouse quartzite ? Red Warrior limestone				Butler 1913
Fish Haven	Laketown				Richardson 1913 Mansfield 1927
Bluebell					Lindgren and Loughlin 1919
Ely Springs	Present				Westgate and Knopf 1932
Fish Haven	Laketown	Sevy	Simon-son		Nolan 1935
Bluebell					Kildale 1938 Lovering 1949 F.F. Hintze 1949 L. Hintze 1949 Eastern Nev. Geological Assoc. 1953
Hansen Creek	Roberts Mountains	Lone Mountain			Merriam 1940
Fish Haven	Laketown				Campbell 1951
Upper Ordovician	Present	Lone Mountain			Rush 1951a 1951b
Fish Haven	Roberts Mtns.	Jack Valley	Decathon	Kings Canyon	Simon-son Rush 1956
Red Warrior limestone					Bissell 1958

Table VII. Table of Terms used by different investigators of Silurian Rocks in Western Utah.

Nolan (1935), in the Gold Hill district, described a Silurian section 800 to 1,200 feet thick which included pentamerids. He used Richardson's terms of Fish Haven dolomite for Upper Ordovician rocks and Laketown dolomite for Silurian. He introduced the terms Sevy and Simonson dolomite for the overlying Devonian beds. The Gold Hill sections are most similar to those exposed near Garrison, Utah (Rush, 1956).

Elsewhere, Lindgren and Loughlin (1919), in the Tintic district, proposed the term Bluebell dolomite, which, according to Morris (1957), includes Late Ordovician, Silurian, and Devonian beds. Staatz and Osterwald (1959) proposed several new names for Silurian strata in the Thomas Range.

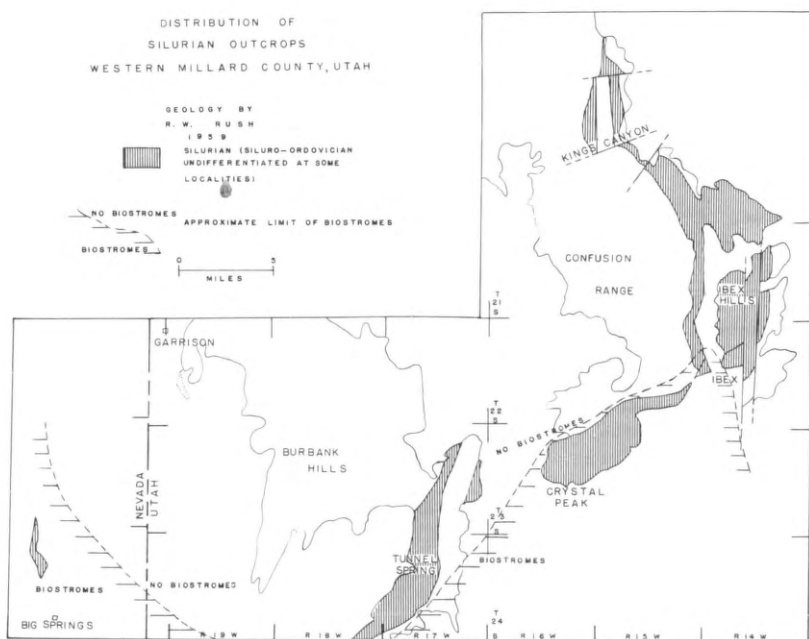


Figure 24.

Butler (1913) described and named the Morehouse quartzite and Red Warrior limestone (Silurian) in the San Francisco district, Utah. However, Nolan (1943) and Hintze (1951) place the Morehouse in the Cambrian. The Red Warrior is probably all Devonian.

Following publications by Bacon (1948) and Newell (1948) of the thick Paleozoic sequence in the Confusion Range of western Utah, the general geology of the Garrison area was summarized by several authors in the Intermountain Assoc. Petroleum Geologists Guidebook No. 6. Rush (1956) summarized the Silurian of this area, and the names he proposed are shown as follows:

Silurian and Adjacent Formations in Western Utah

Devonian	Kings Canyon dolomite (upper Sevy equivalent)
Devonian-Silurian ?	Decathon dolomite (lower Sevy equivalent)
	Unconformity ?
Upper Silurian	Jack Valley formation
Middle Silurian	Roberts Mountain formation
Upper Ordovician	Fish Haven dolomite

The Silurian formations are described as follows:

STRATIGRAPHY —

Roberts Mountain Formation

Merriam (1940) described and named the Roberts Mountain formation from exposures in the Roberts Mountains, Nevada. He described 741 to 1,900 feet of "dark, slate-gray" limestone that become massive and dolomitic near the top. He reported Conchidium sp., Halysites sp., "Heliotidae, Favositidae," "Streptelasmoid Rugosa," and Stromboides ? sp.

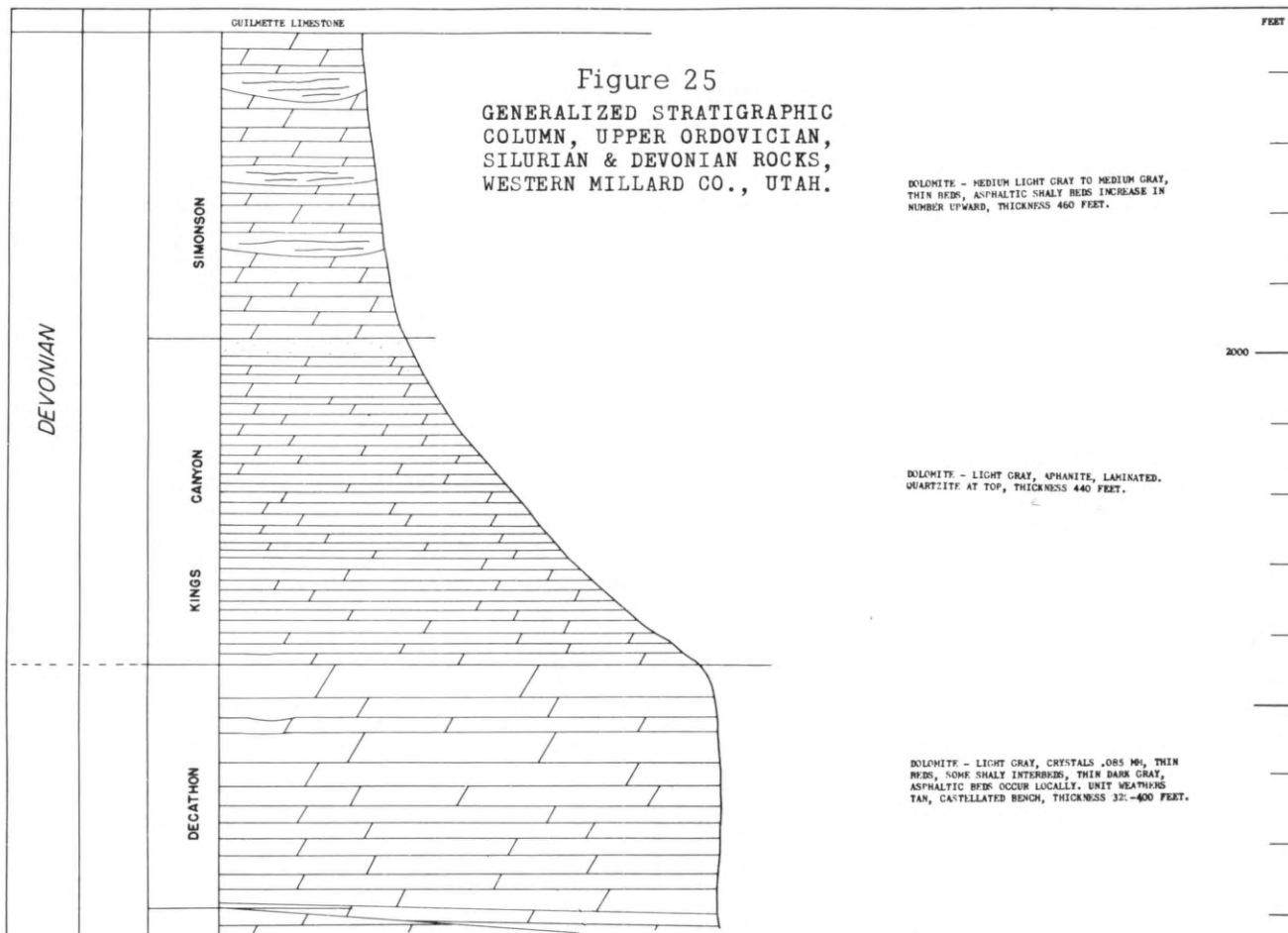
In the Garrison area it is asphaltic dolomite, 396 to 422 feet thick, lying conformably on the Fish Haven dolomite. At Big Springs, Nevada, its upper boundary may be an unconformity because the overlying Jack Valley formation, present near Kings Canyon (Rush, 1956), is believed to be absent. In the Confusion Range the relationship of the Roberts Mountain formation to the Jack Valley is obscured by fault contact.

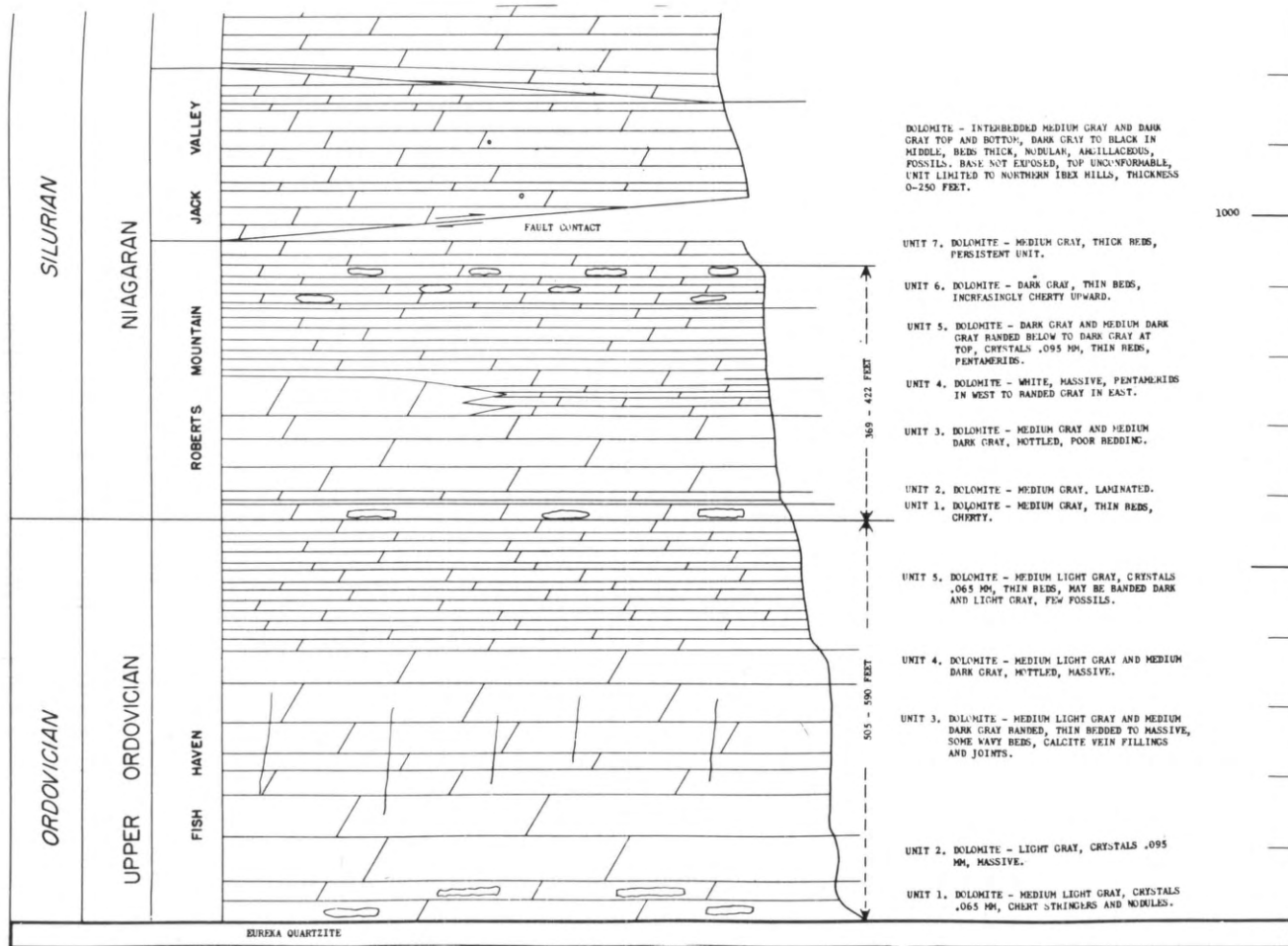
Roberts Mountain fossils from Big Springs, Nevada, include:

Brachiopoda	<u>Conchidium laqueatum</u> Conrad rhynchonellid brachiopod
Coelenterata	<u>Favosites</u> sp. <u>Synaptophyllum</u> sp. streptelasmid corals
Gastropoda	<u>Eotomaria</u> sp. <u>Murchisonia</u> sp.

Roberts Mountain fossils from the Confusion Range, Utah, include:

Brachiopoda	<u>Stegerynchus</u> cf. <u>S. indianense</u> rhynchonellid brachiopod
Coelenterata	<u>Favosites</u> sp. <u>Halysites</u> sp. streptelasmid corals
Cephalopoda	<u>Huronia</u> sp.
Ostracoda	<u>Léperditia</u> sp.





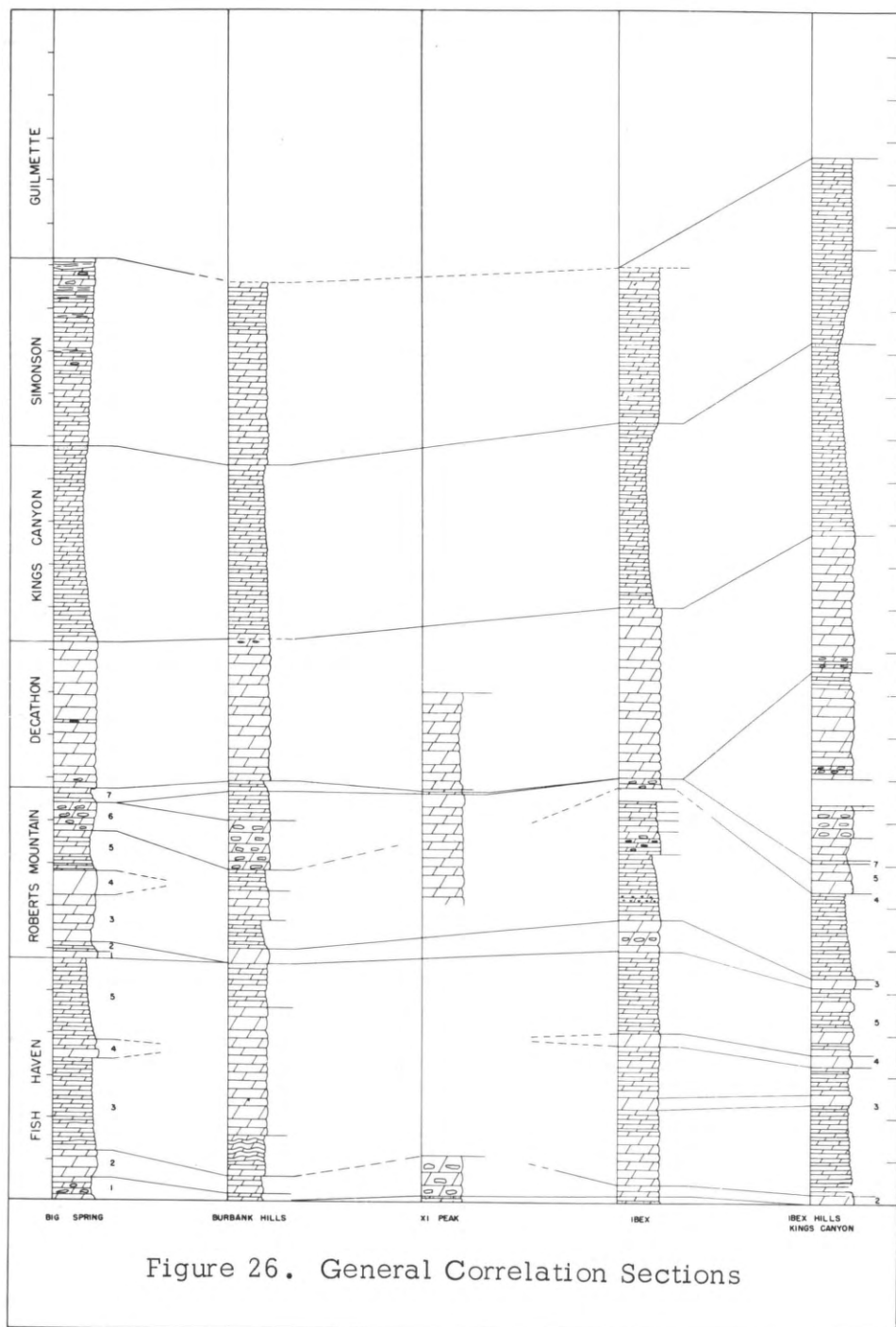


Figure 26. General Correlation Sections

Conchidium and associated forms clearly point to a Niagaran age for the rocks. The Roberts Mountain formation is probably equivalent to the lower part of the Laketown at Gold Hill. The term Laketown dolomite has been used previously by others for Silurian rocks in western Utah (Campbell, 1951), but the original definition of Richardson (1913, p. 409, 410) does not apply to the Silurian rocks of this area.

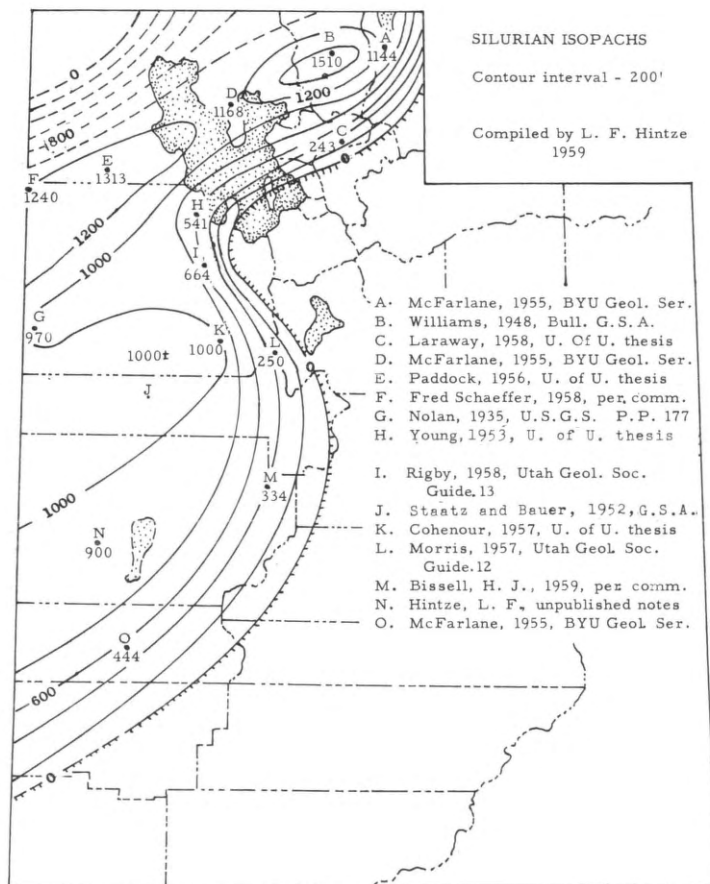


Figure 27.

Jack Valley Formation

This argillaceous, black, nodular dolomite, ranges up to 250 feet; bears strophomenid brachiopods; lies above the Roberts Mountain dolomite, and unconformably (?) below the Decathon dolomite on the west side of Jack Valley in the Confusion Range (Sec. 25, T-21-S, R-15-W) (Rush, 1956).

A part of the Jack Valley formation is exposed in the fault blocks of the Ibex Hills (Sec. 15, T-21-S, R-14-W) and nearby at the head of Kings Canyon, but the base of the unit, in fault contact with other units, was not observed. The upper part of the Jack Valley formation is a series of interbedded medium-gray and dark-gray dolomite beds.

The Jack Valley formation yields Halysites, silicified strophomenid brachiopods, Straparollus-like gastropods, and colonial corals of a favositid type. It is classified as Upper Silurian by Waite (1956).

Decathon Dolomite

The Decathon is a light-gray, tan-weathering, coarsely crystalline, dense dolomite, 350 feet thick. It lies above the Roberts Mountain and below the Kings Canyon formations at Big Springs, Nevada. In Kings Canyon it is equivalent to the lower part of the Sevy dolomite of the Gold Hill district.

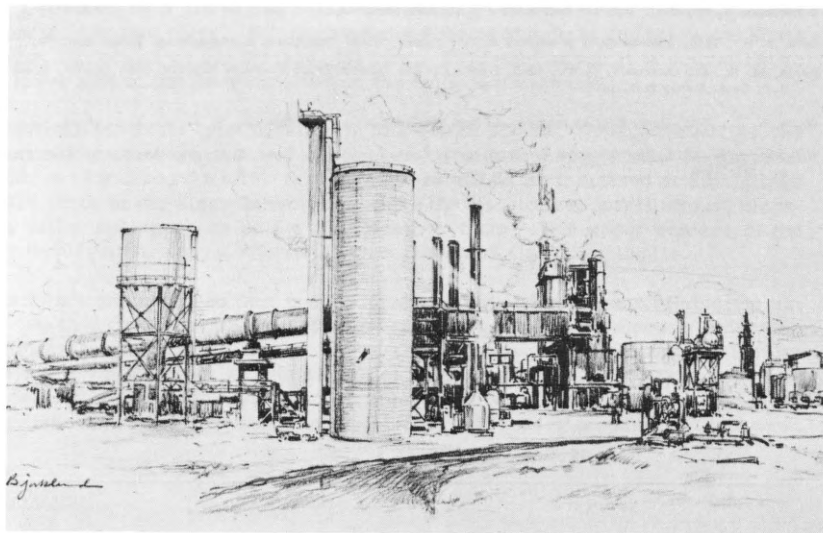
The Decathon, at its type locality in the Snake Range, Nevada, overlies the uppermost medium-gray unit of the Roberts Mountain dolomite with no physical evidence of a disconformity. Such contact relations as indicated at Big Springs do not occur in the Kings Canyon area where the distinctive, fossiliferous, black, Jack Valley dolomite lies below the Decathon beds. The upper contact of the Decathon is apparently conformable with the Kings Canyon dolomite.

Fossils are uncommon to rare in the Decathon, but of those present Halysites sp. and two favositid-type colonial corals are most common. One poorly preserved horn coral was recovered at the top of the formation at Big Springs. Similar corals are slightly more abundant north of Ibex in the Confusion Range. None of the fossils collected are well enough preserved for specific identification, but the presence of Halysites sp. is interpreted as evidence of possible Silurian age.

CITED REFERENCES

- Bacon, C. S., Jr., 1948, Geology of the Confusion Range, west-central Utah: Geol. Soc. America Bull., v. 59, p. 1027-1052.
- Blackwelder, Eliot, 1910, New light on the geology of the Wasatch Mountains, Utah: Geol. Soc. America Bull., v. 21, p. 517-542.
- Butler, B. S., 1913, Geology and ore deposits of the San Francisco and adjacent districts, Utah: U.S. Geol. Survey Prof. Paper 80.
- Campbell, G. S., 1951, Stratigraphy of the House and Confusion Ranges: Intermountain Assoc. Petroleum Geologists Guidebook, no. 6, p. 19-25.
- Hague, Arnold, 1883, Abstract of the report on the geology of the Eureka district, Nevada: U.S. Geol. Survey 3rd Ann. Report, 1881-1882.
- Hintze, F. F., 1913, A contribution to the geology of the Wasatch Mountains, Utah: New York Acad. Sci. Annals, v. 23, p. 85-143.
- Hintze, L. F., 1951, Lower Ordovician detailed stratigraphic sections for western Utah: Utah Geol. and Mineralog. Survey Bull. 39.
- Kindle, E. M., 1908, Fauna and stratigraphy of the Jefferson limestone: Am. Paleont. Bull., v. 4, no. 20, p. 1-39.
- Lindgren, Waldemar, and Loughlin, G. F., 1919, Geology and ore deposits of the Tintic mining district, Utah: U.S. Geol. Survey Prof. Paper 107.
- Mansfield, G. R., 1927, Geography, geology, and mineral resources of part of southeastern Idaho: U.S. Geol. Survey Prof. Paper 152.
- McFarlane, J. J., 1955, Silurian strata of the eastern Great Basin: Brigham Young Univ. Research Studies, Geol. Ser., v. 2, no. 5, p. 53.
- Merriam, C. W., 1940, Devonian stratigraphy and paleontology of the Roberts Mountains region, Nevada: Geol. Soc. America Spec. Paper 25.

- Morris, H. T., 1957, General geology of the East Tintic Mountains, Utah: Utah Geol. Soc. Guidebook, no. 12, p. 1-56.
- Newell, N. D., 1948, Key Permian section, Confusion Range, Utah: Geol. Soc. America Bull., v. 59, p. 1053-1058.
- Nolan, T. B., 1935, The Gold Hill mining district, Utah: U.S. Geol. Survey Prof. Paper 177.
- _____, 1943, The Basin and Range province in Utah, Nevada, and California: U.S. Geol. Survey Prof. Paper 197-D, p. 141-196.
- Richardson, G. B., 1931, The Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., v. 36, p. 406-415.
- Rush, R. W., 1956, Silurian rocks of western Millard County, Utah: Utah Geol. and Mineralog. Survey Bull. 53.
- Staatz, M. H., and Osterwald, F. W., 1959, Geology of the Thomas Range Fluorspar district, Juab County, Utah: U.S. Geol. Survey Bull. 1069.
- Waite, R. H., 1956, Upper Silurian brachiopoda from the Great Basin: Jour. Paleont., v. 30, no. 1, p. 15-18.
- Williams, J. S., 1948, Geology of the Paleozoic rocks, Logan quadrangle, Utah: Geol. Soc. America Bull., v. 59, p. 1121-1164.



Paper 9 DEVONIAN SYSTEM OF UTAH

by J. Keith Rigby¹

INTRODUCTION

Since the discovery of Devonian rocks in Utah by Kindle in 1908, the system has been recognized in every part of the state except in the Uinta Basin area, where it is missing between the Lower Mississippian and Cambrian rocks. Generally speaking, the system is thick in the western and northern parts of the state and is thin in the southeastern part of the state. The change is abrupt along the Wasatch line (Kay, 1951, p. 14), and this zone of change is punctuated by several small uplifts in central Utah.

Thickness and facies variations make it possible to recognize seven sedimentary or structural provinces within the state (Figure 28). The western thick sedimentary section was deposited in three related but distinct basins: one in the northeastern part of the state, one in the northwestern part, and one in the southwestern part of the state. Several small uplifts around the basin margins limit the basins and mark the edges of the shelf province north of the Transcontinental arch uplift and, with the arch, separate the northern and southern shelf areas.

Stratigraphic nomenclature applied in each of the provinces is shown in Figure 30.

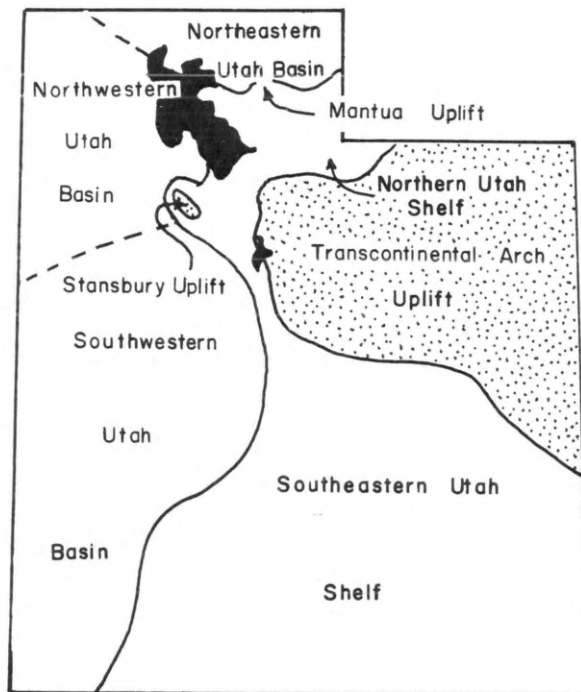


Figure 28. Devonian paleotectonic elements of Utah.

1. Associate Professor of Geology, Brigham Young Univ., Provo, Utah.

Uplifts in the vicinity of the Stansbury Mountains, near Logan, and in Mantua Valley result in local complete removal of Devonian sediments. Other related uplifts result in thinning of the system, but not complete removal. The major positive area is the western prong of the Transcontinental arch which swings westward into eastern Utah near the Uinta Mountains.

NORTHEASTERN UTAH BASIN

The northeastern Utah basin, as used in this paper, includes the area of thick Devonian sedimentation in the Logan area of Rich, Cache, and eastern Box Elder counties. It extends into southeastern Idaho where thicker Devonian sections occur.

Three distinctive formations have been recognized within the basin by Richardson (1913, 1941), Williams, J. S. (1948), and Brooks and Andrichuk (1953).

The Lower Devonian Water Canyon formation was defined by Williams, J. S., (1948, p. 1138-1139) from outcrops near Logan. It consists of a lower member of gray to buff, thin-bedded silty and sandy dolomite and an upper member of sandy dolomite, dolomitic sandstone, and sandstone intraformational breccia; is 540 feet thick in the Logan quadrangle; but is missing over most of the Randolph quadrangle and surrounding margins of the basin.

Somber gray crystalline dolomite of the Jefferson dolomite occurs above the Water Canyon formation near Logan or at the base of the system elsewhere around the margins of the basin. In the Randolph quadrangle it is approximately 1,200 feet thick (Richardson, 1941) and thickens to 1,850 feet in the Logan quadrangle (Williams, J. S., 1948).

The term Jefferson dolomite has been used differently in various areas of the basin. Richardson used the term to include only the more nearly pure carbonate rocks at the base of the system in the Randolph quadrangle. Williams expanded the formation in the Logan quadrangle to include the overlying Three Forks shale, as well as rocks equivalent to the Jefferson of Richardson. Williams erected members of the Jefferson which roughly correlate with the Jefferson and Three Forks of Richardson, the Hyrum dolomite member equivalent to the Jefferson, and the Beirdneau sandstone member equivalent to the Three Forks shale.

The uppermost Devonian rocks of the basin are included in the Three Forks shale (Richardson, 1941) or the Beirdneau member of the Jefferson formation (Williams, J. S., 1948). These rocks are mainly gray to olive-gray sandstone with minor interbeds of shale in the Logan quadrangle and interbedded limestone in the Randolph area. The unit is from 200 to 978 feet thick in the Randolph quadrangle and 800 to 900 feet thick near Logan.

Within the northeastern Utah basin, clastic rocks are more common throughout the sections along the southeastern margin of the basin. Westward, and north-westward into the interior of the basin, more nearly pure carbonates dominate.

Thin stratigraphic sections are most common in the clastic areas and thicker sections within the carbonate areas of the basin. Thinning within the basin is probably by both overlap and wedging. The Water Canyon formation is apparently limited to the interior of the basin and is overlapped by the Jefferson dolomite.

Jefferson dolomite also laps out onto the margins of the shelf at the edge of the basin.

A maximum thickness of 2,500 feet is indicated in the central part of the basin (Brooks and Andrichuk, 1953, Figure 31). The system thins to less than one thousand feet at the basin margin with the northern shelf, and it wedges out completely at the Mantua uplift (Figure 28, 29).

NORTHWESTERN UTAH BASIN

The northwestern Utah basin includes most of Utah west and northwest of Great Salt Lake in Box Elder and Tooele Counties. It is separated from the northeastern basin by uplifts in the vicinity of Mantua and the Promontory Range. A less-negative sill, seemingly the structural continuation westward of the western prong of the Transcontinental arch highland of eastern Utah, separates it from the southwestern basin.

Greatest thickness of Devonian rocks within the basin is nearly 4,200 feet in the Newfoundland Mountains (Stokes and Heylman, 1958, p. 10) in northern Tooele County. Thicknesses decrease to less than 3,000 feet in the Wendover area (Bissell, 1958) to the west and the system wedges out completely at the basin margin in the Stansbury Range. Northern continuation of the basin into northwestern Box Elder County is questionable, for middle Paleozoic rocks, if present, are obscured by metamorphism.

The Gold Hill district lies at the southern end of the basin development in Utah, and nomenclature applied within the basin is largely that defined by Nolan (1935) from the Gold Hill area, that is, in ascending order: Sevy dolomite, Simonson dolomite, and Guilmette limestone. The Pilot shale, an Upper Devonian unit, occurs above the Guilmette limestone in the western and southern part of the basin, but is not present at Gold Hill.

In the type area the Sevy dolomite is 450 feet thick and composed of white to light-gray, cryptocrystalline to microcrystalline dolomite. The overlying Simonson dolomite is 1,030 feet thick and composed of interbedded light-gray and dark-brown or brown-gray medium-crystalline dolomite. The Guilmette limestone consists of irregularly massive limestone 880 feet thick. North of Gold Hill, the Pilot shale is nearly 500 feet thick (Bissell, 1958).

At the northeastern edge of the basin, Olson (1956, p. 54-56) measured a section of Water Canyon and Jefferson formations in the Promontory Range. The Water Canyon dolomite consists of white to whitish-gray, microcrystalline to fine-grained crystalline dolomite 497 to 639 feet thick. The overlying Jefferson consists of dark-gray to light-gray dolomite with some minor thin limestone and quartzite beds. It is at least 940 feet thick. Locally, Jefferson dolomite and some of the Water Canyon dolomite have been removed prior to Mississippian deposition. This reflects in the minor uplift and thin section shown in Figure 29. Undoubtedly, the light colored dolomite termed Water Canyon is equivalent to the Sevy dolomite to the west; the overlying Jefferson dolomite is correlative with the Simonson and possibly with part of the Guilmette formation.

Devonian rocks of the southern Lakeside Mountains (Young, 1955; Petersen, 1956) have been described using both northeastern Utah and Gold Hill terminology. Correlations are similar to those described above, with the lower 240 feet of

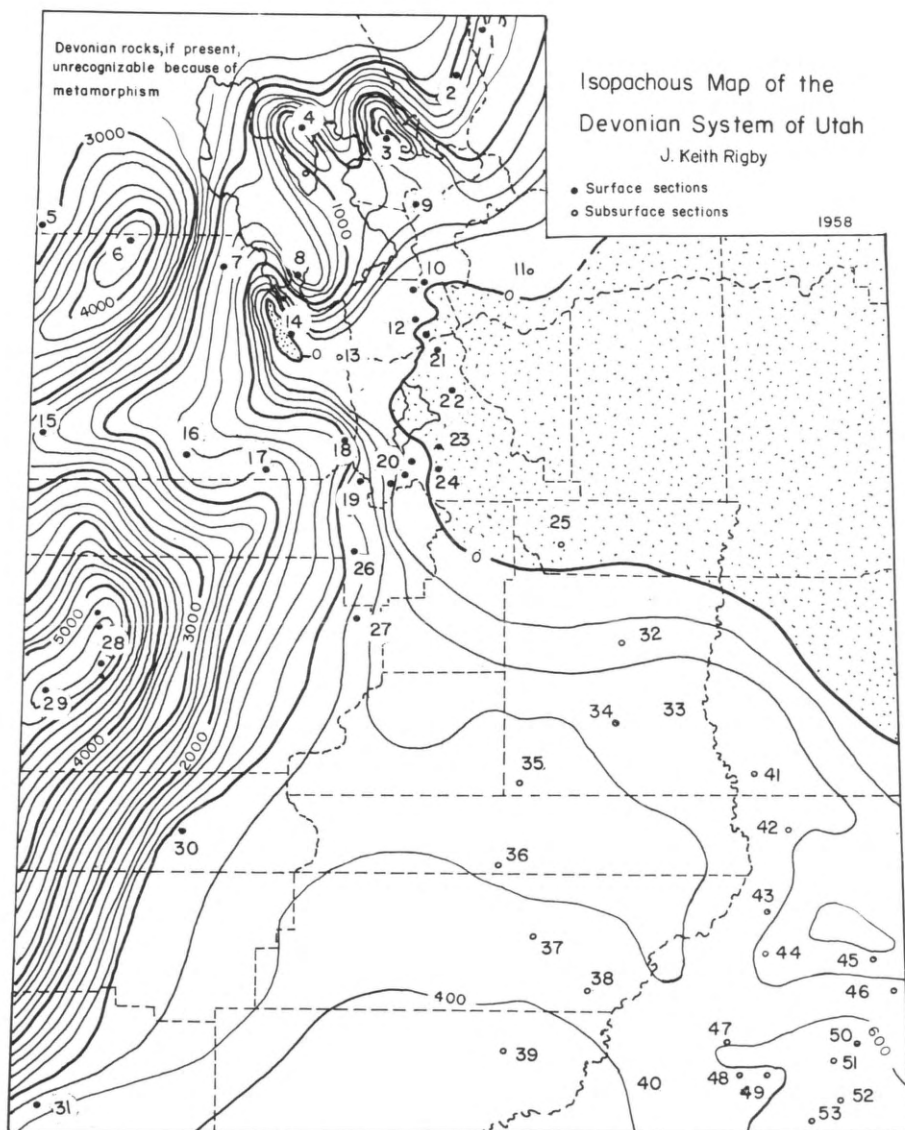


Figure 29.

LOCALITY INDEX TO FIGURE 29

Locality	Area	Source
1	Randolph quadrangle	Richardson, 1941
2	Logan	Williams, 1948
3	Mantua	Same
4	Promontory Mountains	Olson, 1956
5	Wendover	Bissell, 1958
6	Newfoundland Mountains	Stokes and Heylman, 1958
7	Lakeside Mountains	Young, 1953
8	Stansbury Island	Petersen, M. S., 1956
9	Ogden Canyon-Durst Mountain	Eardley, 1944
10	Salt Lake City	Granger, Sharp, Crittenden, and Calkins, 1952
11	N.W. Uinta Mountains	Williams, N. C., 1953
12	Little Cottonwood district	Granger, Sharp, Crittenden, and Calkins, 1952
13	Oquirrh Mountains	Rigby and Bissell, 1958
14	Stansbury Mountains	Rigby, 1958
15	Gold Hill	Nolan, 1935
16	Dugway Range	Donovan, 1951
17	Sheeprock Mountains	Cohenour, 1957
18	North end, East Tintic Mtns.	Bissell and Rigby, field notes Dearden, 1954
19	Tintic district	Morris, 1957
20	Long Ridge	Elison, 1952 Peacock, 1953 Peterson, D. O., 1953
21	American Fork Canyon	Perkins, 1955
22	Provo Rock Canyon	Bissell and Rigby, field notes Gaines, 1950
23	Payson Canyon	Peterson, Deverl, 1956
24	Dry Mountain, S Wasatch Range	Smith, 1956
25	Price (subsurface)	Sadlick, 1956
26	Gilson Range	Petersen, M.S., 1956
27	Scipio	Bissell, 1958, field notes
28	Confusion Range	Donovan, 1951
29	Burbank Hills	Rush, 1951

Locality	Area	Source
30	San Francisco district	Bissell, 1958, field notes
31	Virgin Mountains	Reber, 1952
32	El Paso Nat. Gas Packsaddle 1	All reference points from locality 32 on are from Neff and Brown 1958. Contours for this same area are taken directly, in large part, from this publication.
33	Equity Oil Government 1	
34	Reynolds Sinbad Unit 1	
35	Mountain Fuel Supply Last Chance 1-a	
36	Pacific Western Teasdale 1	
37	Hunt Government 1	
38	Galie Muley Creek 1	
39	Byrd Oil Government-Reese Canyon 1	
40	Skelly Nokai 1-A	
41	Tidewater Big Flat 74-11	
42	Gulf Aztec Lockhart Fed. 1	
43	Texas Unit 1	
44	Midwest Hughes 1	
45	Western Natural Redd 1	
46	Gulf Coalbed Canyon 2	
47	Sinclair Fehr-Federal 1	
48	Utah Southern Noble 1	
49	Hill <u>et al.</u> , State 1	
50	Reynolds Hatch 1	
51	Shell Bluff 1	
52	Shell Desert Creek 1	
53	Ohio Navajo 1	

light-gray dolomite termed Water Canyon by Young and Sevy dolomite by Petersen. The Jefferson dolomite of Young is equivalent to the Simonson, Guilmette, and possibly Pinyon Peak limestone of Peterson and is approximately 1,470 feet thick where measured by Young.

SOUTHWESTERN UTAH BASIN

The southwestern Utah basin in the Devonian includes all of Utah west of the Wasatch line and south of Tooele County (Figures 28, 29). It includes the thickest Devonian stratigraphic section measured in the state to date. Devonian rocks are known from several ranges in the basin, but thicknesses are available for only a few.

Stratigraphic nomenclature, particularly of recent workers, is that suggested by Nolan (1935) for the Gold Hill district. Lithologic similarity of sections from one range to another is striking, with the sequence being practically the same as that in the Gold Hill area. The following table summarizes thicknesses of known sections within the basin:

Thickness of Devonian Formations in the Southwestern Utah Basin

Range	Sevy dolomite	Simonson dolomite	Guilmette limestone	Pilot shale	Source
Confusion	1,600	929	-	-	Osmond - 1954
	-	-	2,500	950	Bissell - 1958
San Francisco	220	550	225	50	Bissell - 1958
Dugway	Undifferentiated section 1,647' thick				Donovan - 1951

Butler (1913, p. 34-35), in the San Francisco Mountains, proposed the term Mowitza shale for the unit now correlated with the Pilot shale of ranges to the west and northwest. The underlying Red Warrior limestone includes not only Devonian rocks, but Silurian and possibly Ordovician rocks also. Bissell has subdivided the Red Warrior limestone into lithologic units correlatable with the Gold Hill section (see table above).

Other authors have described Devonian rocks from the basin, but they have not subdivided the system or correlated their units with those of surrounding areas. Rush (1951) described a dolomite and limestone section in the Burbank Hills which apparently contains a complete section of Pilot shale, Guilmette limestone, and a partial section of Simonson dolomite. The base of the system is not exposed.

In the southwestern part of the state, at the southern edge of the southwestern basin, Reber (1952, p. 103) mentions the presence of Devonian rocks in the Beaver Dam Mountains. In another paper in the same volume, McNair (1952, p. 46) shows slightly over 600 feet of Muddy Peak limestone present. The formation consists of brown limestone and dolomitic limestone and is correlated with the Sultan and Martin limestones of surrounding areas and with the Simonson and probably part of the Guilmette formations of areas to the north.

BASIN MARGIN TRANSITION

Along the eastern or southeastern margin of the various basins many of the ranges have well exposed but unique Devonian sections. Stratigraphic nomenclature of these ranges represents combinations of Tintic district and Gold Hill district terminologies, with some local names.

Devonian rocks within the Tintic district are included in three formations: Bluebell dolomite, Victoria formation, and Pinyon Peak limestone (Morris, 1957, p. 12-14). The Bluebell dolomite includes rocks of Late Ordovician to Middle Devonian ages. M. S. Petersen (1956, p. 5) concluded that the upper 300 feet of the Bluebell is equivalent to the Sevy, Simonson, and lowermost Guilmette formations, for lithologically the upper part is strikingly similar to those units farther west.

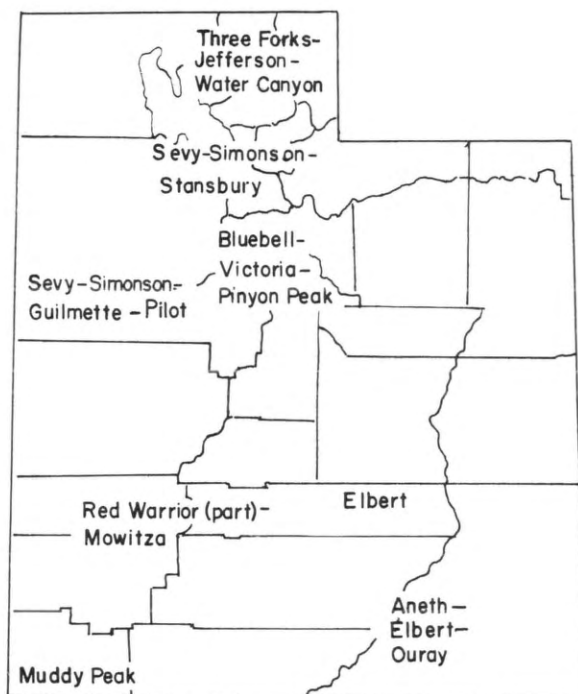


Figure 30. Devonian stratigraphic terms of Utah, 1958.

The Victoria quartzite disconformably overlies the Bluebell dolomite and consists of interbedded dolomitic sandstone and gray dolomite. The Victoria quartzite is 250 to 300 feet thick within the district. The overlying Pinyon Peak formation, a medium-grained blue-gray limestone with many veinlets and partings of clay and silt, is 70 to 300 feet thick in the type area and is considered to be Devonian (Beach, 1961).

Cohenour (1957, p. 117-126) described the Devonian rocks of the Sheeprock Mountains and used a combination of Gold Hill and Tintic terminology. He recognized a section of light-gray Sevy dolomite 355 to 1,044 feet thick below

the characteristically alternating brown-gray and light-gray dolomite of the Simonson dolomite. The latter formation is from 450 to 563 feet thick. He recognized the Victoria and Pinyon Peak formations above this, but did not differentiate them in a section 736 feet thick. These units represent an interbedded sandy and dolomitic series at the base, with sand and sandy limestone common toward the top.

Characteristic Sevy and Simonson dolomites have also been mapped below an upper clastic unit in the Stansbury Mountains by Rigby (1958), Teichert (1958), and Stokes and Arnold (1958). The Sevy dolomite is 60 to 80 feet thick and the Simonson dolomite from 200 to 235 feet thick. These units are overlain unconformably by the Stansbury formation. The latter formation consists of approximately 1,700 feet of boulder and pebble conglomerate and interbedded sandstone at the northern end of the range and grades to a vitreous quartzite at the southeast margin of the range. It is interbedded conglomerate and limestone along the western side of the range where it is approximately 200 feet thick. Locally, the Stansbury formation is absent and Mississippian and latest Devonian rocks rest on older formations. The overlying Pinyon Peak limestone is typically argillaceous-mottled, blue-gray sandy limestone and ranges up to 85 feet thick. The coarse character of the Upper Devonian sediments is related to a major uplift within the Stansbury region during Late Devonian time.

An abrupt shift from geosynclinal to shelf thicknesses and facies takes place in central Utah between the Tintic district and the southern Wasatch Mountains. Several workers (Elison, 1952; Peacock, 1953; Petersen, H., 1953; Sirrine, 1953; Petersen, M., 1956; White, 1953) have mapped and measured sections in this interval at the south end of Utah county, and have documented the thinning of the Lower and Middle Devonian rocks and the overlap of the Upper Devonian units onto the shelf margin.

In Current Creek, about midway from the Tintic district to Mount Nebo in the Wasatch Mountains, the Simonson part of the Bluebell dolomite is present as a series of alternating dark and light-gray dolomites below the Pinyon Peak limestone and the Victoria quartzite. The entire section is approximately 370 feet thick. The lowest Devonian units present to the west have wedged out between the Tintic area and Current Creek.

Toward the east, in the vicinity of Warm Springs Mountain, all but the 30-foot Victoria quartzite and 30 to 40 feet of the overlying Pinyon Peak limestone are absent. At the south end of West Mountain all that remains of the Devonian section is a 30 to 40-foot thickness of Pinyon Peak limestone. Southeast, on Dry Mountain, and east in the southern Wasatch, even this unit is no longer present between the Mississippian and Cambrian rocks. This marks the southwestern margin of the western prong of the Transcontinental arch uplift which affected the northeastern part of Utah during the mid-Paleozoic.

SOUTHEASTERN UTAH SHELF

Devonian rocks are exposed as thin stratigraphic sections around the northwestern edge of the southeastern Utah shelf and are known from the remainder of the shelf area largely from subsurface records. The gradation from the moderately thick Devonian section in the Tintic district eastward onto the shelf margin has been described. Thin gradational sections are also present in the Oquirrh Range and the central and southern Wasatch Mountains.

	Randolph quadrangle	Logan quadrangle 2	Promontory Range 3	Salt Lake City area 4	Gold Hill district 5	Stansbury Mountains(S) 6	Stansbury Mountains(N) 7	Oquirrh Mountains 8	Tintic district 9	Long Ridge & S. Wasatch Mts. 10	Emery County 11	Paradox Basin 12	San Francisco Mountains 13	Confusion Range 14
Mississippian				"City Creek" ls.		Pinyon Peak ls.	Pinyon Peak ls.	Pinyon Peak ls.	Pinyon Peak ls.	Pinyon Peak ls.		Ogury limestone	Mowitz shale	Pilot shale
DEVONIAN SYSTEM	UPPER	Three Forks formation	Beirdeau member	Three Forks formation	Stansbury fm.	Stansbury formation	Stansbury formation	Stansbury fm.	Victoria qtzf.	Victoria qtzf.	Elbert fm.	Elbert fm.		
	MIDDLE	Jefferson dolomite	Jefferson dolomite	Jefferson dolomite	Guilmette limestone	Simonson dolomite	Simonson dolomite		Bluebell	Bluebell dolomite		Aneth fm.	Red	Guilmette limestone
	LOWER	Water Canyon fm.	Water Canyon formation	Water Canyon formation	Sevy dolomite	Sevy dolomite			dolomite				Warrior	Simonson dolomite
Silurian or underlying bds.	Laketown dolo.	Laketown dolo.	Laketown dolo.	Cambrian	Laketown dolo.	Laketown dolo.	Comb.-Silurian	Cambrian	Silurian part	Ordovician	Cambrian	Cambrian	Silurian part	Laketown dolo.

* most recent information or summary

1. Richardson, 1941
2. Williams, 1948
3. Olson, 1956

4. Granger, et al., 1952
5. Nolan, 1935
6. Rigby, 1958

7. Rigby, 1958
8. Bissell and Rigby
9. Morris, 1957

10. B.Y.U. Theses 1952-7
11. Sadlick, 1956
12. Neff and Brown, 1958

13. Bissell notes
14. Donovan, 1951

Figure 31. Tentative correlation of the Devonian formations of Utah.

The only Devonian rocks exposed in the Oquirrh Mountains are present in a thin wedge of Pinyon Peak limestone which lies below the basal somber-gray Fitchville dolomite and above the tilted Cambrian formations. The unit termed Jefferson (?) by Gilluly (1932, p. 20), and considered as Devonian for some time, is now recognized to be Upper Devonian and Lower Mississippian (Beach, 1961) and equivalent to the Fitchville dolomites of the Tintic district.

Devonian rocks of the southeastern part of the shelf area of Utah have been subdivided, from oldest to youngest, into Aneth, Elbert, and Ouray formations. The most recent summary of work by petroleum geologists in the area is by Neff and Brown (1958, p. 102-108), wherein an isopach of the Devonian rocks of the Paradox Basin and adjacent areas and a correlation chart of electric logs are presented.

Maximum thickness within the shelf area is approximately 700 feet in the southeastern part of San Juan County (Neff and Brown, 1958, Exhibit III). This maximum thickness lies at the center of a northwesterly-trending sag or gentle trough within the Devonian rocks. Northeast and southwest of this trough, Devonian thicknesses decrease to 300 or 400 feet, ultimately decreasing to zero along the southwestern edge of the Uncompahgre uplift and the western part of the Transcontinental arch.

The Aneth formation is limited to the southeasternmost part of Utah and is of argillaceous, dark-brown to black limestone and dolomite with interbedded evaporitic calcareous gray-green, brown, and gray shale. The Elbert formation consists of a lower sandy, thin-bedded sandstone and shale and an upper consistently gray dolomite. The Ouray formation is light-gray and tan, dense to oolitic limestone with minor green shale partings.

NORTHERN UTAH SHELF

The northern Utah shelf is that area which lies north of the Transcontinental and Stansbury uplifts and south and southeast of the northeastern and northwestern Utah basins with their thick sections of carbonates. The Mantua uplift, an area from which Devonian sediments were stripped prior to Mississippian deposition, is a northwestern continuation of the shelf area (Figure 29).

Significant exposures of Devonian rocks have been mapped in Ogden Canyon, on Durst Mountain, near Salt Lake City, and along the northwestern flank of the Uinta Mountains in Summit County.

Thin clastic sections characterize Devonian rocks of the northern Utah shelf. East of Ogden and on Durst Mountain (Eardley, 1944), the Devonian consists of yellowish- to reddish-gray shale and sandstone similar to the Three Forks formation or Beirdneau sandstone. The sequence is approximately 600 feet thick on Durst Mountain. The absence of carbonates, such as is characteristic of the Jefferson farther north and west, indicates the approximate margin of the northeastern Utah basin and the northern Utah shelf.

Hintze (1949, p. 58-65) summarized the Devonian of Utah and emphasized the presence of Devonian rocks within the central Wasatch Mountains. Thin lenticular sandstone and argillaceous limestone beds, lithologically similar to the Pinyon Peak limestone, have been differentiated in the vicinity of Salt Lake City in a section which totals approximately 160 feet (Granger and others, 1952, p. 8). Elsewhere in the range the Devonian rocks are either missing or present as thin lenses above the Late Devonian unconformable surface.

A section of tan calcareous shale and siltstone of Late Devonian age and approximately 40 feet thick (Williams, N. C., 1953) occurs between Cambrian quartzite and Mississippian rocks. The clastic character and thinness indicate the area is near the wedge-out of the Devonian onto the Transcontinental arch, and marks the approximate boundary of the shelf zone.

SUMMARY OF THE DEVONIAN SYSTEM OF UTAH

Nearly complete Devonian sections of carbonate rocks are exposed in the western part of Utah. Maximum thickness is reached in the vicinity of the Confusion Range where the section is more than 5,000 feet thick. Lower and Middle Devonian rocks are limited to the western basins, west of the Wasatch line. Upper Devonian rocks blanket the state, with the exception of the Uinta Basin area which remained high into the Early Mississippian. Thicknesses of a few hundred feet are characteristic of Devonian sections on the shelf areas, both north and south of the Transcontinental arch uplift.

Clastic sediments are associated with the Stansbury and Transcontinental arch uplifts in Late Devonian time. Coarse conglomerate at the margins of the uplifts grade into shale and sandy or shaly limestone away from the uplifts.

Petroleum possibilities of the shelf sections of Devonian rocks are limited because of their generally nonporous nature. Thick carbonate sections, some dolomitized and with considerable porosity, occur in the western part of the state, but structural complications make production there improbable. Possibilities exist along the southern side of the northeastern Utah basin, in the zone of stratigraphic overlap onto the margin of the uplifted areas in the central part of the state.

CITED REFERENCES

(For a more complete bibliography to 1949, see Hintze, F. F., 1949).

- Beach, G. A., 1961, Late Devonian and Early Mississippian Biostratigraphy of central Utah: Brigham Young Univ. Geol. Studies, v. 8, p. 37-54.
- Bissell, H. J., 1958, Field notes and preliminary compilation.
- Brooks, J. E., and Andrichuk, J. M., 1953, Regional stratigraphy of the Devonian system in northeastern Utah, southeastern Idaho, and western Wyoming: Intermountain Assoc. Petroleum Geologists Guidebook 4th Ann. Field Conf., p. 28-31.
- Butler, B. S., 1913, Geology and ore deposits of the San Francisco and adjacent districts, Utah: U.S. Geol. Survey Prof. Paper 80.
- Cohenour, R. E., 1957, Geology of the Sheeprock Mountains, Tooele and Juab Counties, Utah: Univ. of Utah, Ph.D. thesis, 308 p. Published version--1959, Sheeprock Mountains, Tooele and Juab Counties, Utah: Utah Geol. and Mineralog. Survey Bull. 63.
- Dearden, M. O., 1954, Geology of the central Boulder Mountains area, Utah: Brigham Young University, M.S. thesis, Brigham Young Univ. Research Studies, Geol. ser., v. 1., no. 5.
- Donovan, J. T., 1951, Devonian rocks of the Confusion Basin and vicinity: Intermountain Assoc. Petroleum Geologists Guidebook to the Geology of Utah, no. 6, p. 47-53.
- Eardley, A. J., 1944, Geology of the north-central Wasatch Mountains, Utah: Geol. Soc. America Bull., v. 55, p. 819-894.
- Elison, J. H., 1952, Geology of the Keigley quarries and the Genola Hills area, Utah: Brigham Young Univ., M.S. thesis.

- Gaines, P. W., 1950, Stratigraphy and structure of the Provo Canyon-Rock Canyon area, south-central Wasatch Mountains, Utah: Brigham Young Univ., M. S. thesis.
- Gilluly, James, 1932, Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U.S. Geol. Survey Prof. Paper 173, 171-p.
- Granger, A. E., and others, 1952, Geology of the Wasatch Mountains, east of Salt Lake City: Utah Geol. Soc. Guidebook to the Geology of Utah, no. 9, p. 1-38.
- Hintze, F. F., 1949, The Ordovician, Silurian, and Devonian systems of Utah: Oil and Gas Possibilities of Utah, Salt Lake City, Utah Geol. and Mineralog. Survey, publisher, p. 38, 55-66.
- Kay, Marshall, 1951, North American Geosynclines: Geol. Soc. America Mem. 48, 143 p.
- Kindle, E. M., 1908, The fauna and stratigraphy of the Jefferson limestone in the northern Rocky Mountain region: Am. Paleont. Bull., v. 4, p. 1-39.
- McNair, A. H., 1952, Summary of the Pre-Coconino stratigraphy of southwestern Utah, northwestern Arizona, and southeastern Nevada: Intermountain Assoc. Petroleum Geologists Guidebook to the Geology of Utah, no. 7, p. 45-51.
- Morris, H. T., 1957, General Geology of the East Tintic Mountains, Utah: Utah Geol. Soc. Guidebook to the Geology of Utah, no. 12, p. 1-56.
- Neff, A. W., and Brown, S. L., 1958, Ordovician to Mississippian rocks of the Paradox Basin: Intermountain Assoc. Petroleum Geologists Guidebook 9th Ann. Field Conf., p. 102-108.
- Nolan, T. B., 1935, The Gold Hill mining district, Utah: U.S. Geol. Survey Prof. Paper 177.
- Osmond, J. C., Jr., 1954, Dolomites in Silurian and Devonian of east-central Nevada: Am. Assoc. Petroleum Geologists Bull., v. 38, no. 9, p. 1911-1956.
- Olson, R. H., 1956, Geology of the Promontory Range: Utah Geol. Soc. Guidebook, no. 11, p. 41-75.
- Peacock, D. H., 1953, Geology of the Government Hill area, a part of Long Ridge, Utah: Brigham Young Univ., M.S. thesis.
- Perkins, R. F., 1955, Structure and Stratigraphy of the Lower American Fork Canyon-Mahogany Mountain area, Utah County, Utah: Brigham Young Univ., M.S. thesis, Brigham Young Univ. Research Studies, Geol. ser., v. 2, no. 1.
- Petersen, H. N., 1953, Structure and Paleozoic stratigraphy of the Current Creek area near Goshen, Utah: Brigham Young Univ., M.S. thesis.
- Petersen, M. S., 1956, Devonian strata of central Utah: Brigham Young Univ. Research Studies, Geol. ser., v. 3, no. 3, 36 p.
- Peterson, D. O., 1953, Structure and stratigraphy of the Little Valley area, Long Ridge, Utah: Brigham Young Univ. M.S. thesis.
- Peterson, Deverl, 1956, Stratigraphy and structure of the west Loafer Mountain, upper Payson Canyon area, Utah Co. Utah: Brigham Young Univ. Research Studies, Geol. ser., v. 3, no. 4.
- Reber, S. J., 1952, Stratigraphy and structure of the south-central and northern Beaver Dam Mountains, Utah: in Intermountain Assoc. Petroleum Geologists Guidebook, no. 7, p. 101-108.
- Richardson, C. B., 1913, The Paleozoic section in northern Utah: Am. Jour. Sci., ser. 4, v. 36, p. 406-415.
- _____, 1941, Geology and mineral resources of the Randolph quadrangle, Utah: U.S. Geol. Survey Bull. 923.
- Rigby, J. K., 1958, Geology of the Stansbury Mountains, eastern Tooele Co., Utah: Utah Geol. Soc. Guidebook to the Geology of Utah, no. 13, p. 1-134.
- Rush, R. W., 1951, Stratigraphy of the Burbank Hills, western Millard Co., Utah: Utah Geol. and Mineralog. Survey Bulletin 38, 24 p.
- Sadlick, Walter, 1956, Some upper Devonian-Mississippian problems in eastern Utah: Intermountain Assoc. Petroleum Geologists Guidebook 7th Ann. Field Conf., p. 65-76.
- Sirrinc, C. V., 1956, Geology of the North Canyon area, southern Wasatch Mountains, Utah: Brigham Young Univ. M.S. thesis, Brigham Young Univ. Research Studies, Geol. ser., v. 3, no. 7.
- Snyder, C. T., 1952, Summary of the stratigraphy from Cedar City, Utah to Las Vegas, Nevada: Intermountain Assoc. Petroleum Geologists Guidebook, no. 7, p. 7-14.

- Stokes, W. L., and Arnold, D. E., 1958, Northern Stansbury range and the Stansbury formation: Utah Geol. Soc. Guidebook, no. 13, p. 151-160.
- Stokes, W. L., and Heylman, E. B., 1958, Outline of the geologic history and stratigraphy of Utah: available from Utah Geol. and Mineralog. Survey, Salt Lake City, Utah, 38 p.
- Teichert, J. A., 1958, Geology of the southern Stansbury Range, Tooele Co., Utah: Univ. of Utah, M.S. thesis. Published version--1959, Geology of the southern Stansbury range, Tooele Co., Utah: Utah Geol. and Mineralog. Survey Bull. 65, 75 p.
- White, B. O., 1953, Geology of West Mountain and northern portion of Long Ridge, Utah: Brigham Young Univ., M.S. thesis.
- Williams, J. S., 1958, Geology of the Paleozoic rocks, Logan quadrangle, Utah: Geol. Soc. America Bull., v. 59, p. 1121-1164.
- Williams, N. C., 1953, Late Precambrian and early Paleozoic geology of western Uinta Mountains, Utah: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 2734-2742.
- Young, J. C., 1953, Geology of the southern Lakeside Mountains, Utah: Univ. of Utah, M.S. thesis. Published version--1955, Geology of the southern Lakeside Mountains, Utah: Utah Geol. and Mineralog. Survey Bulletin 56, 188 p.

Paper 10 CARBONIFEROUS AND PERMIAN ROCKS OF UTAH

by J. Stewart Williams¹

MISSISSIPPIAN SYSTEM

General Statement

By late Kinderhookian time the sea had completely covered the area of Utah (Figure 32). The sea's northwesterly shore lay in central Nevada against the Antler Peak orogenic area. To the southeast it reached to the landarea in south-central Colorado and northern New Mexico. This sea deposited the Madison limestone of northern Utah, and its equivalents: the Leadville, Redwall, Rogers Spring, and Joana limestones (Figure 34). Before the close of Osagean time the water withdrew, returning again in a restricted pattern in Meramecian time, to remain in northwestern Utah until the close of the period.

The contracted sea of the Middle and Upper Mississippian series was centralized in the Oquirrh basin of northwestern Utah, a part of the Cordilleran mio-geosyncline which at this time began a negative trend which continued until Lower Permian time. From the Oquirrh basin the Meramecian sea spread eastward and southeastward onto the Utah-Colorado shelf, but did not reach the Four Corners area (Figure 33). To the northwest, it was more restricted than its predecessor, due to the growth of the Antler Peak orogenic belt. As Chesterian time advanced, the sea became limited to the Oquirrh basin itself, until at the close of Chesterian time a new excursion eastward deposited the Manning Canyon shale along the Uinta Mountains. This re-expansion merged into the seas of Pennsylvanian time.



Figure 32. Kinderhookian - Osagean Time.

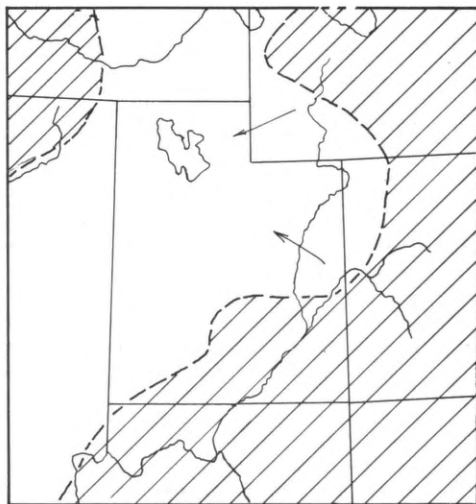


Figure 33. Meramecian - Chesterian Time.

1. Dean, School of Graduate Studies; Professor and Head of the Department of Geology, Utah State University, Logan, Utah.

The Madison Limestone and Its Equivalents

The Madison limestone of the Logan area is equivalent to only one formation of the Madison group as now recognized in Montana, namely the Lodgepole limestone (Williams, 1943; Strickland, 1956). The Lodgepole is thin-bedded, cherty, fossiliferous, and blue-gray in color. In the Cottonwood district Calkins and Butler (1943, p. 23) report that parts of the Madison formation are dolomitic. In the Tintic district the lithology of the Madison is varied (Morris, 1957, p. 14-17), but parts are dolomitic and parts are thin bedded and cherty. According to Crittenden (1959, p. 65), rocks equivalent to the Madison limestone in the area from the Cottonwood district to the Tintic district are now called the Fitchville formation (below) and the Gardison limestone. The former consists of about 200 feet of medium- to coarse-grained gray dolomite with minor beds of limy siltstone. The latter consists of thin-bedded, blue-gray, fossiliferous limestone with partings of silty dolomite, and an overlying massive dolomite and limestone with white chert. The Gardison totals about 450 feet in thickness.

Eastward, along the Uinta Mountains the Madison becomes somewhat silty and sandy (Williams, 1943) but maintains its identity as a limestone well into Colorado (Thomas and others, 1945). In the subsurface of east-central Utah, Sadlick (1956, p. 71-73) reports the Madison to be essentially dolomite, but with interbeds of limestone. The dolomite is light gray to brown in color, with similarly colored chert. In the Paradox basin area the Leadville may be separated into two members: a lower member of massive, tan, brown, gray, or pink dolomite, coarsely to finely crystalline, and often cherty; and a much thinner upper member of thin-bedded limestone (Neff and Brown, 1958, p. 102). The limestone is said to be light colored, compact and sometimes oolitic. The Redwall limestone of the Kaiparowits region is described by Heylman (1958, p. 1787) as consisting of white, pink, and gray crystalline dolomite and limestone with varying amounts of chert. Longwell's description of the Rogers Spring limestone (1921, p. 46) indicates that in extreme southwestern Utah the Madison equivalent may be thicker-bedded and darker-colored than elsewhere, and without conspicuous chert. Farther north the Joana limestone is massive, bluish-gray and somewhat cherty (Spencer, 1917, p. 24, 26).

The Madison limestone and its equivalents are generally on the order of 1,000 feet in thickness, showing little variation considering their wide extent. The thin section in the Cottonwood district (Calkins and Butler, 1943, p. 23) might be ascribed to pre-Meramecian erosion, but generally the Meramecian Desert limestone is reported as entirely conformable to the Madison.

In Leatham Hollow in the Bear River Range, Cache County, Holland (1952) has studied the base of the Madison limestone and distinguished the Leatham formation: 76 feet of shale, sandy shale, and nodular limestone. The base of the Leatham is said to be an unconformity marked by a 3-inch bed of conglomeratic limestone with angular chert pebbles. The top of the new formation seems less well marked and comes at the base of 30 feet of brownish-black arenaceous shale which becomes the basal member of the Madison or Lodgepole limestone. The Leatham is said to be the exact correlative of the Sappington sandstone of Montana.

As far as known the Leatham has not been recognized at other than the type locality. It was not found in Wellsville Mountain by Beus and Gelnett in their 1958 study. Southward in the Wasatch Range, northeast of Salt Lake City, Granger (1953, p. 2) reports the Madison limestone in contact with the Devonian Pinyon Peak limestone

with no suggestion of an equivalent of the Leatham. Southeast of Salt Lake City Crittenden and others (1952, p. 8) describe the oldest Mississippian rocks as consisting of thick layers of massive dolomite, except for a few feet of yellowish limy sandstone and shale at the base, which, the writer now suggests, might be the attenuated Leatham equivalent. Eastward, along the north flank of the Uinta Mountains, Norman Williams (1953) reports the Madison lying unconformably on rocks as old as the Precambrian and as young as the Pinyon Peak. The basal Madison here is dolomitic limestone.

Meramecian and Chesterian Rocks

The most complete post-Madison section of Mississippian rocks is in the Oquirrh Mountains and vicinity, the result of the continuous sinking of the Oquirrh basin. Gilluly (1932, p. 25-34) describes the Deseret limestone as consisting of blue gray, fine-grained limestone with greater or lesser amounts of chert. Its base is marked by a thin black shale member with phosphatic oolite. The formation includes widely scattered beds of quartzitic sandstone. The Deseret grades upward into the Humbug formation, approximately 30 percent of which is composed of sandstone and quartzitic sandstone. The Humbug is about equal to the Deseret in thickness.

The Deseret and Humbug formations are recognized eastward along the Uinta Mountains to the Colorado line (Sadlick, 1955, p. 51-52). They are the equivalents of Unit 1 in the Dry Lake section, Cache County (Williams, 1958, p. 31). Westward, they are probably represented in the Woodman formation of the Gold Hill district (Nolan, 1935, p. 27). Southeastward, the Humbug formation has been identified in the subsurface nearly to the San Rafael Swell (Sadlick, 1956, p. 69) and the Deseret limestone somewhat farther.

In the Tintic district, the type locality of the Humbug formation (Morris, 1957, p. 19-20), both the Humbug and Deseret are closely similar to the occurrence in the Oquirrh Mountains.

The Great Blue limestone (including its lower and upper members, and the Long Trail shale) has a total thickness of about 3,000 feet in the Oquirrh Mountains. It does not outcrop east of the Wasatch Range, but has a thickness of several hundred feet in the Cottonwood district (Crittenden and others, 1952, p. 10), where it is called the Doughnut formation, and a thickness of 2,800 feet in Rock Canyon, northeast of Provo (Baker and others, 1949, p. 1177). South of the Oquirrh in the East Tintic Mountains, the Great Blue limestone, is 2,500 feet thick and to the southeast, in the Stansbury Mountains, 900-1,300 feet thick (Rigby, 1958, p. 38). The Ochre Mountain limestone of the Gold Hill district (Nolan, 1935, p. 29-30) is probably the equivalent of the Great Blue and has the same order of thickness. North of Great Salt Lake in the Promontory Range and the Blue Springs Hills, the Great Blue is present, but is as yet not well known. In the Dry Lake section of the Logan quadrangle, Units 2, 3, and 4 are probably correlative of the lower limestone member, the Long Trail shale member, and the upper limestone member of the Great Blue, respectively.

The Great Blue and its equivalents are described as largely blue-gray limestone, somewhat cherty, with interlayered subordinate quartzitic sandstone, sandstone, sandy limestone, and black shale. Black shale is notable in all described sections. The sandstone and quartzitic sandstone are more often than not associated with the shale members and interbeds. In the East Tintic section nearly half of the formation is a shale and quartzite member. The shale is described as sooty

black to greenish gray; the quartzite, as medium to fine-grained, gray green to brown, and commonly cross bedded (Morris, 1957, p. 21).

Such a unit as this, at the top of the section in the Oquirrh Mountains, was named the Manning Canyon shale by Gilluly (1932, p. 31-34). The Manning Canyon grades downward into the Great Blue and contains some limestone beds. Study of the fossils in the formation indicates that it transcends the Mississippian-Pennsylvanian boundary, the upper several hundred feet being Pennsylvanian. The Manning Canyon is 1,140 feet thick at its type locality.

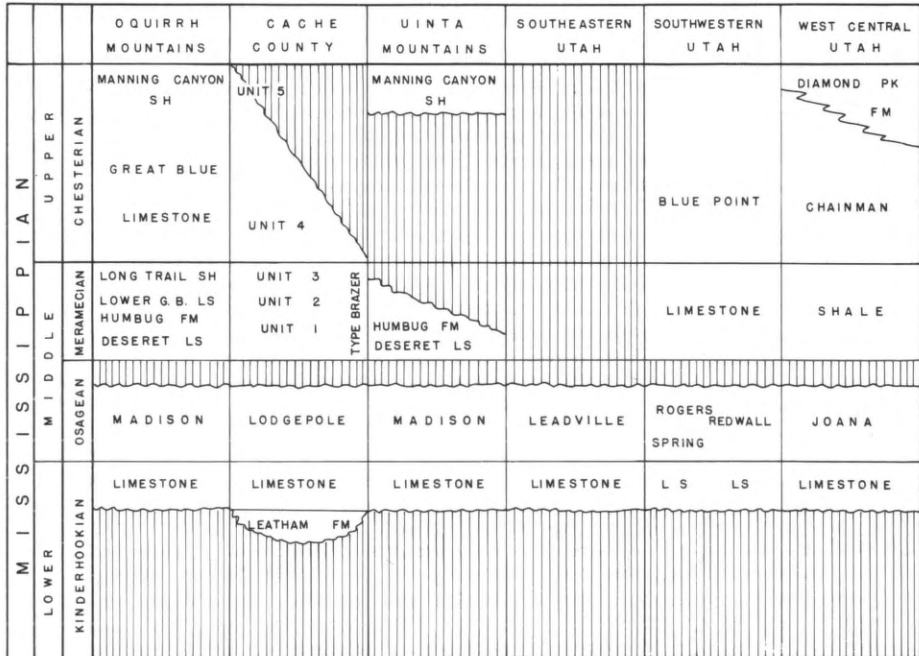


Figure 34. Mississippian Correlation Chart

The Manning Canyon shale is an important stratigraphic guide in the Promontory Range (Olson, 1956, p. 60) and in the other ranges at the Utah-Idaho line north of Great Salt Lake. The shaly Unit 5 in the Dry Lake section in Cache County is thought to be its equivalent. East of Provo, the Manning Canyon has thickened somewhat at the expense of the Great Blue and reaches 1,646 feet (Baker and others, 1949, p. 1179). It is present in the East Tintic and Stansbury Mountains and at Gold Hill.

According to the interpretation adopted for this paper, the black shale beneath the Pennsylvanian section along the Uinta Mountains is the Manning Canyon equivalent. This interpretation is that of Sadlick (1955, 1959) rather than that of Baker

and others (1949) and Crittenden (1959). The choice between these hypotheses hinges on whether the shale is part Pennsylvanian or not. If the shale does not contain the Mississippian-Pennsylvanian boundary, as does the type Manning Canyon, it might better be called the Doughnut formation, as suggested by Crittenden. The faunal evidence appears to be accumulating against Sadlick's interpretation (Crittenden, 1959, p. 71-72) but perhaps is not yet conclusive. Sadlick's evidence of transitional lithology between the black shale and the Round Valley limestone (1959) also requires consideration. In keeping with the adopted hypothesis, we may say that, at the very close of the Mississippian period, the rather restricted Chesterian sea (centered in the Oquirrh basin) began an expansion eastward, heralding the much more extensive Rocky Mountain sea of early Pennsylvanian.

In central western Utah and westward into Nevada, the Meramecian and Chesterian are represented by the Chainman shale and Diamond Peak formations. The Chainman shale in the vicinity of Eureka, Nevada (Nolan, and others, 1956, p. 59-60) may be several thousand feet thick and is mostly black shale, but the overlying Diamond Peak, into which the shale grades vertically and laterally, contains much conglomerate and limestone as well. In Diamond Peak this formation has a thickness of some 3,000 feet. Farther south, in extreme south-western Utah, the Blue Point limestone of Longwell (1921, p. 46), named in the Muddy Mountains, is probably present but is not well known.

PENNSYLVANIAN SYSTEM

General Statement

Like the Mississippian, the Pennsylvanian seas of the Utah area seem to have followed a cyclic history, expanding from the most persistent part of the geosyncline, the Oquirrh basin, at the beginning of the period, reaching a maximum in Desmoinesian time when they covered much of the Wyoming shelf and were widespread in the Paradox basin, and withdrawing to the most persistent part of the two basins at the close of the period. Uniform conditions in and about the Oquirrh basin resulted in the tremendously thick (16,000 feet, Pennsylvanian portion) and very monotonous Oquirrh formation, but an apparently more intense tectonism in the Paradox basin and its surrounding positive areas created there a diversity of stratigraphic units with complex facies interrelations, which are important for their production and potential production of petroleum.

Discovery of oil at Rangeley, Colorado, in the Pennsylvanian Weber sandstone gave a strong impetus to the study of the system in eastern Utah and led directly to a clarification of the stratigraphy along the Uinta Mountains. Later the extensive drilling program in the Paradox basin made possible the refinement of the old Hermosa and Rico formations, and a much more complete understanding of the Pennsylvanian geology of the Four Corners area.

Oquirrh Basin Facies

The Manning Canyon shale grades upward into "a great series of interbedded limestones and coarse quartzites and sandstones, with very little dolomite, and only subordinate amounts of shale" (Gilluly, 1932, p. 34), to which Gilluly gave the name Oquirrh formation. The term quartzite in this description covered lime-cemented sandstones, as well as silica-cemented ones. Nygreen (1958) has

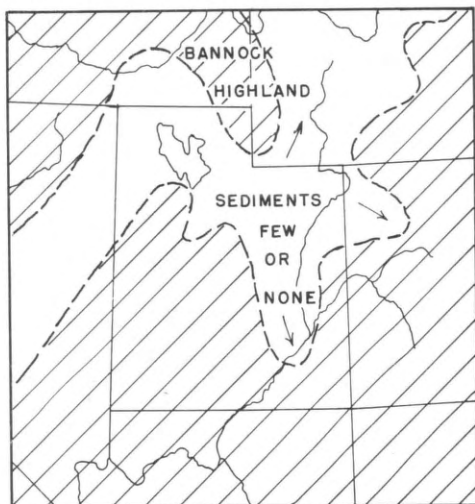


Figure 35. Springeran Time

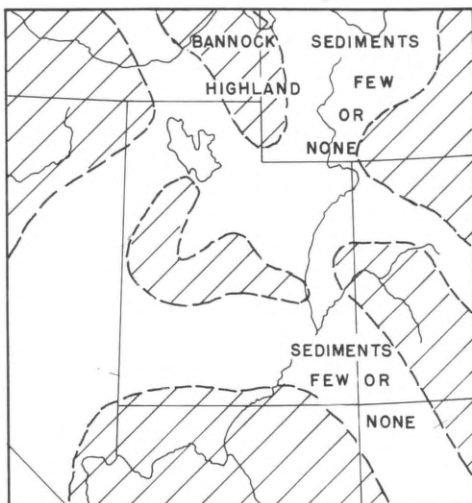


Figure 36. Morrowan Time

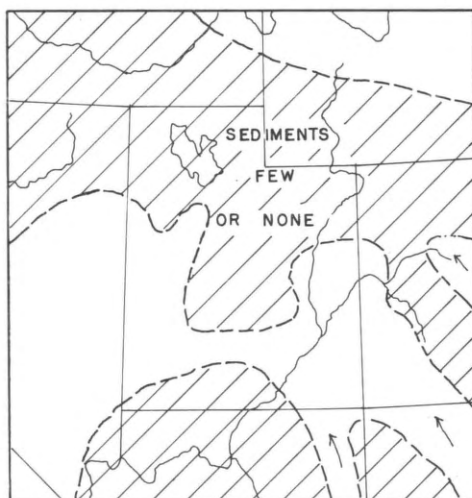


Figure 37. Atokan Time

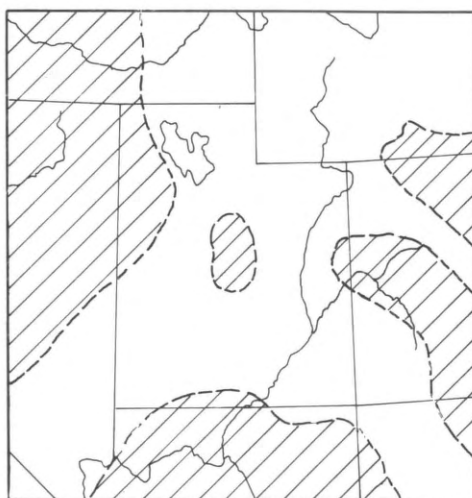


Figure 38. Desmoinesian Time

recognized a West Canyon limestone member at the base of the formation in the type area, about 1,500 feet of limestone with minor amounts of interbedded sandstone and siltstone. According to his report, the limestone is mainly bioclastic, medium blue gray, and thin- to thick-bedded; while the sandstones are fine grained, silty, and calcareous. In the formation, above the basal member, the proportion of sand and carbonate are reversed, and calcareous sandstone is the dominant rock type.

In the central and southern Wasatch Mountains, the Oquirrh formation is thicker than in the type area where the top is not exposed. Here the upper part is Wolfcampian. In Provo Canyon the basal limestone member is distinguishable (Baker, 1947), as it is in Wellsville Mountain at the northern end of the range (Nygren, 1958).

There is a possibility that the uppermost beds in Wellsville Mountain are Permian (Beus, 1958, p. 40). West of these Wasatch Mountains localities, the Oquirrh formation outcrops widely in the ranges of northwestern Utah, including the Blue Springs Hills, the Deer Creek Range, and the Raft River, Promontory, Lakeside, and Stansbury Mountains.

Atokan fossils have not been found in the Oquirrh Mountains, Provo, or Wellsville Mountain sections of the formation and so it is thought that the sea withdrew from the basin briefly at that time. Otherwise, all of Pennsylvanian time seems to be represented (Figure 41). Failure of Beus and Gelnett (1958) to find Missourian fossils in the Wellsville Mountain section is the basis for the suggested restriction of the basin at that time by a westward extension of the risen Wyoming shelf which had driven the sea completely from the southwestern part of Wyoming (Figure 39).

Lake of Springern, Atokan, and perhaps even Morrowan rocks in the Wellsville Mountain section (Williams, 1958, p. 35) as well as at the type area of the Wood River formation in central Idaho (Bostwick, 1955) and at the area of the Wells formation in southeastern Idaho, while some sediments in western Wyoming appear to represent these series, is the basis for postulating the Bannock highland (Figures 35 and 36). This highland may perhaps be considered the rather active rim of the Oquirrh basin; the rim rose at this time, separating the Wyoming shelf, where shallow seas had spread via the Uinta Mountain trough, from the basin. In Atokan time the highland merged with the Uncompahgre and Front Range highlands of Colorado to separate essentially the Molas sea of southeastern Utah from the Amsden sea of northern Wyoming (Figure 37). In Desmoinesian time it was submerged, but rose again in late Pennsylvanian, with the Wyoming shelf, to restrict the sea to the Oquirrh basin (Figures 39 and 40).

The Oquirrh facies of the Pennsylvanian gives way in a very short distance to the east to the much thinner, more variegated facies of the Wyoming and Utah-Colorado shelves. This is represented across Cache Valley and the Bear River Range by the change to the Weber-Wells facies (Williams, 1953) and across the Charleston overthrust in the central Wasatch by the change to the Morgan-Weber facies (Baker and others, 1949, p. 1192). The thinner rocks of Rich County and the Uinta Mountains area may be discussed as the Morgan-Weber facies.

Morgan-Weber Facies

The Weber quartzite or sandstone was named by Clarence King in 1876, and the Morgan formation by F. B. Weeks (in Blackwelder, 1910). The type localities of these formations are in the canyon of the Weber River in the north-central Wasatch Mountains. The Weber at its type section (Eardley, 1944, p. 833) consists of about 3,000 feet of sandstone and quartzite with a few relatively thin interbeds of chert and limestone. The quartzite is described as white, grayish white, light gray, medium gray, and buff. Some of the sandstone is called reddish-brown. The limestone (actually in part dolomite) is smoke gray to dark blue in color. The Weber sandstone is recognized as far north as the section

in Laketown Canyon. The upper boundary of the Weber is an unconformity with the overlying Permian Park City formation. At its base the Weber is gradational with the Morgan formation, essentially a red beds unit.

The name Morgan has been used along the Uinta Mountains for all beds between the Weber and the pre-Pennsylvanian rocks. These beds have been divided by various workers into two or three parts. The basal member is in places a pale-gray limestone with minor amounts of green shale and quartzite, which was not really included in the type Morgan by Blackwelder, as has been pointed out by Sadlick (1955, p. 56). This limestone has been called the middle member when beds below it have been included in the Morgan. The upper member is red clastics grading upward into the typical Weber sandstone. Apparently the beds below the gray limestone are the Manning Canyon shale or its equivalent, and the gray limestone may best be called the Round Valley limestone, following Sadlick (1955).

The Morgan is present at all Pennsylvanian outcrops from its type locality eastward into Colorado, where it grades into the Maroon formation. The age of the restricted formation is Desmoinesian, and it is apparently younger than the Amsden formation of Wyoming (Morrowan and Atokan), though lithologically very similar to it. The Amsden also bears the same stratigraphic relationship to the Tensleep as does the Morgan to the Weber, but was apparently largely deposited in a northern Wyoming Atokan sea, while there was little or no deposition in the Uinta area. Later, as the Desmoinesian sea spread, the Amsden red beds lithotype moved southward to that area.

In its type area the Morgan red beds consist of red shale and red, earthy, relatively soft sandstone with some thin intercalated limestones. Toward the Colorado line the formation is said to include gray and purplish shales, purplish siltstones, and mauve-gray to reddish-gray marlstones, with cherty brownish-weathering limestones and dolomites. The Round Valley limestone is described as pale gray in color with minor amounts of green shale and quartzite. Its megafossils at many places are replaced with red chert. Its thickness varies from 240 to 480 feet; that of the Morgan is of the same order, and the Weber itself is generally near 1,000 feet in thickness. Hence, along the Uintas this Pennsylvanian shelf facies does not exceed a few thousand feet in thickness, in marked contrast to the thick Oquirrh basin succession. An excellent and detailed description of the lithology and invertebrate fossils of the Morgan formation in Whirlpool Canyon may be found in "The Morgan Formation of Whirlpool Canyon, Green River Dinosaur National Mounment, Uintah County, Utah", page 219-232 of the Oil and Gas Possibilities of Utah, Utah Geol. and Mineralog. Survey, 1949.

Pennsylvanian of the Paradox Basin

Pennsylvanian seas appear to have spread southeastward across Utah from the Oquirrh basin and the Uinta Mountains area into the Paradox basin and the Colorado trough, arriving there in Morrowan time (Figures 35 and 36). In Atokan time they persisted there while northern Utah received little or no deposition (Figure 37). In the Desmoinesian epoch access to the basin through the Oquirrh sag to the northwest, the Fremont sag to the west, and the Cabezón sag to the southeast was sufficiently impaired to create an evaporite sea in which the Paradox formation was deposited (Wengerd and Matheny, 1958). The better ventilated seas in late Pennsylvanian time were restricted by the rapid arrival of sediments from the rising borderlands, but they persisted in the basin until Permian time (Figure 39 and 40).

Outcroppings of Pennsylvanian rocks in the Colorado Plateaus portion of Utah are indeed few. Largest are in the canyons of the San Juan and Colorado Rivers, in the former where it crosses the Monument Valley uplift, and in the latter near its confluence with the Green River and below this junction, in Cataract Canyon. Other Pennsylvanian outcrops occur in and around the valleys created on the salt anticlines in eastern Grand and San Juan Counties, and in the deepest canyons of the San Rafael Swell. At no place is the base of the system exposed. The two most complete sections are at Honaker Trail in San Juan Canyon below Mexican Hat (Gregory, 1938, p. 65) and at "The Slide", just above the junction of the Green and Colorado, in the canyon of the Colorado (Baker, 1933, p. 20, 21). The Pennsylvanian system as developed in the Paradox basin is about 2,000 feet thick.

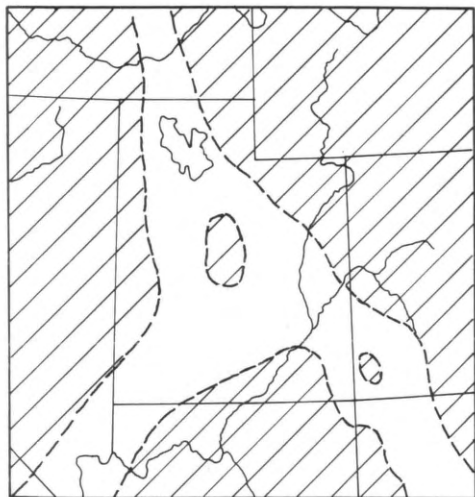


Figure 39. Missourian Time

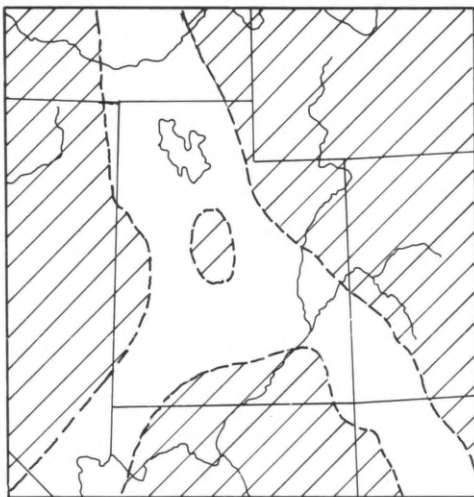


Figure 40. Virgilian Time

When the intensive subsurface exploration of the Paradox basin began, the major outlines of its Pennsylvanian stratigraphy had already been completed by geologists of the U.S. Geological Survey. The section had been correlated with that of southwestern Colorado, and the Hermosa and Rico formations were recognized in Utah outcrops. Baker and his colleagues (1933) had largely determined the regional extent of the Paradox formation, and the fact that it was older than parts of the Hermosa formation. They considered the Rico formation to be Permian. By 1944 these workers were aware of the facies relationships of the Hermosa and Paradox formations (Bass, 1944), and the Paradox was designated a member of the Hermosa formation. The presence of the Molas formation at the base of the section was recognized.

The Hermosa at Honaker Trail was described (Gregory, 1938) as predominately limestone in its lower part, but with increasing amounts of sandstone and shale in the upper part. The limestone was said to be massive and crystalline, with nodules and lenses of red, gray, and black chert. The sandstones were noted as fine grained, calcareous, thin bedded to massive, and interlayered with shale.

The shale was described as grading from red, arenaceous and calcareous varieties to thinly foliated, black, argillaceous and bituminous types. In the section measured at The Slide, sandstone and limestone were reported in about equal abundance, and with a large amount of shale (Baker, 1933, p. 20-21). A section of the Hermosa formation in Fisher Valley, Grand County, reported by Dane (1935, p. 34-35), is largely sandstone with a thick member of black or gray shale and gypsum. The section in the type area (Bass, 1944) consists of alternating beds of arkosic sandstone, with some grit and conglomerate, and thin beds of compact, dark-gray, fossiliferous limestone. There are interbeds of black shale, one member of black shale 80 feet thick, and units of black shale and gypsum.

The Rico formation is a rather thin unit (300-500 feet) of interbedded limestones, sandstones, conglomerates, and sandy shales. It is a red beds unit, differing from the Hermosa below in the presence of red color and from the Cutler above in the presence of limestones. From similarities of the Utah section with its type locality in the Rico Mountains, Colorado, it has been recognized in eastern Utah above the Hermosa formation. In San Juan County (Gregory, 1938) described the formation as forming "flights of colored steps that lead from the bottom to the top" in canyons and gulches, and creating exceptionally attractive scenery on steep structural slopes, such as the Raplee anticline, where gullies are marked by the bright red sandstone revealed where streams have cut through the overlying grey limestone. Farther north in the Colorado River Baker (1933) reports the sandstones of the formation as commonly massive, with many coarse grained, conglomeratic, and arkosic. Colors of individual beds are red, purple, pink, and brown. The limestones are usually thin, sandy, and greenish. Northwest of Moab the Rico formation cannot be distinguished from the Cutler formation.

The Molas formation (Merrill and Winar, 1958) is the basal Pennsylvanian formation in southeastern Utah. It consists of 0 to 200 feet of variegated claystone, siltstone, shale, and sandstone, with some intraformational conglomerate. At its base it fills fissures and solution cavities in the underlying Mississippian limestone, and includes boulders of Leadville and Ouray limestone. According to Wengerd and Matheny (1958, p. 2064) it is thin or absent in the Emery County area but thickens to more than 150 feet in the Monument Valley uplift.

The results of much recent work on the Pennsylvanian stratigraphy of the Paradox basin are summarized by Wengerd and Matheny (1958). They report the work of the senior author and Strickland (1954) raising the Hermosa formation to group rank; and recognizing the beds below the evaporite Paradox formation as the Pinkerton Trail formation. Wengerd and Strickland would designate the post-Paradox part of the group as the Honaker Trail formation, and reduce the Rico to a member of the Cutler formation. The Pinkerton Trail formation, about 200 feet thick in southeastern Utah, consists of gray fossiliferous limestone interbedded with gray silty shale. This formation is not exposed at Honaker Trail. It is in most areas Atokan and lower Desmoinesian.

The Paradox formation includes the evaporite facies and associated penesaline rocks. It is composed of greenish-gray sandy siltstone, dark-gray siltstone, dark-gray shale, and evaporitic dolomite, gypsum, and anhydrite. On the shelves of the basin it includes bioherms and biostromes of dolomitic limestone. Its thickness along the axis of the Paradox basin is estimated to be greater than 4,000 feet. The Paradox formation is represented in the lower part of the

Honaker Trail section. The Honaker Trail formation includes most of the exposure at that place up to the Rico facies of the Cutler formation. It is the product of a well-ventilated sea that followed the restricted salt pans of Paradox time and consists of gray to reddish-gray cherty limestones and reddish to buff-gray calcareous and sandy siltstones. Westward it grades into dolomite, and eastward into a sandier, arkosic facies. The Honaker Trail formation is of late Desmoinesian and Missourian age on the Monument Valley uplift, and the upper part of it is younger in the central part of the basin.

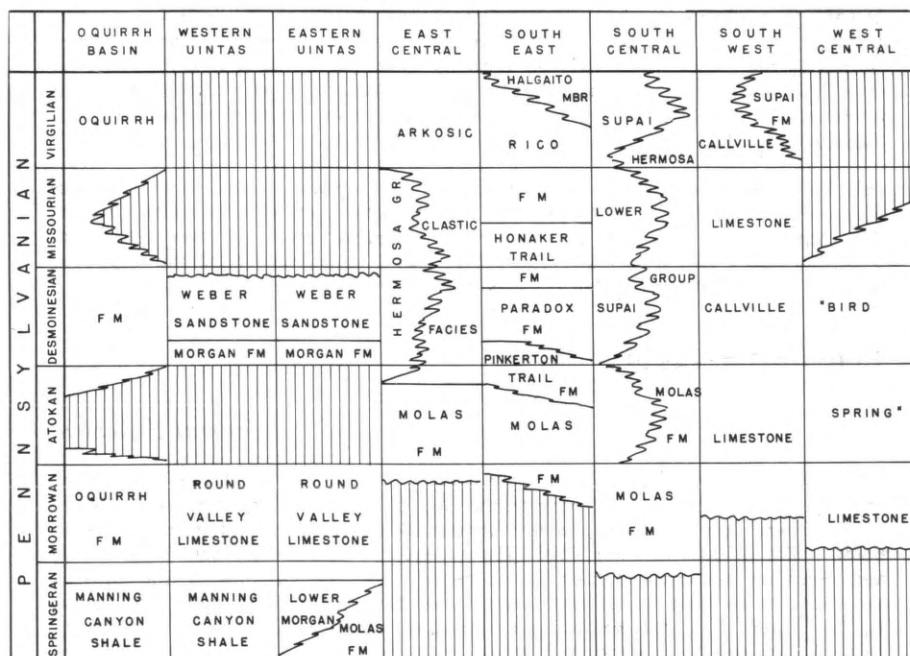


Figure 41. Pennsylvanian Correlation Chart

According to Wengerd and Matheny (1958, p. 2080), the Rico lithofacies, transitional between marine and non-marine deposits in the Paradox basin, is as old as Missourian in parts of the area (Monument Valley uplift) and as young as Wolfcampian at the Four Corners.

As shown in Figure 41, the Hermosa group of San Juan County grades toward the southwest into the lower Supai formation. To the northeast as the Uncompahgre highland is approached, the Hermosa group grades into the coarse clastics shed from that highland.

Pennsylvanian of the Southwestern Area

The Pennsylvanian system in southwestern Utah has obviously not had the study the system has received in southeastern Utah. Exposures in the basin ranges have not been well studied. Limestones in west-central Utah beneath the Permian red beds have been assigned to the Bird Spring formation of Hewett (1931). Kraetsch and Jones (1951) report them as being Morrowan to Desmoinesian in the lower part, and Wolfcampian at the top. This means that deposition was perhaps interrupted here, as it was farther west (Nolan and others, 1956, p. 63) in Late Pennsylvanian time. These limestones are described as gray, cherty, and fossiliferous. In extreme southwestern Utah the Pennsylvanian is represented by the Callville limestone, a sandy limestone in medium beds, colored gray and pinkish gray (McNair, 1952, p. 50). The upper part of this formation is Permian. To the east the top of the Callville presumably grades into the Supai formation.

Following Schuchert (1955) the paleogeographic maps of the Pennsylvanian (Figures 35-40) show the seaways of Utah as connected at most times through the southwestern corner of the state to the Pacific ocean. If this concept is true, the "Bird Spring formation" and the Callville limestone may be expected to yield more or less complete records of Pennsylvanian sedimentation.

PERMIAN SYSTEM

General Statement

Wolfcampian time in the area of Utah was marked by continuing deposition of the Oquirrh calcareous sandstone in the Oquirrh basin and by continuing deposition in the Paradox basin, where terrestrial sediments shed from the rising borderlands pushed out the sea. Here, early in the epoch, the marine Rico and Hermosa carbonate facies disappeared, and the balance of the time is recorded in massive terrestrial sandstones and interlayered red beds units. In Leonardian time the Kaibab sea spread northeastward across the southern part of the area, interfingering with the same type of terrestrial red beds. It extended midway up the state. North of its shore in the Oquirrh basin and to the northeast on the Wyoming shelf, a new cycle of inundation began, which soon developed into the widespread Park City-Phosphoria sea, extending from Nevada northeastward far into Colorado, Wyoming, and Idaho (Figure 44). Withdrawal of this sea marked the end of Paleozoic deposition in Utah.

Terrestrial Formations of Southeastern Utah

The Permian stratigraphy of southern and southeastern Utah is well summarized by Heylman for the Kaiparowits region (1958, p. 1792-1800) and by Kunkel (1958) for the Paradox basin. Their descriptions detail the cessation of marine carbonate deposition in Wolfcampian time in the central and western parts of the Paradox basin and the change to a low coastal plain where red arkosic alluvium from the Uncompahgre uplift interfingers with buff aeolian sand blown into the area, generally from the west, and occasionally leveled by brief incursions of the sea. The red-beds tongues or members that thicken and coarsen eastward into the arkosic facies of the Cutler formation are the Halgaito, Organ Rock, and Hoskinnini members of the Cutler formation, well exposed in the Monument Valley area. The sandstones are the Cedar Mesa, White Rim, and DeChelly members of the Cutler formation, and the Coconino sandstone of the Grand Canyon

section. The sandstone members of the Cutler appear to thicken northwestward and merge into the "Coconino" sandstone of the San Rafael Swell which probably also contains an equivalent of the type Coconino of the Grand Canyon area.

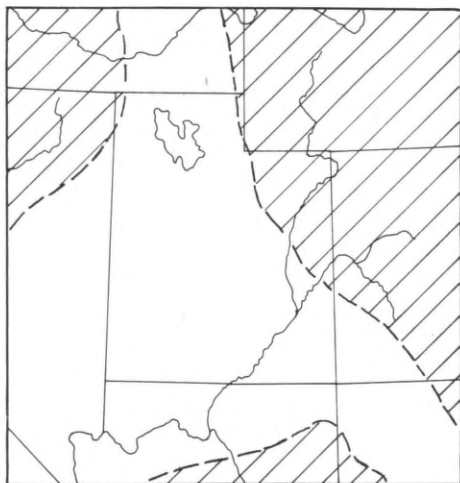


Figure 42. Wolfcampian Time

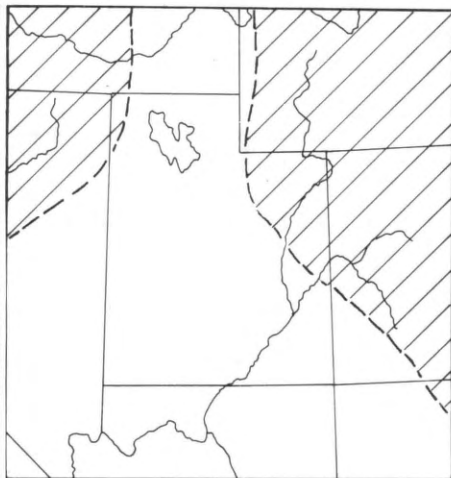


Figure 43. Leonardian (Toroweap-Kaibab) Time

The Halgaito tongue does not occur north or west of the Monument Valley area. It is described as consisting of several hundred feet of red to chocolate-brown thin-bedded sandstones, siltstones, and mudstones with scattered thin lenses of limestone and conglomerate. The Organ Rock tongue is thicker (up to 870 feet) and more extensive, reaching into the southeastern part of the Kaiparowits region and northward into the Green River Desert. Lithologically, it is similar to the Halgaito tongue. The Hoskinnini tongue is thin and largely confined to the Monument Valley area, although it may be represented in thin red beds at the top of the Cutler in other parts of the Paradox basin (Kunkel, 1958, p. 167). The sandstone members are composed of medium-to-fine grains, weakly cemented with calcium carbonate, and varying in color from light gray through buff to reddish brown. Generally, they are massive with high-angle cross-bedding and are thought to be partly of aeolian origin, although the presence in most outcrops of regular bedding planes suggests control by a nearby sea. The Cedar Mesa sandstone was named for the mesa (which it supports), north of Mexican Hat, and is well developed along the San Juan River. In White Canyon to the northwest, several of the state's most famous natural bridges are developed in the Cedar Mesa sandstone. Its thickness is reported as 400 to 12,000 feet (Gregory, 1938). Eastward, in Comb Wash the Cedar Mesa grades into gypsiferous shales and

sandstones, with some limestone and much pink-to-white gypsum or anhydrite. These beds, known as the Cedar Mesa evaporite facies (Kunkel, 1958, p. 166), extend rather widely over the south-central part of the Paradox basin and at the Colorado line grade into the Cutler facies. The DeChelly sandstone, 800 feet thick at the type locality in northeastern Arizona, thins northward into Utah. Farther north, along the Colorado River as it nears its junction with the Green, the stratigraphic position of the DeChelly, above the Organ Rock tongue, is occupied by the White Rim sandstone. This member is similar lithologically to the other sandstone members. It is on the order of 100 feet in thickness, and grades eastward into red beds.

From the San Rafael Swell northward there are no Permian exposures until the southern Wasatch Mountains are reached. Here, Baker discovered two formations of unusual interest between the Oquirrh and Park City formations. They are the Kirkman limestone, 0-1,600 feet of gray-to-black, fetid, brecciated limestone, and the Diamond Creek sandstone, 800-1,000 feet of gray or buff or red, fine to coarse-grained cross-bedded sandstone (Baker and others, 1949, p. 1187). Baker's tentative correlation of the Diamond Creek with the "Coconino" sandstone of the San Rafael Swell is probably sound. The Kirkman and Diamond Creek are not known beyond their type area. Next above the Diamond Creek in the southern Wasatch Mountains are the 600-900 feet of limestone and calcareous sandstone of the lower member of the Park City formation. The sandy beds of this member, and the Diamond Creek, below, appear to be represented farther north in Mansfield's area in the upper member of the Wells formation. This is described by Cressman and Gulbrandsen (1955) as 1,300-1,500 feet of calcareous quartz sandstone, commonly cross-bedded and brecciated, and varying in color from light gray to reddish brown. Thus, it appears that the marine invasion of Park City-Phosphoria time was preceded in southeastern Idaho and northeastern Utah by the deposition of sandstone, probably largely terrestrial, reflecting the widespread terrestrial conditions of the southern part of the state.

Kaibab Limestone and Associated Formations

In the closing stages of the terrestrial deposition in southeastern Utah, the Permian sea again approached the area from the west, depositing the Toroweap and Kaibab formations. Each formation represents a cycle of advance and retreat. The Toroweap formation is not exposed in south-central Utah, but is present in the wells that have been drilled there (Heylman, 1958, p. 1795). Logs of these define a distinct basin in the Kaiparowits region where evaporites were deposited at the edge of the retreating Toroweap sea. Here the formation reaches a thickness of 500 feet.

After an interval of erosion, a second pulse brought the Leonardian sea eastward from the persistent parts of the Cordillerian geosyncline in southern Nevada, depositing in this cycle the Kaibab limestone. In the Circle Cliffs the Kaibab is described as massive white vuggy dolomite interbedded with chert and is about 200 feet thick. In the San Rafael Swell it is said to be light gray to light brown medium-to finely-crystalline limestone and dolomite, notably cherty (Herman and Sharps, 1956, p. 84), and about 100 feet thick. In the San Rafael Swell the formation is terminated upward by a marked erosion surface overlain by a basal conglomerate.

In West-central Utah a thick Wolfcampian red beds section overlies the "Bird Springs formation," a limestone with Wolfcampian fossils at its top (Campbell, 1951, p. 63-65). Thus, it seems that earliest Permian deposition of carbonates

here, as in parts of the Colorado Plateaus, was followed by near-shore, if not terrestrial, sedimentation. These red beds, some 3,000 feet thick, have been referred to the Supai formation of the Grand Canyon area. Above these Supai beds 1,000 feet of light gray to tan fossiliferous limestone, readily referable to the Kaibab, has been observed. Here, then, appears to have been a persistent part of the Toroweap-Kaibab sea, from which the incursions into south-central Utah took place. This sea may well have extended westward into Nevada where the Carbon Ridge formation, containing both variegated sandy limestones and sandstones as well as crystalline cherty limestones (Nolan and others, 1956, p. 64-66), was deposited.

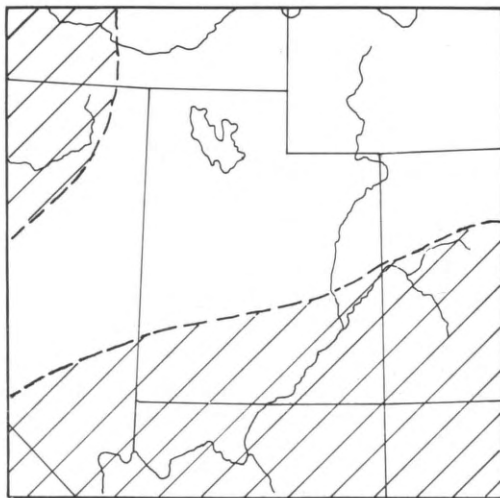


Figure 44. Guadalupian (Park City-Phosphoria) Time

Park City Formation and Correlatives

The Park City formation was named by Boutwell in 1907 from exposures in the Park City district on the east side of the Wasatch Mountains. Here it consists of upper and lower members of cherty limestone and sandstone, separated by a middle shaly member containing phosphatic shale and oolite. It lies upon the Pennsylvanian Weber quartzite and is overlain by Triassic beds. The formation in its type locality is about 600 feet thick. In 1912 the two upper members of the formation in southeastern Idaho were named the Phosphoria formation by Richards and Mansfield. The lower member in this area was assigned to the underlying Wells formation and was considered to be Pennsylvanian in age. The formation has great economic importance because of the phosphate it contains.

Following World War II, the U.S. Geological Survey undertook an intensive study of the Phosphoria and Park City formation, and a summary description of them has been published (McKelvey and others, 1956, p. 2826-2863). The middle member of the Park City formation, the principal phosphatic member, has been named the Meade Peak phosphatic shale member of the Phosphoria formation. It is 125-225 feet thick in the Blackfoot River-Montpelier area of southeastern Idaho, and 180-300 feet thick in the central and southern Wasatch Mountains. Eastwardly, it thins from 60-90 feet in the western Uinta Mountains to a wedge-

edge at the Colorado line. It consists mostly of brown calcareous phosphatic mudstone grading downward and upward into beds of oolitic phosphorite. Thus, the high grade phosphate ore occurs at the bottom and top of the member.

Above the Meade Peak member in the Crawford Mountains, Rich County, Utah, three stratigraphic units are recognized. The Rex chert member of the Phosphoria formation lies next above the Meade Peak. It is characterized by resistant cherty rocks, ranging from pure chert to cherty mudstone and limestone. Bedding varies from even to wavy, and thickness of beds from thin to massive. In the Crawfords this member is 70-200 feet thick. It thins southward and disappears in the Wasatch Mountains. It thickens northward and westward in Idaho. Above this lies the Franson tongue of the Park City formation, 110 feet of light gray and grayish brown cherty calcareous sandstone, named from Franson Canyon at the west end of the Uinta Mountains. In the Wasatch Mountains the Franson member is the whole of the upper member of the Park City formation, except for the thin tongue of Rex member at the base. Eastward, along the Uinta Mountains the Franson member interfingers with the Mackentire red-beds tongue of the Woodside formation. The Mackentire and Franson members total about 100 feet near the Colorado line. The Retort phosphatic shale member, 0-5 feet thick, completes the Crawford Mountains section. This member, named for a locality in Montana, is about 25-30 feet thick in western Wyoming, but disappears westward in Idaho and southward in Utah.

The lower member of the Park City formation consists of cherty limestone and calcareous sandstone and siltstone. It reaches a thickness of 880 feet in the southern Wasatch Mountains (Baker and others, 1949, p. 1188) and is about 250 feet thick in the central Wasatch. Eastward, along the Uinta Mountains it thins and disappears. Northward into Idaho it is probably represented by the upper Wells formation as mapped and described by Cressman and Gulbrandsen (1955) in the Dry Valley quadrangle. The Permian age of the lower member in Utah has been established by James S. Williams, A. A. Baker, and others. It is thought probably to be Leonardian, like the Kaibab and Toroweap formations, while the Meade Park, Franson and Rex members are probably lower Guadalupian (McKelvey and others, 1956, p. 2857).

Equivalents of the Park City Phosphoria formations have been recognized in extreme northwestern Utah, in the Hogup Mountains west of Great Salt Lake, and in unnamed hills southeast of Lucin (Cheney and McKelvey, 1956, p. 1717). They can be identified farther west well into Nevada and northward in the Cassia and Sublett Ranges in Idaho. In the Sublett Range the Phosphoria equivalents are thick. There are 85 feet of dark mudstone and phosphorite, probably the equivalent of the Meade Peak member, overlain by 1,200 feet of dark chert, cherty mudstone, and mudstone, apparently the equivalent of the Rex and cherty shale members farther east. The Gerster formation of the Gold Hill district (Nolan, 1935, p. 39) has since its designation been correlated with the Park City and Phosphoria on the basis of its fossils. It is described as consisting of thin-bedded shaly and sandy limestone, weathering yellowish brown or pink, and richly fossiliferous. There is some sandstone and some cherty limestone. Below these rocks originally designated Gerster are some 600 feet of cherty and sandy dolomite, in turn underlain by 25-75 feet of phosphatic beds believed to be the equivalent of the Meade Peak member. Thus, the restudied Gerster formation is about 1,200 feet thick (Cheney and McKelvey, 1956, p. 1717). In the Hogup exposures between the Gold Hill and Sublett outcrops, the Phosphoria equivalents are 3,000 to 4,000 feet thick, thus marking the most rapidly subsiding part of the Phosphoria-Park City sea.

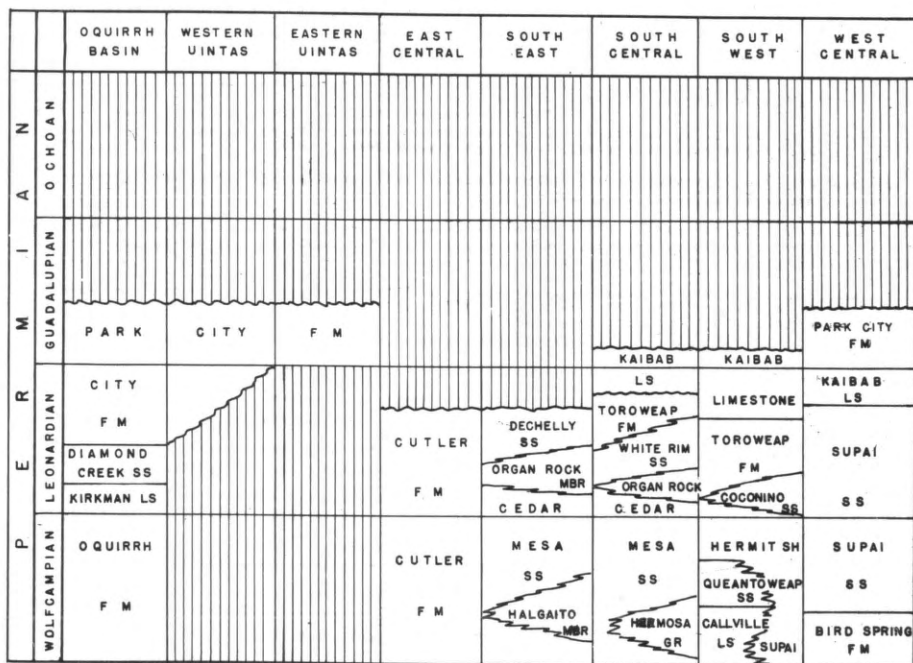


Figure 45. Permian Correlation Chart

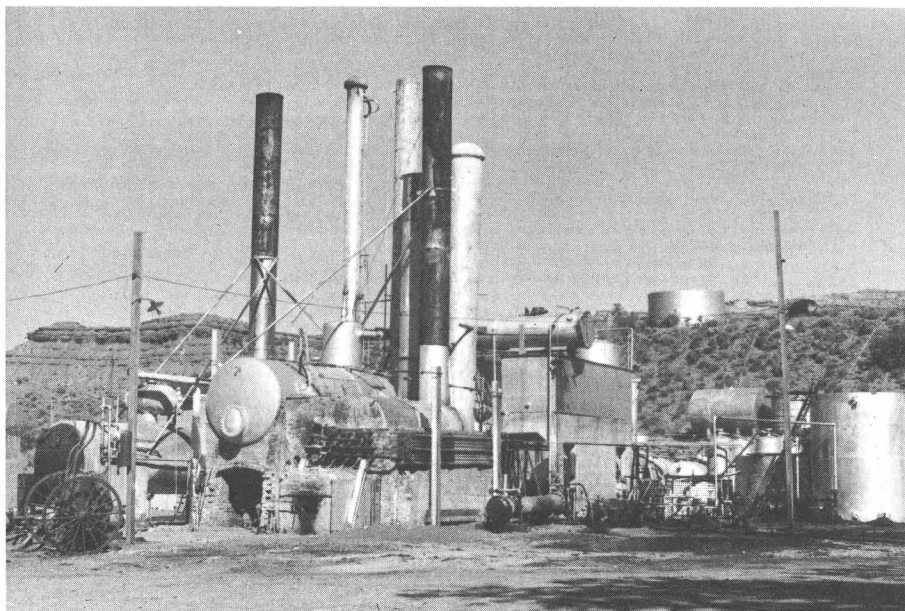
CONCLUSION

A review of the Carboniferous and Permian rocks of Utah reveals much basic information recorded, and the major outlines of the stratigraphy of the Mississippian, Pennsylvanian, and Permian systems fairly well completed for much of the state. The areas of least information are the central part where rocks of these ages lie deeply buried beneath the High Plateaus and the southwestern area, where exposures have received comparatively little study. Principal basins of deposition are the Oquirrh basin of northwestern Utah and its extension south-westward along the axis of the geosyncline and the Paradox basin of southeastern Utah. Nomenclature for these areas is, perhaps, nearly complete. Detailed studies of the future will continuously refine the paleogeographic information on which maps of the type here presented may be drawn.

CITED REFERENCES

- Baker, A. A., 1933, Geology and oil possibilities of the Moab district, Grand and San Juan Counties, Utah: U.S. Geol. Survey Bull. 841, 95 p. 11 pls.
- _____, 1947, Stratigraphy of the Wasatch Mountains in the vicinity of Provo, Utah: U.S. Geol. Survey Oil and Gas Inv. Prelim Chart 30.
- Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., 1933, Paradox formation of eastern Utah and western Colorado: Am. Assoc. Petroleum Geologists Bull., v. 17, no. 8, p. 963-980.
- Baker, A. A., Huddle, J. W., and Kinney, D. W., 1949, Paleozoic geology of north and west sides of Uinta Basin, Utah: Am. Assoc. Petroleum Geologists Bull., v. 33, no. 7, p. 1161-1197.
- Bass, N. W., 1944, Paleozoic stratigraphy as revealed by deep wells in parts of southwestern Colorado, northwestern New Mexico, northeastern Arizona, and southeastern Utah: U.S. Geol. Survey Oil and Gas Inv. Prelim Chart 7.
- Beus, S. S., 1958, Geology of the northern part of Wellsville Mountain, northern Wasatch Range, Utah: Utah State Univ., M.S. thesis.
- Blackwelder, Eliot, 1910, New light on the geology of the Wasatch Mtns., Utah: Geol. Soc. America Bull. 21, p. 517-542.
- Bestwick, D. A., 1955, Stratigraphy of the Wood River formation, south-central Idaho Jour. Paleont., v. 29, no. 6, p. 941-951.
- Calkins, F. C., and Butler, B. S., 1943, Geology and ore deposits of the Cottonwood-American Fork area, Utah: U.S. Geol. Survey Prof. Paper 201, 152 p. 51 pls.
- Campbell, G. S., 1951, Permian system of Millard County, Utah: Intermountain Assoc. Petroleum Geologists Guidebook no. 6, p. 63-65.
- Cheney, T. M., and McKelvey, V. E., 1956, Fusulinid-bearing rocks in Sublett Range, southern Idaho: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 7, p. 1716-1723.
- Cressman, E. R., and Gulbrandsen, R. A., 1955, Geology of the Dry Valley quadrangle, Idaho: U.S. Geol. Survey Bull. 1015-I.
- Crittenden, M. C., Jr., 1959, Mississippian stratigraphy of the central Wasatch and western Uinta Mountains, Utah: Intermountain Assoc. Petroleum Geologists Guidebook 10th Ann. Field Conf., p. 63-74.
- Crittenden, M. D., Jr., Sharp, B. J., and Calkins, F. C., 1952, Geology of the central Wasatch Mtns., Utah: Utah Geol. Soc. Guidebook no. 8, p. 1-37.
- Dane, C. H., 1935, Geology of the Salt Valley anticline and adjacent areas, Grand County, Utah: U.S. Geol. Survey Bull. 863, 184 p.
- Eardley, A. J., 1944, Geology of the north-central Wasatch Mountains, Utah: Geol. Soc. Am. Bull., v. 55, p. 819-894.
- Gelnett, Ronald, 1958, Geology of the southern part of Wellsville Mountain, northern Wasatch Range, Utah: Utah State Univ., M.S. thesis.
- Gilluly, James, 1932, Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U.S. Geol. Survey Prof. Paper 173, 171 p.
- Granger, A. E., 1953, Stratigraphy of the Wasatch Range near Salt Lake City, Utah: U.S. Geol. Survey Circ. 296, 14 p.
- Gregory, H. E., 1938, The San Juan Country: U.S. Geol. Survey Prof. Paper 188.
- Herman, George, and Sharps, S. L., 1956, Pennsylvanian and Permian stratigraphy of the Paradox salt embayment: Intermountain Assoc. Petroleum Geologists Guidebook 7th Ann. Field Conf., p. 77-84.
- Hewett, D. F., 1931, Geology and ore deposits of the Goodsprings Quadrangle, Nevada: U.S. Geol. Survey Prof. Paper 162, 172 p.
- Heylman, E. B., 1958, Paleozoic stratigraphy and oil possibilities of Kaiparowits region, Utah: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 8, p. 1781-1811.
- Holland, F. D., Jr., 1952, Stratigraphic details of lower Mississippian rocks of northeastern Utah and southwestern Montana: Am. Assoc. Petroleum Geologists Bull., v. 36, no. 9, p. 1697-1734.
- Kraetsch, R. B., and Jones, R. L., 1951, Pennsylvanian rocks of the Confusion Range and vicinity: Intermountain Assoc. Petroleum Geologists Guidebook, no. 6, p. 60-62.
- Kunkel, R. P., 1958, Permian stratigraphy of the Paradox Basin: Intermountain Assoc. Petroleum Geologists Guidebook 9th Ann. Field Conf., p. 163-168.
- Longwell, C. R., 1921, Geology of the Muddy Mountains, Nevada, with a section to the Grand Wash Cliffs in western Arizona: Am. Jour. Sci., ser. 5, v. 1, no. 1, p. 39-62.

- McKelvey, and others, 1956, Summary description of Phosphoria, Park City, and Shedhorn formations in western phosphate field: *Am. Assoc. Petroleum Geologists Bull.*, v. 40, no. 12, p. 2826-2863.
- McNair, A. H., 1952, Summary of the pre-Coconino stratigraphy of southwestern Utah, northwestern Arizona, and southeastern Nevada: *Intermountain Assoc. Petroleum Geologists Guidebook*, no. 7, p. 45-51.
- Merrill, W. M., and Winar, R. M., 1958, Molas and associated formations in San Juan Basin-Needle Mountains area, southwestern Colorado: *Am. Assoc. Petroleum Geologists Bull.*, v. 42, no. 9, p. 2107-2132.
- Morris, H. T., 1957, General geology of the East Tintic Mountains, Utah: *Utah Geol. Soc. Guidebook*, no. 12, p. 1-56.
- Neff, A. W., and Brown, S. C., 1958, Ordovician-Mississippian rocks of the Paradox basin: *Intermountain Assoc. Petroleum Geologists Guidebook 9th Ann. Field Conf.*, p. 102-108.
- Nolan, T. B., 1935, The Gold Hill mining district, Utah: *U.S. Geol. Survey Prof. Paper* 177, 172 p.
- Nolan, T. B., Merriam, C. W., and Williams, J. S., 1956, The stratigraphic section in the vicinity of Eureka, Nevada: *U.S. Geol. Survey Prof. Paper* 276, 77 p.
- Nygreen, P. W., 1955, Stratigraphy of the lower Oquirrh formation in the type area and near Logan, Utah: *Univ. of Nebraska, M.S., thesis*. Published version--1958, The Oquirrh formation, stratigraphy of the lower portion in the type area and near Logan, Utah: *Utah Geol. and Mineralog. Survey Bull.*, 61, 67 p.
- Olson, R. H., 1956, Geology of Promontory Range: *Utah Geol. Soc. Guidebook to the Geology of Utah*, no. 11, p. 41-75.
- Rigby, J. K., 1958, Geology of the Stansbury Mountains, Tooele County, Utah: *Utah Geol. Soc. Guidebook* no. 13, p. 1-134.
- Sadlick, Walter, 1955, Carboniferous formations of northeastern Uinta Mountains: *Wyoming Geol. Soc. Guidebook 10th Ann. Field Conf.*, p. 49-59.
- _____, 1956, Some upper Devonian-Mississippian problems in eastern Utah: *Intermountain Assoc. Petroleum Geologists Guidebook 7th Ann. Field Conf.*, p. 65-76.
- _____, 1959, Illustrated sections of strata adjustment to the Mississippian-Pennsylvanian boundary, western Uinta Mountains: *Intermountain Assoc. Petroleum Geologists Guidebook 10th Ann. Field Conf.*, p. 75-81.
- Schuchert, Charles, 1955, *Atlas of paleogeographic maps of North America*: New York, John Wiley and Sons, Inc., publishers, 177 p.
- Spencer, A. C., 1917, The geology and ore deposits of Ely, Nevada: *U.S. Geol. Survey Prof. Paper* 96.
- Strickland, J. W., 1956, Mississippian stratigraphy, western Wyoming: *Wyoming Geol. Soc. Guidebook 11th Ann. Field Conf.*, p. 51-57.
- Thomas, C. R., McCann, F. T., and Raman, N. D., 1945, Mesozoic and Paleozoic stratigraphy in northwestern Colorado and northeastern Utah: *U.S. Geol. Survey Oil and Gas Inv. Prelim Chart* 16.
- Untermann, G. E., and Untermann, B. R., 1949, The Morgan formation of Whirlpool Canyon, Green River Dinosaur National Monument, Uintah County, Utah: The oil and gas possibilities of Utah, Salt Lake City, Utah Geol. and Mineralog. Survey, publisher, p. 219-232.
- Wengerd, S. A., and Matheny, Marvin L., 1958, Pennsylvanian system of Four Corners region: *Am. Assoc. Petroleum Geologists Bull.*, v. 42, no. 9, p. 2048-2102.
- Wengerd, S. A., and Strickland, J. W., 1954, Pennsylvanian stratigraphy of Paradox salt basin, Four Corners region, Colorado and Utah: *Am. Assoc. Petroleum Geologists Bull.*, v. 42, no. 9, p. 2048-2106.
- Williams, J. S., 1943, Carboniferous formations of the Uinta and northern Wasatch Mountains, Utah: *Geol. Soc. America Bull.*, v. 54, p. 591-624.
- _____, 1953, Pennsylvanian and Permian rocks: *Intermountain Assoc. Petroleum Geologists Guidebook 4th Ann. Field Conf.*, p. 38-40.
- _____, 1955, Resume of Paleozoic stratigraphy, Ordovician to Pennsylvanian, of the Green River Basin area, Wyoming: *Wyoming Geol. Soc. Guidebook 10th Ann. Field Conf.*, p. 43-47.
- _____, 1958, Geologic atlas of Utah, Cache County: *Utah Geol. and Mineralog. Survey Bull.*, 64, 104 p.
- Williams, N. C., 1953, Late Precambrian and early Paleozoic geology of western Uinta Mountains, Utah: *Am. Assoc. Petroleum Geologists Bull.*, v. 37, p. 2734-2743.



Refinery located in Virgin Oil Field, Washington County, Utah. Refines diesel fuel oil. (Photo by E. B. Heylman)

Paper 11 TRIASSIC AND JURASSIC PERIODS IN UTAH

by William Lee Stokes¹

INTRODUCTION

Triassic and Jurassic rocks are widely exposed in eastern, central, and southern Utah, not only in the plateau sections, but also in the Uinta and Wasatch ranges. There are also scattered small patches of Triassic in the Basin and Range province. The exposed formations show all the typical varieties of sedimentary rock and, in addition, such unusual ones as widespread aeolian sandstones, extensive "red beds" and thick deposits of salt and gypsum. Economically the two systems are best known for their content of radioactive minerals, which are widely mined in the Colorado Plateau.

TRIASSIC

Stratigraphic Limits

Where exposed, the Triassic rocks rest upon the Permian without strong evidences of unconformity or time lapse, even though fossils suggest that long portions of the Permian and Triassic are not represented by sediments. In the eastern part of the state where the transition lies in non-marine and scantily fossiliferous red beds, the time plane cannot be fixed with absolute certainty. It seems illogical to suppose that there was complete and absolute cessation of deposition during this interval, and future investigation can be expected to provide evidence of life and events during the late Permian and Early Triassic which will fix the boundary more precisely. In western parts of Utah where beds involved are more fossiliferous, the boundary can be placed with greater certainty, and a long time lapse must be assumed.

The upper limit has been mapped for many years at the contact of the Chinle and Wingate formations, which is usually an excellent topographic and cartographic break. Recently discovered evidence shows that the Wingate and probably even the Kayenta are of Triassic age, so the boundary must be shifted accordingly. In the absence of positive evidence as to the exact position of the time plane, it is assumed for the purposes of this paper that the boundary lies between the Navajo and Kayenta formations. In southwestern Utah it lies between the Kayenta and the Moenave formations and in northern Utah between the Nugget and Chinle.

Between the upper and lower limits thus described lie beds of Early, Middle, and Late Triassic age with an aggregate thickness ranging from a few hundred to several thousand feet.

Major Divisions

In the Wasatch and western Uinta Ranges the Triassic has a threefold division resembling in a superficial way the classical threefold arrangement of the type Triassic of Germany. At the base is a red bed unit (Woodside) followed by a

1. Professor and Head of Geology, Univ. of Utah, Salt Lake City, Utah.

marine limestone (Thaynes) with a second red-bed sequence at the top (Ankareh, Shinarump, Chinle). West of the general vicinity of the western end of the Uinta Range, the red beds show decreasing importance, while eastward the continental facies dominate. Thus, in the eastern part of the Uinta Range and areas east of the Green and Colorado Rivers the Triassic section is essentially two shaly units, Moenkopi below and Chinle above, separated by a conglomeratic interval.

In a belt down the central part of Utah embracing the central Uintas, San Rafael Swell, Circle Cliffs, High Plateaus, and St. George areas, the marine and non-marine facies show more complex interfingering relationships. The small patches in the Great Basin have generally been correlated with the Thaynes formation. They are mostly marine and thus of Early Triassic age.

The most useful datum plane or key bed in the continental section is the Shinarump and closely related deposits at approximately the same position which can be located in both surface and subsurface sections. The marine formations contain many excellent cephalopod faunas by which correlations with standard world-wide zones are possible.

Individual Formations (alphabetically arranged)

Ankareh formation or group: Middle (?) and Upper Triassic, 500 to 2,000 feet. Continental shale, sandstone, limestone, and conglomerate. There has been much confusion in the definition and correlation of this and equivalent units. According to Kummel (1954), the name should be applied in the central Wasatch and Uinta Mountains to all the strata between the Thaynes and Nugget. This is the latest of a long series of suggested methods of subdividing and naming the Triassic rocks of northern Utah (Figure 46).

In terms of well-known subdivision in the Colorado Plateau, the lower part of the Ankareh is equivalent to the Upper Moenkopi; the conglomeratic Gartra is a Shinarump equivalent, and the upper portion (Stanaker) correlates with the Chinle.

Chinle formation or group: Upper Triassic, 200 to 1,350 feet. Continental shale, sandstone, limestone, conglomerate, siltstone, marl, and bentonite. The Chinle is widely exposed in southern Utah on both sides of the Colorado River, in the San Rafael Swell and Circle Cliffs, around the southern margins of the High Plateaus, and southward into Arizona. The name has also been applied as far north as the Uinta Mountains and even in the Wasatch Range. The details of stratigraphy are so complex that no final and inclusive scheme of classification has been achieved. In general, the formation has been subdivided wherever detailed work has been done, but not all of the subdivisions have received formal designations. In southeastern Utah six distinct lithologic units have been recognized. In ascending order these are a claystone and sandstone unit; a sandstone called the Moss Back, which has been miscorrelated locally with the Shinarump; a variegated claystone unit; a reddish-orange unit; a limy unit; and a reddish siltstone unit. These intertongue to a high degree, and mapping is difficult. In the San Rafael only the lower two and the uppermost unit are present; in White Canyon all except the variegated claystone unit are present. The Moss Back is the most important from an economic standpoint and contains important deposits of uranium in areas north of White Canyon and in the San Rafael Swell.

In southwestern Utah the Chinle until recently has been mapped to include all rocks above the Shinarump and below the Navajo. Recent work has resulted in splitting off much of the upper part of the unit, so that it now contains only those sediments between the Shinarump and the base of the Dinosaur Canyon sandstone member of the Moenave formation.

The Chinle formation is about 250 feet thick in the San Rafael Swell, and it thickens to the southwest and southeast by introduction of additional facies. The formation is famous for its varicolored outcrops. Much bentonite is present and with it are traces of metallic elements, including fine flour gold, silver, vanadium, and uranium.

Scattered vertebrate remains prove a Late Triassic age, but exact lower and upper limits are not understood. The formation apparently originated on a wide flood plain under shifting conditions of sedimentation.

Equivalents of the Chinle formation have been called the Stanaker in the Uinta Mountains (Thomas and Krueger, 1946) and the Wood shale in Idaho (Williams, 1945).

Kayenta formation: Upper Triassic, 0-500 feet thick. Sandstone and conglomeratic sandstone with minor red mudstone, color reddish with tints of purple. The formation is dominantly fluvial in origin, and the outcrops have a rough, ledgy, step-like appearance which contrasts with the more smooth-weathering Navajo and Wingate. Dinosaur and other vertebrate fossils have been found which prove a Triassic age.

The Kayenta is easily mapped where the Wingate and Navajo are well displayed, but in southwestern Utah where the Wingate is absent the Kayenta shows more complex relations. At Cedar City and Kanab the Kayenta and Navajo show inter-fingering tongues representing alternating periods when wind deposition (Navajo) dominated over river deposition (Kayenta). The Shurtz sandstone tongue of the Navajo has been mapped near Cedar City. It is separated from the main mass of Navajo by the Cedar City tongue of the Kayenta. The term "Lamb Point tongue" of the Navajo is applied to rocks of the Kanab area formerly mapped as Wingate. It lies about 300 feet above the Moenave formation and is separated from the main Navajo by the Tenny Canyon tongue, which is up to 220 feet thick, of the Kayenta.

North and west from the San Rafael Swell the Kayenta is thought to pass into red beds, but details are lacking.

Moenave formation: Triassic (?), 400-500 feet. The term Moenave formation was proposed in 1955 (Averitt, et al., 1955); on maps published before this time, equivalent beds are included in the Chinle and Wingate formations. The type section is at Moenave, Arizona. Two members are included, the lower sandstone and siltstone being called the Dinosaur Canyon sandstone and the upper unit, the Springdale sandstone. In southern Utah, the Dinosaur Canyon sandstone member consists largely of reddish-orange sandstone and siltstone with a few beds of grayish-red to purplish shale. It usually forms a steep slope below the Springdale sandstone member.

The Springdale sandstone (containing the "Silver Reef" bed of Washington County) forms a distinct ledge that is traceable for many miles along the Vermilion Cliffs and elsewhere in Utah and Arizona. It is composed of fine-grained massive sandstone that is pale reddish-brown on fresh surfaces and darker brown when weathered. The average thickness is about 175 feet.

Moenkopi formation or group: Lower Triassic, up to 2,000 feet thick; mixed marine and non-marine including siltstone, sandstone, and limestone. The formation is widely exposed in the Colorado Plateau, and equivalent beds outcrop in the Wasatch and Uinta Ranges. In the Zion Park area six subdivisions have been proposed as follows (ascending order): (1) Timpoweap member, (2) lower red member, (3) Virgin limestone member, (4) middle red member, (5) Shnabkaib member, and (6) upper red member. The first and third are marine; the others are non-marine and littoral. The marine tongues extend eastward and have been recognized in the Circle Cliffs, San Rafael Swell, and near the confluence of the Green and Colorado Rivers. The name "Sinbad limestone" has been applied to a marine tongue in the San Rafael Swell and Circle Cliffs. Beyond the edge of marine deposition the Moenkopi is entirely red beds. The entire formation thins and disappears eastward near the Utah-Colorado line. It is not recognized with certainty in Lisbon Valley, Utah.

Scott (1950) has suggested that the name Moenkopi be applied to those Triassic sediments of the Wasatch Range that lie between the Permian Park City formation and the Shinarump, but this and other nomenclatural details must be solved by future usage.

Shinarump conglomerate: Middle and upper Triassic, up to 200 feet thick. Conglomerate and sandstone with minor siltstone and shale. The colors are mostly gray, brown, and yellow, but other colors are locally present. The unit is a persistent cliff and bench former. It is one of the most important uranium-producing formations in the Colorado Plateau. Mode of origin is not understood, but it has been regarded as a sort of fossil pediment. Fossils are rare, but the unit probably accumulated mainly during the mid-Triassic. Recent work has shown that the Moss Back member of Chinle, lying higher than the true Shinarump, has been miscorrelated with it in parts of southeastern Utah. Currently the Shinarump of most areas is being mapped as a member of the Chinle rather than a separate formation.

Thaynes formation or group: Lower Triassic, up to 2,650 feet thick. Limestone, shaly limestone, and calcareous sandstone. Color is drab gray to brownish. Usually forms steep but smooth slopes. The famous Meekoceras fauna occurs in the limy members. The name is employed only in the Wasatch and western Uinta Mountains; equivalents, as proven by fossils, are present in the Moenkopi. The limy members die out eastward, and where these are not present, the names "Moenkopi," "Woodside," or "Red Wash" have been used (Thomas and Krueger, 1946; Williams, 1945).

Wingate sandstone: Upper Triassic, 0-470 feet thick. Color ranges through brown, yellow, and red, and there is a distinct tendency to the production of dark, varnished surfaces. Mainly cross-bedded but there are interspersed plane-bedded units. Usually appears as a massive vertical cliff rising above the Chinle. Steep plane surfaces cut by vertical joints are common, and talus is abundant.

The Wingate passes laterally into red silty beds in all directions from south-central Utah. These equivalent sediments have usually been called Chinle, but this has given rise to the necessity of correlating a supposed Jurassic formation with a supposed Triassic formation. Fossils recently found in Arizona indicate that the Wingate is Triassic (Lewis, 1958). Details of this problem are discussed under a later heading. At present the Triassic-Jurassic boundary is drawn between the Navajo and Kayenta.

Woodside shale: Lower Triassic, up to 800 feet thick. Silty red shale with minor siltstones. Usually forms a slope. Name used only in Wasatch and western Uinta Ranges. Practically unfossiliferous but position proves Early Triassic age. Equivalents are probably present in lower Moenkopi of Colorado Plateau. Interfingers with Dinwoody shale northward in the Idaho-Wyoming area. The Dinwoody is recognized in the Bear Lake exposure and in extreme northeastern Utah.

Triassic of the Great Basin

The name Harrington formation was proposed by Butler (1913) for Triassic rocks of the San Francisco mining district. He assigned an over-all thickness of about 5,000 feet to the unit and included a great variety of rocks that are in reality not Triassic in age. More recent work has reduced Butler's thickness figures greatly and has shown that the units present can be interpreted and mapped in terms of the typical Plateau section. Several other more or less isolated exposures of Triassic are known in the Utah part of the Great Basin. One of these was discovered by Nolan in the Gold Hill district (1935). Larger and more complete sections with cephalopod faunas are known in the Confusion Basin. It seems worthy of note that recent geologic work in the Nevada portion of the Great Basin has brought to light at least a dozen exposures of Meekoceras-bearing rocks which give a more complete understanding of the distribution and origin of the Lower Triassic rocks of the region (Clark, 1957).

Problems of Correlation

The increasing information on the Triassic system resulting from more detailed field work has given rise to refinements of nomenclature and schemes of classification which in some cases have confused rather than clarified the problems of correlation. Figure 46 is intended to show the evolution of nomenclature for the Triassic of the Wasatch and eastern Uinta Ranges. Time alone will tell which, if any, of the schemes shown will survive. The chief difficulty centers around the relative merits of names brought in from the Idaho-Wyoming area, those employed in the Colorado Plateau, and those established for local sections. The tendency seems to favor locally derived names for the lower units and Colorado Plateau names for the upper ones. Since there is a considerable gap between areas where the Idaho terminology is in current usage, there seems to be a tendency to disregard names from this source even where they have priority; however, for the small outcrops of Triassic on the eastern shores of Bear Lake the terminology of the Idaho-Wyoming areas must apply. Those geologists who have studied the Idaho-Wyoming Triassic have suggested certain changes in nomenclature, but these have not yet come into general use.

The Wingate has given rise to very difficult correlation problems. The type section is at Fort Wingate, New Mexico. Owing to a striking lithologic similarity, Gregory thought he recognized the same unit west and northwest of the Defiance uplift, and from this correlation many thousands of miles of outcrop, chiefly in Utah, were mapped as Wingate. Detailed study has revealed that the Wingate of the type section is equivalent to the Entrada of the San Rafael section and that the so-called Wingate of the Colorado Plateau has only a very thin equivalent at Fort Wingate. The problem thus presented has not been solved. If the rules of nomenclature are strictly adhered to, the name Wingate should apply to what has been called Entrada and the name Entrada abandoned. The so-called Wingate should then receive a new name. No definite steps have been taken to settle the dispute; those working in the Utah section favor retaining the Wingate as presently used; other geologists want to see the rules of priority applied.

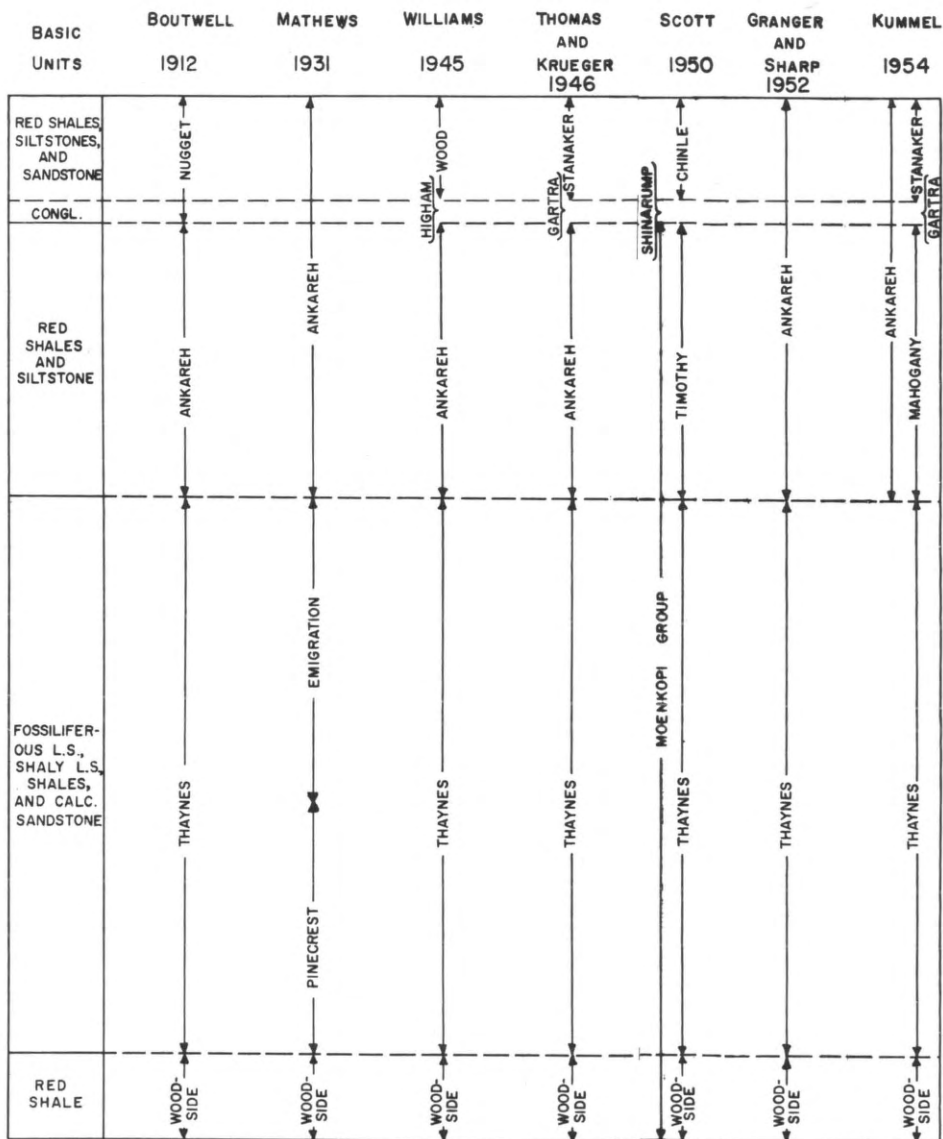


Figure 46. Evolution of Triassic Nomenclature of the Central Wasatch Mountains.

After many years of doubt the Wingate sandstone has been assigned to the Triassic. Fossil evidence and lateral tracing prove that it cannot be of Jurassic age. The newly proposed Moenave formation of southwestern Utah includes shaly beds formerly included in the Chinle that are, in reality, marginal facies of the Wingate.

Triassic Paleogeography

Triassic stratigraphy may be interpreted in terms of rather simple paleogeography. An invasion of marine waters entered Utah from the west during Early Triassic time and spread eastward covering roughly two-thirds of the state. The calcareous deposits of this sea interfinger with non-marine clastic sediments of the "red bed" type, derived chiefly from the Ancestral Rockies which were then prominent in Colorado and eastern Utah.

The seaway persisted for most of the early part of the Triassic period and then disappeared, leaving a vast subaerial plain which sloped gently toward the north and northwest. Upon this plain was deposited a series of thin but wide-spread gravel sheets making up the Shinarump conglomerate, Mossback sandstone and perhaps other conglomerates. These formations were probably laid down in the manner of sediments, and their distribution and growth involved most of Middle Triassic time. During Late Triassic time, deposition by fluvial action characterized the area, and the upper part of the Chinle formation and its equivalents were laid down. Volcanic activity in some unknown region, probably to the southwest, contributed considerable volcanic ash to the Chinle; however, the bulk of material was evidently derived from erosion of highlands to the south and southwest. Local uplift of salt anticlines in east central Utah caused restricted unconformities and omissions in the Triassic beds, but they were otherwise relatively undisturbed during deposition.

JURASSIC

Stratigraphic Limits

The placement of the Triassic-Jurassic boundary has already been discussed. Largely because of the lack of fossils, exact time planes cannot be drawn; and the boundary, as mapped, is largely one of convenience.

The upper boundary, by contrast, has received much attention because of the widespread nature of the formations involved and the wealth of fossil material, including the famous dinosaur faunas, which must be evaluated. The study of this boundary has attracted the attention of numerous specialists in both paleontology and stratigraphy and has world-wide implications. It should be noted that for a period before 1936, the Morrison formation, which is now thought to be the latest Jurassic deposit in Utah, was considered to be Lower Cretaceous, in which case its lower contact represented the Jurassic-Cretaceous break and its upper contact the Lower Cretaceous-Upper Cretaceous interval. Since 1936 most investigators have accepted the Jurassic age of the Morrison and have considered the Jurassic-Cretaceous boundary to lie between the Morrison and the overlying Dakota (?). This implies that the Lower Cretaceous is absent and that a long period of nondeposition is represented by the unconformity at the base of the Dakota (?). This interpretation is also a matter of convenience, for the base of the Dakota is relatively easy to map.

Recent work has shown that Lower Cretaceous rocks are present over much of the Colorado Plateau. In the past these rocks have been included in the Morrison. This interpretation places the Jurassic-Cretaceous boundary in the midst of a series of almost homogeneous continental beds, where the boundary is difficult to detect or map. Since usable fossils are rare, it may prove to be uneconomical to try to map this contact or to localize it in well logs. Scientific accuracy demands, however, that the presence of Lower Cretaceous be recognized, regardless of what may be chosen as convenient map or subsurface units.

At the present time, therefore, neither the upper nor the lower boundaries of the Jurassic can be said to be accurately known or mapped over most of the Utah area.

Major Divisions

The Jurassic rocks of Utah fall easily into two well defined lithologic groups, the selection and delimitation of which constitute an outstanding application of the concepts of stratigraphic nomenclature.

The Navajo, together with the Kayenta and Wingate of Triassic age, has been named the Glen Canyon group from the excellent exposures between Hite and Lees Ferry on the Colorado River. This natural aggregation of dominantly sandy, wind-blown deposits can be recognized and mapped without much difficulty. The group is topographically conspicuous and is chiefly responsible for such scenic spots as Zion Park, Capitol Reef, Crossing of the Fathers, Hole in the Rock, and Rainbow Natural Bridge.

The second aggregation of formations, comprising the Carmel, Entrada, Curtis, and Summerville, has been termed the San Rafael group from the exposures in the San Rafael Swell. For the most part, the type sections are well chosen, but the Carmel type section is near Mount Carmel in southwestern Utah, some distance from the Swell.

The recognition of these two major divisions has little value outside the Colorado Plateau, but the concept of a tripartate division of the Jurassic into non-marine below, marine in the center, and non-marine above is useful in the Wasatch and Uinta areas.

Individual Formations (alphabetically arranged)

Arapien shale: Middle and Upper Jurassic, not less than 3,000 feet thick. Siltstone, shale, limestone, gypsum, and salt. The usual colors are gray and red. Five lithologic units, designated as A, B, C, D, and E, are recognized by Hardy (1952). The most extensive outcrops are along the eastern margin of the Sevier Valley from east of Gunnison to near Richfield. In this and other areas the formation is structurally much deformed. The Arapien is considered by Hardy to be equivalent to the Carmel and the upper part of the Twin Creek limestone. The name Arapien formerly applied to all the strata between the Nugget and Morrison but as restricted by Hardy includes only the strata of the former Twelvemile Canyon member. The remainder of the original Arapien constitutes the Twist Gulch formation.

Bluff sandstone: Upper Jurassic, up to 300 feet thick. Sandstone and siltstone. Color ranges from reddish to gray. In areas of development, as at Bluff, Utah, a vertical cliff is formed, but the feather edges give less conspicuous outcrops. The Bluff sandstone is found only in the Four Corners area; it is unfossiliferous, and the exact correlations have been difficult to determine. It has been classified as part of the Morrison (Gregory, 1938) and as Entrada (Stokes, 1944). More precise work shows it to be equivalent to the Summerville formation and the lower Salt Wash member of the Morrison.

Carmel formation: Upper Jurassic. 50 to 1,500 feet thick. Limestone, siltstone, shale, and gypsum; dominant colors are red and gray, but variations are common. The formation is usually soft, but the limestone members give broad dip slopes where present. Marine facies occur in the San Rafael Swell and southward almost to the southwest corner of Utah. Beyond the fossiliferous facies are non-marine equivalents of various kinds, correlation of which has been difficult (Bissell, 1945).

Curtis formation: Upper Jurassic; up to 260 feet thick. Sandstone, shale, limestone, and conglomerate. The color is distinctly greenish, owing to the glauconite which is present. The formation is rather nonresistant and weathers in much the same manner as the overlying Summerville and underlying Entrada. As a distinct and mappable unit the Curtis extends roughly to the vicinity of Green River, Utah, and the central Henry Mountains. It has been assumed to be equivalent to the Twist Gulch formation, and a supposed correlative has been mapped in the southern High Plateaus, but the correlations mentioned have so far not been supported by fossil evidence. It is probable that the so-called Curtis of southwestern Utah is part of the Carmel (as recognized in the San Rafael area). In the eastern Uintas the formation reaches a thickness of 280 feet, and parts are highly fossiliferous.

Entrada formation: Upper Jurassic; up to 1,000 feet thick. Sandstone and siltstone, light-red, pink, "salmon," and gray. The formation is widely exposed in the Colorado Plateau and eastern Uinta Mountains. The equivalent in the Wasatch and western Uintas is the Preuss sandstone. At the type section the unit is silty and rather nonresistant; eastward, it becomes increasingly sandy and forms striking cliffs. The two facies are roughly divided by the Colorado River. The exact time or lithologic equivalents in the Four Corners area are not well understood. The Moab tongue lies at the top in Grand and northern San Juan Counties. In southwestern Utah, it is probable that the rocks mapped as Entrada are part of the Carmel.

Morrison formation: Upper Jurassic; up to 800 feet thick. Chiefly sandstone and mudstone with minor bentonite and conglomerate beds. Color extremely varied, especially in the bentonitic portions. The lower part of the Morrison throughout the Colorado Plateau has been termed the Salt Wash sandstone; this is the important uranium producer. The more widespread part is the Brushy Basin shale member. The Morrison originated by river action on a vast, very level plain. Fossils are abundant, but exact age determination has been long disputed.

Stratigraphy of the Morrison is more complex in the Four Corners area than elsewhere in the state. Here the lower part includes the Salt Wash and Recapture members and the upper part the Westwater Canyon and Brushy Basin members.

Navajo-Nugget sandstone: Lower and Middle Jurassic (?); up to 2,000 feet thick. Sandstone, strikingly cross-bedded with very few horizontal planes. The dominant color is light yellow or gray, but some areas show "salmon," pink, orange, or brownish tints. The unit is commonly lighter in color toward the top. Vertical

cliffs are common, but in areas where the dips are not flat there is a development of "beehive" forms and hummocky benches. A few fossils are known, but none are sufficient to fix the age exactly. The formation is much quarried for building stone in northern Utah, and many scenic spots of the Colorado Plateau owe their interest to erosion of this formation. The facies relationships of southwestern Utah are given under the discussion of the *Kayenta*.

Preuss formation: Upper Jurassic, 1,000 feet thick. Sandstone and silty sandstone, reddish gray to red, mainly plane-bedded. The name is applied in Utah only in the central Wasatch and Uinta Mountains. The equivalent formation over most of Utah is the Entrada sandstone. Fossils are unknown in Utah, but have been found in Idaho.

Stump sandstone: Upper Jurassic; up to 300 feet thick. Sandstone and sandy limestone, usually thin-bedded and gray in color. The formation is recognized only in the central Wasatch and Uinta Mountains. The Curtis is an equivalent formation. The Stump sandstone is characterized by abundant glauconite and by marine fossils, the most common of which is the belemnite *Pachyteuthis densis*.

Summerville formation: Upper Jurassic, up to 400 feet thick. Siltstone, sandstone, shale, and gypsum; the color is brownish-red to pink. Gypsum seams and veinlets are common, and the most striking characteristic is the extremely fine, even bedding seen on fresh or vertical exposures. Large chert concretions and manganese nodules are found in eastern Utah. The lower part of the formation passes eastward into the Moab tongue of the Entrada and probably northward into the upper part of the Curtis. Fossils are unknown.

Twin Creek limestone: Middle and Upper Jurassic; up to 3,000 feet thick. Limestone, medium to light-gray with characteristic splintery fracture. Several mappable subdivisions have been recognized but not formally named. The name has been employed in the Wasatch Range as far south as Thistle and in the western Uinta Mountains; partial equivalents are the Carmel and Arapien. The famous Devils Slide on the Weber River is in the Twin Creek, and the formation supplies raw material for cement plants at several localities.

Twist Gulch formation: Upper Jurassic; at least 1,910 feet thick. Red siltstone and reddish-gray sandstone with minor olive-green and bluish-gray shale. The chief exposures are in the Sanpete-Sevier valleys. In these exposures the formation is structurally disturbed. Exact stratigraphic relations are not known, but the formation is certainly equivalent to all or part of the San Rafael group above the Carmel formation.

Problems of Correlation

Although the Glen Canyon group as a whole is easily distinguished by physical characteristics, each of the individual formations comprising it has been involved in nomenclatural difficulties. The Navajo sandstone was set up as a formation with no type section being designated except the "Navajo country". Fortunately, the unit is distinctive enough that little difficulty is experienced in mapping it. Although the Navajo of the Plateau province is similar in appearance to the Nugget of the Wasatch and Uinta Mountains, a positive correlation cannot yet be made; there are no continuous outcrops for tracing, and fossils are totally lacking. If the two units are really continuous, then the *Kayenta* and *Wingate* must pinch out and disappear in the interval from the San Rafael Swell to the Wasatch Range. The implication is that these formations may pass into red beds beneath the Navajo, in which case the content of Chinle in the marginal areas is greater than it is in the central part of the basin.

The Kayenta was originally known as the Todilto from a supposed correlation with the type Todilto in New Mexico and Arizona. When it became known that the present Kayenta is a much older unit, Baker, Dane and Reeside (1936) suggested the new name with a type section at Kayenta, Arizona. The Wingate has been definitely assigned to the Triassic and has been discussed previously.

The San Rafael group is fairly well defined between the top of the Navajo sandstone and the base of the Morrison formation. The Carmel, Entrada, Curtis, and Summerville formations are easily separated in the San Rafael Swell, but away from this central area complexities of stratigraphy appear and nomenclature is confused. The chief difficulty arises from the interfingering of the marine fossiliferous beds into non-marine and unfossiliferous beds. Although the general policy of keeping names to a minimum by utilizing previously recognized units has proved to be a good one in most instances, there are other cases where attempts to force the San Rafael nomenclature on distant areas has created unworkable and unnatural situations. An example of the difficulties created is the present uncertain status of units between the Morrison and Navajo in the Four Corners area. Although many geologists have studied the section, no scheme yet proposed has proven acceptable to a majority of workers. A similar situation exists in southwestern Utah where large units within the San Rafael group cannot be correlated with the standard sections.

The differences in lithology and thickness that are evident between the San Rafael group at the type locality and at the Sanpete-Sevier areas present additional problems of nomenclature. Although the exposures are only about 35 miles apart, it has been impossible to subdivide one section in terms of the other.

Special problems of correlation exist in the Iron Springs district, which has important iron deposits in the Jurassic rocks. Because of significant differences between the Iron Springs area and typical San Rafael rocks, the name Homestake has been applied to the Carmel equivalent. An overlying, unfossiliferous unit has been tentatively correlated with the Entrada. It should be noted that the Homestake was regarded as Carboniferous until Mackin (1947) reported the presence of Jurassic fossils.

Another problem of terminology is posed by the outcrops of Jurassic on the northeast flank of the Uinta Range. Although most units in this remote portion of Utah correlate well with Wyoming areas, the Jurassic seems to agree best with San Rafael subdivisions. Current workers are therefore using such terms as Navajo, Carmel, and Curtis; but the problem must be considered as unsettled.

Jurassic Paleogeology

During the first half of Jurassic time Utah experienced desert conditions on an extensive scale. This interval was marked by the deposition of the massive aeolian sandstone accumulations constituting the Navajo formation. The sand constituting this unit was derived chiefly from the northwest, as shown by the prevailing directions of cross-bedding. The landscape must have been a featureless expanse of slowly shifting sand with, perhaps, here and there a temporary lake or oasis. The Navajo indicates mainly aeolian deposition, but the Kayenta seems to record a more moist interlude during which fluvial conditions prevailed. The Glen Canyon group, deposited far from the ocean, represents one of the most extensive and massive terrestrial deposits preserved in the interior of the continent.

During the Late Triassic and Early Jurassic intervals, radical changes took place which practically destroyed the ancient Rocky Mountain geosyncline into which marine waters had transgressed eastward many times in the Paleozoic. As a result of these changes, the seas which entered Utah in the Middle and Late Jurassic followed a new and different pattern from the north. Utah, in fact, represents the approximate southward penetration of waters from the north, and there seems to have been no connections with Pacific seaways on the west or Gulf of Mexico embayments to the south or southeast during this interval.

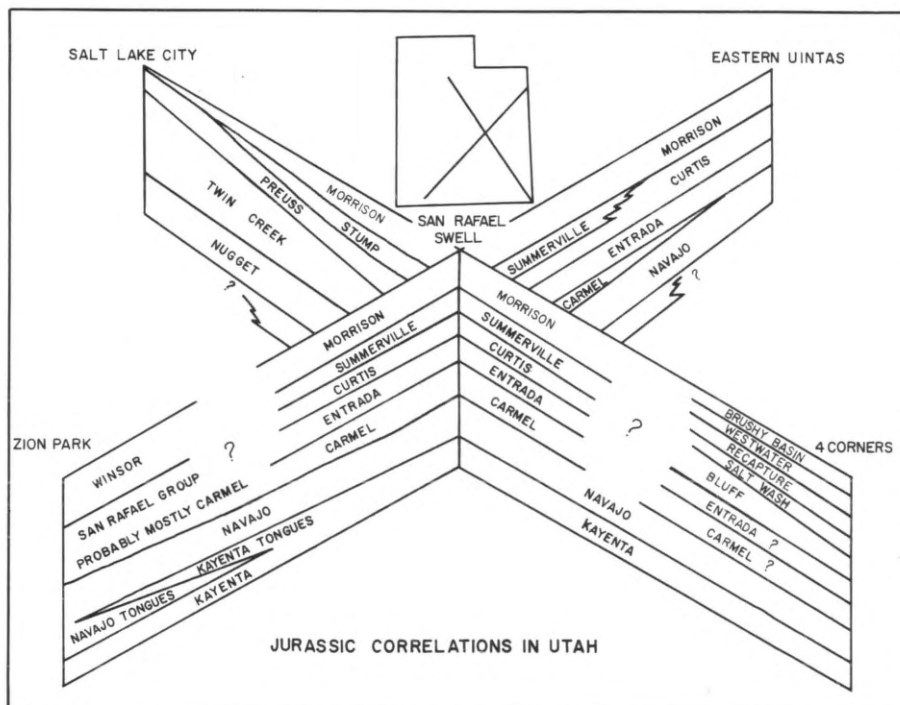


Figure 47.

The thickest sections of Jurassic marine rocks in Utah are in the westernmost preserved outcrops, and there are no indications of anything ever having been deposited west of these exposures. It seems likely therefore that the basin of deposition sank rapidly on the west and shallowed gently eastward.

On the east the marine beds interfinger in a complex way with non-marine beds derived from areas to the south, southwest, and east. Large parts of the Summerville, Entrada, Carmel, and Curtis consist of sediment that is definitely of aqueous origin but devoid of fossils. These peculiar beds may be interpreted as playa lake facies formed under conditions of alternating submergence and emergence on extremely flat and extensive plains where life was impossible. In more northern areas where the seas were deeper, fossils appear and are locally

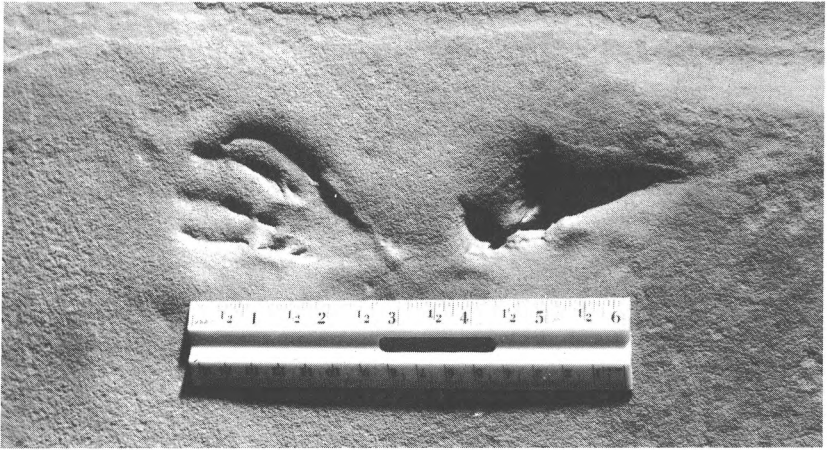
abundant. About the margins of the basin were areas of shifting sand now preserved in such formations as the Bluff, Junction Creek, and Moab tongue. In deeper pockets that perhaps received periodic replenishments of sea water, deposition of salt and gypsum was possible.

In the western Uinta Mountains and Wasatch regions, the Twin Creek limestone records rather uninterrupted marine deposition for a long period of time. After the withdrawal of the Twin Creek sea, a period of non-marine deposition ensued, as indicated by the Entrada and equivalents. A second and later marine invasion, which resulted in the Curtis and equivalents, had a somewhat different configuration than the one responsible for the Twin Creek. Broadly speaking, the Twin Creek is thick and the Curtis thin in the Wasatch Range, and the Twin Creek is thin and the Curtis thick in the eastern Uinta Mountains. Glauconite is common in the Curtis, and gypsum is present in the Carmel and in the Summerville.

Near the end of the Jurassic tremendous changes attendant to the early stages of the Sierra Nevada revolution took place. This event, directly or indirectly, seems to have initiated the deposition of the Morrison formation. Rainfall may have increased; river systems were integrated or reoriented, so that sediments commenced to be supplied from the west by eastward-flowing rivers. Across the extremely flat plains left by the playa lakes and sea-bottoms of previous time, the river channel and flood plain complex of the Morrison spread until it covered practically the entire western interior. There were evidently sizeable contributions of volcanic ash, which is now bentonite, that must have been drifted in by air currents from western volcanic centers. At the close of the Jurassic a vast featureless plain characterized eastern Utah, and a mountainous highland lay to the west.

CITED REFERENCES

- Averitt, Paul, Detterman, J. S., Harshbarger, J. W., Repenning, C. A., and Wilson, R. F., 1955, Revisions in correlation and nomenclature of Triassic and Jurassic formations in southwestern Utah and northern Arizona: *Am. Assoc. Petroleum Geologists Bull.*, v. 39, no. 12, p. 2515-2535.
- Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., 1936, Correlation of the Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: *U.S. Geol. Survey Prof. Paper* 183, 65 p.
- Bissell, H. J., 1954, The Kaiparowits Region: *Intermountain Assoc. Petroleum Geologists Guidebook 5th Ann. Field Conf.*, p. 63-70.
- Butler, B. S., 1913, Geology and ore deposits of the San Francisco and adjacent districts, Utah: *U.S. Geol. Survey Prof. Paper* 80.
- Clark, D. L., 1957, Marine Triassic stratigraphy in eastern Great Basin: *Am. Assoc. Petroleum Geologists Bull.*, v. 41, no. 10, p. 2192-2222.
- Gregory, H. E., 1938, The San Juan country: *U.S. Geol. Survey Prof. Paper* 188.
- Hardy, C. T., 1952, Eastern Sevier Valley, Sevier and Sanpete Counties: *Utah Geol. and Mineralog. Survey Bull.* 43.
- Nolan, T. B., 1935, The Gold Hill mining district, Utah: *U.S. Geol. Survey Prof. Paper* 177.
- Scott, W. F., 1950, Triassic stratigraphy in the central Wasatch Mountains, Utah (abs): *Geol. Soc. America Bull.*, v. 61, p. 1530.
- Stokes, W. L., 1494, Morrison and related deposits in and adjacent to the Colorado Plateau: *Geol. Soc. America Bull.*, v. 155, p. 951-992.
- _____, 1952, Lower Cretaceous in the Colorado Plateau: *Am. Assoc. Petroleum Geologists Bull.*, v. 36, no. 9, p. 1766-1776.
- Thomas, H. D., and Krueger, M. L., 1946, Late Paleozoic and early Mesozoic stratigraphy of Uinta Mountains, Utah: *Am. Assoc. Petroleum Geologists Bull.*, v. 30, p. 1255-1293.
- Williams, J. S., 1945, Nomenclature of Triassic rocks in northeastern Utah: *Am. Jour. Sci.*, v. 243.



Pterodactyl Tracks from the Morrison Formation (Photograph by Wm. L. Stokes)

Paper 12 THE CRETACEOUS SYSTEM OF UTAH

by John A. Burger¹

INTRODUCTION

Rocks belonging to the Cretaceous system form extensive outcrops in the central, eastern, and southwestern portions of Utah (see Figure 48). At many localities the exposures are excellent, and at some of these localities the Cretaceous rocks have been extensively studied. However, there are many locales of good exposures that have not been extensively studied, and there are some Cretaceous rocks that have received little or no study.

The Cretaceous strata of Utah show rapid, variable facies and thickness changes. To adequately document these changes is beyond the scope of this paper. A few generalities will serve to introduce a discussion of the Cretaceous system of Utah:

1. Rocks of Cretaceous age form extensive outcrops in many parts of Utah and crop out on the flanks of most major uplifts.
2. Rocks of Cretaceous age are absent or very imperfectly known in the Basin and Range province in western Utah.
3. The Cretaceous formations are known by a great number of names.
4. There is complex intertonguing between many of the stratigraphic units.
5. The Cretaceous system of Utah can be generalized from oldest to youngest as consisting of: (a) a lower group of interbedded conglomerates, sandstones, shales, and limestones of continental origin (Cedar Mountain, Burro Canyon, and Kelvin formations); (b) the overlying mixed marine and continental deposits (Dakota formation, Dakota (?), Dakota group); and (c) an overlying body of generally thick marine shale (Mancos shale) which contains numerous sandstone wedges and lenses. The Mancos in turn intertongues to the west with a body of thick coarse clastic sediments (Indianola group, Aspen shale, Frontier formation). The Mancos shale also intertongues extensively with (d) the overlying mixed marine and continental rocks (Mesa-verde group), which are in turn overlain by (e) predominantly coarse clastic continental rocks (Kaiparowits, Wanship, Echo Canyon, North Horn, and Currant Creek formations). Locally the youngest Cretaceous rocks are transitional into rocks of Paleocene age.
6. The Cretaceous rocks of Utah are predominantly clastic. Chemical or biochemical sediments are not important volume-wise. From west to east there is a striking decrease in grain size of sediments, which implies a general western source for the Cretaceous rocks.
7. Regional relations indicate a north-trending orogenic belt was intermittently active in western Utah during Cretaceous time.
8. Guide fossils are generally lacking except in the marine strata, and faunal correlations are difficult or impossible to make in the non-marine rocks.

1. Assistant Professor of Geology, Beloit College, Beloit, Wisconsin; formerly, Geologist, Texaco, Inc., Salt Lake City, Utah.

SCALE 0 10 25 50 MILES



Excellent bibliographies in the papers by Cobban and Reeside (1952a, 1952b), Spieker (1946, 1949), Gregory (1950), and Young (1955) will serve as an introduction to geological literature of the Cretaceous system of Utah.

Several new names have been introduced in the past few years for strata assigned to the Cretaceous system. Among these are Cedar Mountain formation (Stokes, 1944, p. 966), a Lower Cretaceous unit underlying the Dakota sandstone in the Colorado Plateau province; the Burro Canyon formation (Stokes and Phoenix, 1948), similarly a Lower Cretaceous unit in the Colorado Plateau; the South Flat formation (Hunt, 1954, p. 118), recognized in the Gunnison Plateau of central Utah; the Wanship formation (Williams, 1955, p. 127), and the Echo Canyon conglomerate (Williams and Madsen, 1959, p. 123), both in the Coalville area of western Uinta Mountains.

At the outset of a discussion of Cretaceous stratigraphy of Utah, it is well to emphasize the concept that a formation is herein considered a mappable unit of similar lithologic aspect (facies) and need not be everywhere the same age. Most of the Cretaceous formations in Utah have in greater or lesser degree a time-transgressive nature, and correlation of these formations in the "classic" sense is difficult if not at times impossible.

The reader is referred to Table VI of this symposium for a correlation chart of the Cretaceous system in Utah.

DISCUSSION BY AREAS

North Flank of the Uinta Mountains

Cretaceous rocks form a relatively narrow belt of outcrop between Clay Basin and Manila, Utah. The rocks generally dip quite steeply northward into the Green River Basin. Locally, the Cretaceous rocks are overturned where they are involved in the high-angle faulting along the north flank fault system.

There are small outcrops of Cretaceous strata along the north flank in Summit County near and west of Moffit Pass (T-1-N, R-8, 9-E). Root (1952, p. 26) tentatively identified these rocks as belonging to the Aspen and Frontier formations. Any Cretaceous rocks in the area between Moffit Pass and Manila are buried beneath Tertiary and Quaternary cover.

The Uinta Mountains serve as a convenient boundary for applying different sets of names to the Cretaceous strata. North of the Uintas and along their north flank, Wyoming nomenclature is best applied, although several exceptions to this have been made by various authors. South of the Uintas, the Colorado Plateau nomenclature has widest acceptance.

Cretaceous units recognized in the area from oldest to youngest are: Cloverly formation, Dakota formation (Thermopolis), Aspen (or Mowry) shale, Frontier formation, Baxter (or Hiliard shale, approximate Mancos equivalents), the Mesaverde group (consisting of Blair, Rock Springs, Ericson, and Almond formations), the Lewis shale, and the Lance (?) formation. There is an erosional unconformity at the base and an angular unconformity locally at the top of the Cretaceous system.

All five generalized vertical subdivisions are displayed between Manila and Clay Basin. Furthermore, there are fairly good indications of a sixth subdivision in this area, which is not recognized elsewhere in Utah. This is a transgressive marine unit (Lewis shale) overlying the Mesaverde group. The Lewis shale has been recognized by some petroleum geologists in well logs and well cuttings at Middle Mountain, near Clay Basin, just a few miles north of the Utah-Wyoming state line. It is not improbable that the prominent strike valley which extends with few interruptions from near Linwood, Utah, to Clay Basin may be underlain in part by the Lewis shale. Lack of outcrops and absence of wells in the strike valley presently prevent identification of the Lewis shale in the valley.

Lower Cretaceous rocks along the north flank of the Uintas are represented by the Cloverly formation. The unit is not easy to recognize, especially when the lower conglomerate member is absent. Stokes (1952, p. 1774) gives the following criteria for distinguishing the Lower Cretaceous rocks of Utah from the Morrison formation (Upper Jurassic) and the Dakota formation: the shales of the Morrison are characterized by bright, vivid colors, whereas the Lower Cretaceous shales are more subdued and have more pale purple and lavender. The Lower Cretaceous rocks have a high percentage of brown or gray calcareous nodules which may constitute up to 30 percent of the rock. Nodules are not so abundant in the underlying Morrison. The so-called "gastroliths" are restricted to the Lower Cretaceous. The Cloverly conglomerates are composed principally of chert and minor amounts of quartzite, whereas the Dakota conglomerates are of mixed chert and quartzite.

The thick Aspen shale of extreme southwestern Wyoming is present in the Manila area as a thin tongue of fish-scale-bearing siliceous shale near the base of the Baxter shale. Similarly, the Frontier formation is only a 120-foot thick series of sandstone, silty sands, and shales at Clay Basin and is best described as a tongue in the Baxter shale. The Baxter shale is more easily eroded than the rocks above or below and forms a broad strike valley from Manila eastward to Clay Basin. The poor exposures do not permit accurate measurement. The combined surface and subsurface thickness of the Baxter shale at Clay Basin is $6,800 \pm$. The Baxter represents the muds and silts laid down in the very extensive Mancos sea, chiefly during Colorado time. The contact with the overlying Mesaverde group is gradational and intertonguing and represents a general eastward regression of the Mancos sea.

The intertonguing characteristic of the Mesaverde group and the Baxter shale is well displayed between Linwood and Clay Basin. The Blair formation (basal unit of the Mesaverde group) is more than 1,000 feet thick west of the Green River near Linwood, and consists of interbedded sandstone, siltstone, and silty shale which tongue out eastward into the upper part of the Baxter shale. In this same area the thick and prominent Chimney Rock tongue of the Rock Springs formation thins eastward to a feather edge into the body of the Baxter shale, which is in turn overlain by the westward-thinning Black Buttes tongue of the Baxter shale. Microfauna from the Black Buttes tongue seem to indicate that this minor westward transgression of the sea was rapid, and that the water was deep and had normal salinity and open circulation. These conditions are not usually found in the Mancos-Mesaverde intertonguing of Utah.

Southwest of the Clay Basin area, the Rock Springs formation thins rapidly by tonguing out into the Baxter shale. About 270 feet of strata assignable to the Rock Springs formation crop out at the famous Vermilion Creek section in extreme northwestern Colorado.

The Blair and Rock Springs formations are of mixed marine and nonmarine origin. In the Manila-Clay Basin area they represent the seaward extremity of a large delta system centered in south-central Wyoming at approximately the site of the present Rock Springs uplift. The Ericson formation consists of massive, medium to coarse-grained sandstones deposited in stream channels and along flood plains by a southeastward-flowing river system whose delta lay in northwestern Colorado. The overlying Almond formation in the area of the Rock Springs uplift records less availability of coarse sands and less vigorous streams of transport than does the Ericson formation. The Almond formation also shows a return to mixed marine and nonmarine marginal deltaic conditions. However, south of the uplift, the lower part of the Almond shows coarser sediments which increase in grain size southward toward the Uinta Mountains. Locally along the Uintas' north flank, the Almond formation contains cobble-size conglomerates and seemingly attests to uplift in the eastern part of the Uinta Mountains at this time. The upper Almond is gradational and sends eastward-projecting sandstone tongues into the lower shales of the Lewis shale. The Lewis represents the last westward transgressive attempt of the Late Cretaceous sea to regain its former broad expanse. The attempt probably failed, according to the record now preserved or known, and the western shoreline was probably near Linwood, Utah. As the Lewis sea withdrew, its fine muds graded upward into sands equivalent to those of the Fox Hills formation, and these in turn graded into the Lance formation.

Wasatch Mountains and Western Uinta Mountains

Rocks assigned to the Cretaceous system crop out at the western end of the Uinta Mountains in the Coalville-Rockport area and extend westward into the central Wasatch Mountains. The rocks are generally of the Coarser clastic facies and represent the piedmont, highland, and flood plain environments. Unconformities between the several stratigraphic units attest to at least two pulses of orogeny in the area during Cretaceous time.

The Cretaceous section in the Coalville area consists, from oldest to youngest of the Kelvin formation, Bear River formation, Aspen shale, Frontier formation, Wanship formation, and the Echo Canyon conglomerate. The base of the Cretaceous is marked by a possible erosional disconformity, and the top is marked by an angular unconformity. Sedimentation was ushered in by coarse conglomerates and also ended with coarse conglomerates. The thick accumulation of coarse clastic continental and shallow water sediments indicates that this was an area of downwarping--a forefold or trough-like trap--past which finer clastic sediments were transported eastward.

Weggeman (1915, p. 161-184) studied the Cretaceous rocks exposed near Coalville and measured a stratigraphic section to which most subsequent workers have made reference. The most recent revisions of the Coalville section have been made by Williams (1955, p. 127) and Williams and Madsen (1959, p. 122-125), who introduced the names Wanship formation and Echo Canyon conglomerate for what have previously been considered the upper part of the Frontier formation and the Almy formation.

The oldest Cretaceous strata consist of conglomerates, sandstones, siltstones, and shales which Mathews (1931, p. 48) called the Kelvin formation. These strata are considered Early Cretaceous on the basis of their stratigraphic position below beds of Early Cretaceous age and above beds of Jurassic age. The Kelvin is overlain by the Bear River formation, which thins rapidly from its type area in southwestern Wyoming and feathers out in the Rockport-Coalville area, as does also the overlying Aspen shale. The next younger unit is the Frontier formation,

which is thicker in the Coalville-Rockport area than is the type Frontier in southwestern Wyoming. The Hilliard formation of southwestern Wyoming is not recognized here, but may be represented in part by the Wanship formation. An unconformity of locally differing magnitude separates the Frontier formation and the overlying Wanship formation. On the basis of regional relations and the occurrence of *Inoceramus* sp. present in the lower part of the massive conglomerate beds overlying the Wanship formation, Williams and Madsen (1959, p. 125) have renamed these rocks the Echo Canyon conglomerate and have provisionally assigned at least the lower part of these conglomerates to the Cretaceous system.

It is not to be expected that the Cretaceous rocks along the northwestern part of the Uintas should be extremely different from those along the southwestern part of the Uintas. The recognition of coarse Late Cretaceous conglomerates younger than those of the Wanship formation has a parallel with the coarse conglomerates of the Currant Creek formation on the south flank of the Uintas, as well as with the coarse conglomerates in the Price River and North Horn formations still farther to the southwest.

It may well be that later work will show that the newly named Echo Canyon conglomerate may contain rocks which are transitional into the Paleocene. A similar history is indicated south of the Uintas in the strata of the North Horn formation. As currently defined, the Echo Canyon conglomerate is unconformably overlain by conglomerates of the Knight formation of Eocene age.

South Flank of the Uinta Mountains

Rocks of the Cretaceous system crop out discontinuously along the south flank of the Uinta Mountains from near Strawberry Reservoir to the Utah-Colorado state line. The rocks display the typical west to east change of facies, from piedmont and flood plain to marine, as well as the five-fold vertical subdivision. The Cretaceous section from oldest to youngest consists of the following formations: Cedar Mountain, Dakota, Aspen shale, Frontier sandstone, Mancos shale, Mesaverde group, and the Currant Creek formation. The Lewis shale is not recognized on outcrop south of the Uintas in Utah, although Walton (1957, p. 100) suggested it might be present in the subsurface of the Uinta Basin, however substantiating evidence is currently lacking.

In many ways the Cretaceous strata along the south flank mirror those found on the north flank. However, one exception is that a fourfold subdivision of the Mesaverde group has not seemed obvious; in fact, to date only a subdivision into a lower marine unit and an upper mixed marine and nonmarine unit has been made along the western part of the Uintas' south flank. In the eastern end, the Colorado names of Iles and Williams Fork formations have been used respectively for the marine and mixed marine and nonmarine divisions. It has not been feasible to extend these Colorado names westward because of erosion of the upper part of the Mesaverde group west of the Colorado state line and because of several broad areas of Tertiary cover.

In the southwestern part of the Uinta Mountains, there is a problem of correlation, age, and nomenclature of beds between the Curtis formation (latest marine Jurassic) and the Aspen shale (youngest Early Cretaceous). The problem has been discussed by Stokes (1944, p. 987-990) and by Bissell (1952a, p. 602-603). Briefly stated, the problem is where to place the upper boundary of the Morrison formation and how to subdivide and correlate the relatively thick stratigraphic section in the western Uintas' south flank and the Wasatch Mountains with the thinner section in other parts of Utah. At Currant Peak along the western south

flank, there is a 2,750-foot thick section between the Curtis formation and the Aspen shale which Stokes (1944, p. 970) breaks down into a lower 600 feet of predominantly red shale, designated as Morrison, an overlying 1,200 feet of interbedded shales and conglomerates, probably equivalent to the Kelvin formation, succeeded by 950 feet of shales and sandstone, identical with the "terra cotta" beds near Rockport, Utah. It may well be that the "terra cotta" beds at Rockport, are equivalent to the Cedar Mountain formation, and inferentially the Cedar Mountain formation would be present in the Currant Peak section.

A strict time correlation cannot be implied by "equivalency," inasmuch as these units lack fossils allowing precise correlation; moreover, the Kelvin formation was deposited in an area of orogenic activity and can be expected to grade into and intertongue eastward with rocks deposited under more stable conditions.

Over much of the Colorado Plateau the base of the Lower Cretaceous is marked by a chert pebble conglomerate known variously as the Buckhorn or Burro Canyon conglomerate member, but the conglomerate is absent or not differentiable along much of the southwestern part of the Uintas (Stokes, 1957, p. 95).

At Currant Peak, Bissell (1952a, p. 605) notes a tripartite division in the Dakota formation which totals 180 feet. In the same general area Walton (1944, p. 100-105) mapped a basal black shale member of the Mancos consisting of the beds overlying the Dakota formation and underlying the Aspen shale. Bissell (1952a, p. 606) measured a section in the Strawberry quadrangle east of Currant Peak where the Aspen conformably overlies the Dakota and the black shale is absent. It appears that black shale may locally be absent, or else it is not sufficiently distinct from the Aspen shale to be differentiated. There is also the problem of nomenclature in whether to consider the Aspen shale and the Frontier formation as members of the Mancos shale in the eastern part of the area (where the Aspen and Frontier are thin tongues enclosed by the Mancos shale), or whether to give them the rank of formation, which they have in their type areas (where they are distinct and not enclosed by the Mancos shale).

The Aspen shale is thin along the south flank of the Uintas, and it may be inferred that Aspen deposition thinned, both to the south and east, away from the type area in extreme southwestern Wyoming. The Aspen thins to a feather edge in the Coalville-Rockport area; it is 88 feet thick near Currant Peak (Bissell, 1952a, p. 606) and is not recognized farther south in the Book Cliffs area of central Utah. Near the Utah-Colorado state line, it is 36 feet thick (Walton, 1944, p. 101).

The Frontier formation is 756 feet thick near the forks of Red Creek along the western south flank, and it thins by shaling out and intertonguing into the Mancos shale eastward, where at the state line it is 157 feet thick (Walton, 1944, p. 101-102). The Frontier formation was probably deposited during a regressive or very shallow water phase of the Mancos sea.

The Mancos shale, lying above the Frontier at the western end of the south flank, is only 1,450 feet thick at Red Creek, but it increases eastward to 5,072 feet thick near Jensen, Utah, in the eastern part of the area (Walton, 1944, p. 101-105).

The Mesaverde group overlies and extensively intertongues with the Mancos shale. An eastward stratigraphic rise of the Mancos-Mesaverde contact of approximately 2,800 feet is indicated between Red Creek and the Vernal area. At Red

Creek the lower marine unit contains a Niobraran fauna, but near Vernal the Niobraran fauna is found in the Mancos shale many feet below the base of the lower marine unit of the Mesaverde.

The upper part of the Mesaverde group consists of a mixed marine and nonmarine assemblage of sandstone, shale, silty and carbonaceous shale, limestone, and coal. Along Red Creek the Mesaverde group is 2,860 feet thick; to the west along Currant Creek, Bissell (1952a, p. 611-612) gives a section 5,165 feet thick, and to the east near the Utah-Colorado state line the Mesaverde group is approximately 3,500 feet thick. Regional relations indicate considerable erosional truncation of the upper part of the Mesaverde group along the central part of the south flank.

In the eastern south flank area, the Mesaverde group can be divided into the Iles formation (lower, predominantly marine unit) and the overlying Williams Fork formation (mixed marine and nonmarine unit). Walton (1944, p. 110-111) introduced the names "Asphalt Ridge sandstone member" and "Rim Rock sandstone member" for two prominent sandstones in the Iles formation. The Asphalt Ridge is the lower of the two members and tongues out eastward between Vernal and the state line. The Rim Rock member is exposed from Vernal to the state line and thins gradually eastward by "shaling out" into the Mancos shale.

Between Strawberry Reservoir and the Duchesne River there is a sequence of coarse conglomerates, sandstones, and mudstones disconformably overlying the Mesaverde group. Walton (1944, p. 117) named these rocks the Currant Creek formation. This formation is in turn unconformably overlain by the Uinta formation of Eocene age. The Currant Creek formation is of local extent and may represent a series of coalescing alluvial fans deposited in response to one of the pulses of the early Laramide orogeny (Huddle and McCann, 1947). The age of the Currant Creek formation is not known because of the lack of contained fossils, but its age may be bracketed by the underlying beds of Montanan age and overlying beds of Eocene age. It is conceivable, on the basis of lithology and stratigraphic position, that the Currant Creek formation is the south flank counterpart of the Echo Canyon conglomerate on the north flank.

Wasatch Plateau and Adjacent Areas

Rocks of the Cretaceous system form extensive outcrops on the margins of the Wasatch Plateau in central Utah and form limited outcrops within the Plateau proper. The Cretaceous and other rock systems of the area are famous for their rapid stratigraphic changes. System boundaries in this area also break conventional "rules". There are transitional strata from well-identified Jurassic to known Cretaceous rocks, and likewise, there are transitional strata from known Cretaceous into definite Paleocene.

The Cretaceous rocks in the Wasatch Plateau may be best described by two sets of names, one set for outcrops along the eastern side of the plateau, and one set for the rocks on the western side. From oldest to youngest on the eastern side of the plateau are: the Cedar Mountain formation and Buckhorn conglomerate member, the Dakota formation, and the Mancos group, consisting of the Tununk shale, Ferron sandstone, Bluegate shale, Emery sandstone, and Masuk shale. Overlying the Mancos is the Mesaverde group, consisting of the Starpoint sandstone, Blackhawk formation, and Price River formation; the youngest Cretaceous rocks are in the lower North Horn formation. On the western side of the Wasatch Plateau is the Indianola group, consisting (in ascending order) of the Sanpete formation, Allen Valley shale, Funk Valley and Sixmile Canyon formations, succeeded by the South Flat, Price River, and the North Horn formations.

The Cedar Mountain formation, its Buckhorn conglomerate member and the Dakota formation are locally exposed in the area east of the Wasatch Plateau between the plateau and the San Rafael Swell, but they have not been recognized on the surface west of the plateau. In the subsurface on the western side of the plateau the Tennessee Gas Transmission No. 1 Irons (Sec. 16, T-15-S, R-3-E), south of Moroni, reportedly penetrated 116 feet of the Dakota formation. It is probable that Lower Cretaceous rocks were deposited west of the Wasatch Plateau, but that they were eroded prior to the deposition of the Indianola group. Such erosion is quite likely in view of the orogenic activity west of the Wasatch Plateau during and prior to Indianola deposition.

A very spectacular facies change can be demonstrated in part of the Cretaceous system in the Wasatch Plateau area. On the east side of the plateau, the Mancos shale consists of five formations, or five members, depending upon the rank assigned these units. Black to gray marine shale predominates in a section which is approximately 4,300 feet thick. The three lower units of the Mancos (Tununk shale, Ferron sandstone, and Bluegate shale) grade rapidly westward, in a distance of approximately 30 miles, into what are recognized as the four formations of the Indianola group. The Indianola group is over 8,000 feet thick and consists chiefly of coarse conglomerates and sandstones deposited in a local trough adjacent to a rising highland.

As the Indianola group is traced westward from its exposures on the west side of the plateau, it becomes coarser and thicker, is not easily differentiated into its four component formations, and may reach an aggregate thickness of 15,000 feet (Spieker, 1949b, p. 21). Christiansen (1951, p. 8) measured 12,500 feet of coarse conglomerates, sandstone, and shale in the Canyon Range, which is 35 miles west of the Wasatch Plateau. On the basis of lithology and broad regional relations, he termed these rocks the Indianola (?). These rocks lie unconformably on Cambrian and Ordovician strata and constitute the westernmost known exposures of Cretaceous rocks in central Utah.

According to Spieker (1949b, p. 18-19) there is in Salina Canyon on the west side of the Wasatch Plateau a 1,300 foot section comprising varicolored shale, sandstone, limestone, and conglomerate which resembles the Morrison formation (Jurassic), and shows gradation and apparent intertonguing with the underlying Arapian shale (Jurassic) and also with the overlying Sanpete formation of the Indianola group (Cretaceous, lowermost Coloradan). There is no physical evidence of a sedimentation break in this part of the geologic section, which is remarkable in view of a widespread disconformity at the base of the Cretaceous on the east side of the Wasatch Plateau. Spieker (1949b, p. 19) says:

"In fact, were I not familiar myself with so many other instances of baffling concealment of actual gaps, I should consider seriously the possibility that the whole Lower Cretaceous and part of the Late Jurassic are represented in the formation, and for that matter, to theorize one brief bit further, evidence of major boundaries obscurely situated in gradational and intertonguing strata is now sufficiently abundant in the Cordilleran region to give the idea some flavor of validity. Against it, however, is the fact that the Morrison (?) sediments are mainly of types that normally accumulate somewhat rapidly."

Hunt (1954, p. 118-128) gave the name South Flat formation to a 2,850-foot-thick series of flood plain and piedmont deposits in the northern part of the Gunnison Plateau, just west of the Wasatch Plateau. The South Flat formation overlies the Indianola group with angular unconformity and is, in turn, overlain

with angular unconformity by the Price River formation. According to Hunt (1954, p. 127-128), the South Flat formation can be tentatively correlated with the Blackhawk formation on the eastern side of the Wasatch Plateau.

On the eastern side of the plateau there are numerous coal beds associated with the sandstones in the Mancos shale and in the overlying Mesaverde group. The Star Point sandstone and the Blackhawk formation of the Mesaverde group each contain several very valuable commercial coal beds. When traced westward, the lower two coal-bearing formations of the Mesaverde group contain progressively less and less coal and consists of sediments deposited in piedmont, fluvial, and highland environments.

In the Book Cliffs area east of the Wasatch Plateau, the Price River formation conformably overlies the Blackhawk formation. Beginning in the central part of the plateau and extending for at least 40 miles westward, the Price River formation rests on the bevelled edge of progressively older rocks until, with some stratigraphic omissions, it rests on Cambrian strata in the Pavant Range. The older formations were exposed and eroded during tectonic movements immediately prior to and during the deposition of the Price River formation, which is dated as medial Montanan.

Throughout the Wasatch Plateau and adjacent regions, the Price River formation is conformably overlain by the North Horn formation. In the Wasatch Plateau the contact is gradational, time transgressive, and becomes younger westward. Near its type area, the lower half of the North Horn formation contains a mammalian fauna of Paleocene age (Spieker, 1949b, p. 27). There is no known break in sedimentation between the two fossil horizons. The North Horn formation, in turn, both intertongues with and grades into the overlying Flagstaff formation of Tertiary age, and locally there is even an angular unconformity between the North Horn and the Flagstaff formation. Extreme lateral variation of facies is characteristic of the North Horn formation, reflecting the expected variance in the continental environment in which the North Horn was deposited. The North Horn formation increases in coarseness and generally in thickness westward. In most places the formation extends farther westward than the underlying Price River formation, and at its westernmost exposures in the Pavant Range laps unconformably onto rocks of Cambrian age.

Cretaceous rocks in the Wasatch Plateau record several pulses of orogenic activity, and they define an elongate north-trending area in which shallow water sediments accumulated to great thicknesses between a rising highland to the west and the broad, epicontinental, Late Cretaceous sea to the east.

The tongues of marine sediments, interbedded with the coarse clastics of the Indianola group, record advances and retreats of the sea, as do the intertonguing wedges of marine and nonmarine rocks of the Mancos and Mesaverde groups--this area was in the transition zone, and the geologic record preserved in the rocks documents the transition very accurately.

Henry Mountains

Cretaceous strata surround the Henry Mountains in a belt of outcrop which ranges up to 25 miles in width. In this area the Cretaceous rocks overlie the Morrison formation. Gilbert (1877) was the first to study the Cretaceous rocks of the Henry Mountains region. He named the following formations from oldest to youngest: Henrys Fork group (which included the Dakota sandstone and the

Morrison formation), Tununk shale, Tununk sandstone, Blue Gate shale, Blue Gate sandstone, Masuk shale, and Masuk sandstone. More recently, Hunt (1946, p. 8) has avoided duplication of formation names and borrowed from the area to the north the names Ferron sandstone for use in place of Tununk sandstone, Emery sandstone for use instead of Blue Gate sandstone, and Mesaverde for Masuk sandstone.

Katich (1954, p. 52) recognized Lower Cretaceous rocks (Cedar Mountain formation) in the northern part of the Henry Mountains area, but finds them absent in the southern part where they may have been removed by pre-Dakota erosion.

Hunt (1953, p. 86) identified thin erosional remnants of the lower part of the Mesaverde group locally overlying the Masuk shale in the west-central part of the Henry Mountains area.

The gross facies of these rocks are more similar to their lithogenetic equivalents east of the Wasatch Plateau than to Cretaceous rocks southwest in the Kaiparowits Plateau.

Katich (1954, p. 52) gives the following formation thicknesses for the Henry Mountains area: Cedar Mountain formation, up to 400 feet thick; Dakota sandstone, as much as 50 feet; the Mancos formation, which may be broken down into five units: (1) Tununk shale, 550 feet; (2) Ferron sandstone, 150-250 feet; (3) Blue Gate shale, 1,500 feet; (4) Emery sandstone, 200 feet; (5) Masuk shale, 700 feet; and the lower part of the Mesaverde group, 300 feet thick. Opinion differs as to the rank for the stratigraphic units in the Mancos. The writer prefers to consider them as formations of the Mancos group, inasmuch as the history of continued stratigraphic study shows refinements into more precise units and because the Mancos, at least in central Utah, lends itself well to a subdivision into five formations.

The upper part of the Mesaverde group has been removed by erosion in the Henry Mountains.

Southeastern Utah

Older Cretaceous rocks form fairly extensive outcrops in southeastern Utah, but in most of the area the younger Cretaceous rocks have been removed by erosion and only the Burro Canyon formation, Dakota formation, and the Mancos shale remain.

For many years geologists considered the Dakota formation to be of Late Cretaceous age in southeastern Utah, and opinion was that there were no rocks of Early Cretaceous age in this area. However, Stokes (1944, p. 966-976 and 1952, p. 1766-1776) presented evidence supporting an Early Cretaceous age for certain strata on the Colorado Plateau. Later paleontologic finds by Cobban and Reeside (1951, p. 1892-1893) and Katich (1951, p. 2093-2094) substantiated Stokes' conclusions. West and north of the Colorado River, Stokes (1952, p. 1774) applied the names Cedar Mountain formation and Buckhorn conglomerate member to the post-Morrison, pre-Dakota interval. East and south of the Colorado River, Stokes suggests using the term Burro Canyon formation for this same interval. The reason for the two sets of names is:

"The differences between rocks of the two large areas of outcrop separated by the Colorado River seem sufficient to justify the recognition of two distinct sets of names for the Colorado Plateau. The only alternative would be to regard the two areas as distinct facies of one formation, but this would imply a more strict age equivalence than present knowledge warrants. It is not unreasonable, however, to suppose that further research will reveal the exact time content of the various units."

The Burro Canyon formation rests conformably on the Morrison formation and consists of conglomerate, sandstone, siltstone, mudstone, shale, and limestone, all of continental origin. According to Stokes (1952, p. 1770-1772), the following characteristics are useful in distinguishing the Lower Cretaceous Burro Canyon and Cedar Mountain formations from the underlying Morrison formation: the Lower Cretaceous shales are more drab; color bands are fewer and less distinct than in the Morrison; lavender or purple predominate and calcareous nodules are abundant; the so-called "gastroliths" appear to be restricted to the Lower Cretaceous. The overlying Dakota formation has many of the same general lithologic types as the Lower Cretaceous, but the chert pebbles in the Lower Cretaceous are brighter colored and less weathered than those of the Dakota. There are more quartzite than chert pebbles in the Dakota formation, but the opposite is true in the underlying Cretaceous conglomerates. There are plant fossils in the coals and carbonaceous shales of the Dakota, but coals and carbonaceous shales and their contained plant fossils are lacking in the Lower Cretaceous formations. Mitchell (1956, p. 111) points out the differences in the deposition between the Dakota and the older Cretaceous rocks. He considers the Dakota to be a transgressive sandstone which was easily leached because of its lateral permeability. Much of the chert became tripolitic. The Lower Cretaceous rocks, on the other hand, were laid down on a desert floor and were covered with muds which infiltrated the original porosities, and these rocks were not leached very extensively.

The Dakota formation in much of southeastern Utah can be divided into a basal sandstone and conglomerate, a middle unit of gray and black carbonaceous shale, and an upper sandstone. Locally any one of these units may be absent (Katich, 1958, p. 194).

Cobban and Reeside (1951) assign the Dakota in eastern Utah to the Early Cretaceous, and Katich (1956, p. 116) suggests that the upper and middle units may be of Late Cretaceous age and that the lower unit could be Early Cretaceous. Complete agreement on the age of the Dakota is lacking, perhaps in part because the Dakota may span the Upper Cretaceous-Lower Cretaceous system boundary, and perhaps in part because the fossils used are not sufficiently diagnostic and limited in their time span.

The Dakota generally rests disconformably on a scoured and channeled Burro Canyon surface. The Dakota in turn is conformably overlain by the Mancos shale.

Complete sections of the Mancos are generally lacking in southeastern Utah and most of the formation has been removed by post-depositional erosion. Katich (1958, p. 194), however, reports that there is a 5- to 10-foot-thick, gray, dense, marly, shaly unit equivalent to the Greenhorn limestone about 75 feet above the base of the Mancos. He also notes that on Pack Creek, southeast of Moab, Utah, there is a thick Mancos section which may be overlain by a basal Mesaverde sandstone.

Book Cliffs

Cretaceous strata are well exposed in east-central Utah in and near the Book Cliffs. The Mesaverde group is especially well exposed in the sheer cliffs and slopes of the area. The North Horn and Tuscher formations form the lower part of the Roan Cliffs, which cap the Book Cliffs. The Mancos shale forms extensive broad benches, pediments, and slopes which are being dissected into badlands at the base of the Book Cliffs and extend southward for many miles. Locally the Cedar Mountain formation, Dakota formation, and the Ferron sandstone punctuate the "Mancos badlands" with low *cuestas*. The best exposures of these somewhat resistant sandy units are along stream gaps.

In ascending order, the Cretaceous rocks of the area consist of: the Cedar Mountain formation, the Dakota formation, the Mancos shale (which can be broken down into a lower shale unit, the Ferron sandstone, a middle shale unit, the Emery sandy zone, and an upper shale unit), and the overlying Mesaverde group (which consists of the Star Point sandstone, the Blackhawk formation, the Price River formation, with its Castlegate sandstone member, and the overlying North Horn and Tuscher formations). The base of the Cretaceous is conformable (?) with the Morrison formation and the overlying youngest Cretaceous rocks show transition into the Paleocene in the western part of the area and a marked erosional unconformity in the eastern part of the Book Cliffs.

The Cedar Mountain and Dakota formations are similar in lithology and stratigraphic relations to their equivalent units discussed for southeastern Utah. In the area between Price and Thompson, Utah, Katich (1956, p. 118) shows that the *Gryphea newberryi* zone is missing in the lower part of the Mancos and that there was either erosion or nondeposition in this area during Greenhorn time. Reeside (1955, p. 85) notes a more extensive hiatus covering Belle Fourche, Greenhorn, and early Carlile time in the lower Mancos section at Vermilion Creek, in northwestern Colorado. Note, however, that there was apparently no similar hiatus only a few miles to the west in the Wasatch Plateau.

According to Katich (1956, p. 118), there is a fossiliferous sandy zone in the post-Niobrara part of the Mancos about 800 feet below the base of the Mesaverde group. The zone contains *Scaphites hippocreppis* and is probably a homogenetic equivalent of the Emery sandstone to the west and the Mancos "B" zone (subsurface) at Douglas Creek gas field in western Colorado.

The Mesaverde group can be divided into a lower mixed marine and nonmarine sequence and an upper predominantly continental sequence. The lower contact is transitional and intertonguing with the Mancos shale. In the western Book Cliffs, the North Horn formation (Late Cretaceous and Paleocene) conformably overlies the Mesaverde group. Eastward, near Green River, Utah, the Mesaverde group is disconformably overlain by the Tuscher formation, which is considered Late Cretaceous, and further eastward near the Colorado-Utah state line the Mesaverde group is disconformably overlain by an unnamed sandstone of probable Paleocene age. In the western Book Cliffs there is no observable stratigraphic break between strata of Late Cretaceous and Paleocene age, whereas in the eastern Book Cliffs there is an erosional unconformity, having relief of approximately 1,000 feet.

Classic examples of intertonguing of sandstone and shale may be studied with relative ease in this area. However, for many years the coal-mining engineers in this area considered that the coal beds and their enclosing strata were of

great lateral extent and that one coal bed could be traced over a broad area. It was not until 1910-1912 that F. R. Clark (1928, p. 14-20) demonstrated that the beds did not have great lateral continuity, but that there was instead an eastward stratigraphic rise of the similar facies and that any single coal bed could not be traced laterally to the east for more than 10 or so miles. Young (1955, p. 177-202) has made a study of the intertonguing facies in the Book Cliffs of Utah and Colorado and shows that at least 13 sandstone tongues of the Mesaverde group thin and shale out to the east into the Mancos shale along the Book Cliffs between Price, Utah, and the Utah-Colorado state line. The Blackhawk formation and Star Point sandstone are two massive and prominent units in the western part of the Book Cliffs, but they tongue out into the Mancos and are not present at the Utah-Colorado state line. The stratigraphic rise of the Mancos-Mesaverde contact is approximately 2,700 feet from near Price to the state line.

A great number of names have been proposed for the rocks of the Mesaverde group in this area. The reader is referred to the summary of nomenclature by Young (1955, p. 179-181).

Southern Utah Plateaus

Rocks of the Cretaceous system form extensive outcrops in the escarpments and plateaus of southern Utah from the Straight Cliffs to the Hurricane Cliffs. Their topographic expression ranges from steep walls and high escarpments in the Straight Cliffs, to broad bench lands of the Kolob and other terraces, to badlands in parts of the eastern Kaibab Plateau.

Cretaceous rocks in southern Utah rest with disconformity on formations of Jurassic age, which in the western part of the area may be the Curtis or Winsor formations, and in the eastern part may be the Morrison formation. Rocks of early Tertiary age disconformably overlie the Cretaceous strata.

Five formations are recognized in the Cretaceous of southern Utah; from oldest to youngest they are: Dakota formation, Tropic formation, Straight Cliffs sandstone, Wahweap sandstone, and the Kaiparowits formation.

The Dakota formation is as much as 100 feet thick and consists of fine- to coarse-grained sandstone, pebble conglomerate, lignite, coal, and carbonaceous shale and siltstone. The conglomerate pebbles consist of varicolored subangular to rounded chert, quartzite, and limestone. Extreme lenticularity and lateral variability characterize the Dakota of the area. In contrast with most other parts of the state, the Dakota in southern Utah is generally soft, friable, and does not form ledges and resistant benches. Over much of the area it grades upward into the sandstones, siltstones, and shale of the Tropic formation. Only in the eastern part of the Kaibab plateau does the Dakota tend to form ledges and hold up broad benches. Gregory (1950a, p. 102, and 1950b, p. 45) concludes that there are probably no rocks of Early Cretaceous age in southern Utah, but Stokes (1952, p. 1775) suggests that, on the basis of the lithology of the conglomerate pebbles and the regional relations, the Dakota of southern Utah may be equivalent to the Buckhorn conglomerate, which is of Early Cretaceous age.

The Tropic formation (Tropic shale of some authors) overlies the Dakota formation and in turn grades upward into and also intertongues with the overlying Straight Cliffs sandstone. It is characterized in the western part of the area as a variable, lenticular assemblage of sandstone, siltstone, carbonaceous and locally calcareous shale, coal, and gray marine shale. To the east, the coarser clastic components decrease and the gray marine shale predominates. The Tropic

formation records the western limit of the Mancos sea and, in its intertonguing with the overlying Straight Cliffs sandstone, documents numerous oscillations of the sea during its general eastward withdrawal from the Western Interior. The dually as much as 10 feet thick. When traced westward across the area, the and fresh water elements at different horizons.

The Straight Cliffs sandstone, in the type area of the Straight Cliffs on the northeastern edge of the Kaiparowits Plateau, consists of thick, massive-bedded, tan to gray sandstone, minor thin shale beds, and numerous coal beds, individually as much as 10 feet thick. When traced eastward across the area, the sandstones become less massive and the shales are more numerous and thicker and the coal passes into carbonaceous shale and lignite (Gregory, 1950a, p. 105).

The Straight Cliffs sandstone records the general west to east withdrawal to the sea across the area and the accompanying eastward migration of the piedmont, flood-plain, and swampland sites of deposition. Extreme lateral and vertical heterogeneity characterize the resulting deposits, and the changes are well-preserved in the Straight Cliffs sandstone.

According to Gregory (1950a, p. 107), at the type area of the Wahweap sandstone along the Wahweap Creek in central Kane County, the separation from the underlying Straight Cliffs sandstone is easily made. Here the Wahweap and Straight Cliffs are different in type of bedding, texture, and composition. The Wahweap has numerous thin sandstones, but lacks carbonaceous, silty, and calcareous shales common to the Straight Cliffs. However, to the west the differences become progressively less pronounced, and in the western part of the area the sandy units above the Tropic formation and below the Kaiparowits are mapped as the Straight Cliffs-Wahweap undifferentiated.

The age of the Wahweap is indefinitely known because few diagnostic fossils have been found to date. It lies above strata containing fossils of Niobraran age and below beds containing fossils of late Montanan age.

There was a period of erosion in southern Utah following Wahweap deposition during which the Wahweap sandstone was scoured, channeled, and locally even completely removed. The Kaiparowits formation was deposited on this erosion surface. The Kaiparowits formation is easily distinguished from the buff, tan, and yellow older sandstone which it overlies; the dark browns and grays of the Kaiparowits contrast markedly with the pink and white of the overlying Tertiary rocks. The Kaiparowits is probably of flood-plain origin and consists of interleaved lenses of sandstone, siltstone, sandy shale, limestone, and channel conglomerate. Iron-bearing cements impart the characteristic dark color to the Kaiparowits.

Nonmarine faunas from the Kaiparowits indicate a late Montanan age. The Kaiparowits formation cannot be traced laterally away from southern Utah because of erosion in surrounding areas or because of deep burial by younger rocks. The Kaiparowits occupies the same general position in the stratigraphic column as the Price River formation of central Utah. Following Kaiparowits deposition, the area was subjected to erosion, and later the Wasatch formation of early Tertiary age was deposited on the erosion surface.

Southwestern Utah

In southwestern Utah, rocks of the Cretaceous system form limited outcrops west of the Hurricane fault in Washington and Iron counties. Good exposures are known in the Iron Springs district, in the Pine Valley Mountains, and near the villages of New Harmony, Newcastle, Enterprise, and Veyo. In this area of Utah the Cretaceous has not been subdivided into the usual five or six formations because the rocks consist of a sequence of coarse-grained sandstone, shale, and conglomerates, and, locally, coal beds, which do lend themselves readily to subdivision.

Leith and Harder (1908, p. 37-41) named the Pinto sandstone from exposures in the Iron Springs district. Mackin (1947, p. 7-8) more recently named the Iron Springs formation for conglomerate, mud-flow breccia, calcareous sandstone, and limestone unconformably overlying the Entrada formations of Jurassic age. This new name was proposed because the Pinto sandstone comprised both the Entrada and Iron Springs formations, which have a marked difference in lithology and are separated by an unconformity. The Iron Springs formation is, in turn, unconformably overlain by the Claron formation. The Claron is considered essentially equivalent to the Wasatch of the High Plateaus of Utah and may in part have a Late Cretaceous as well as an early Paleocene age.

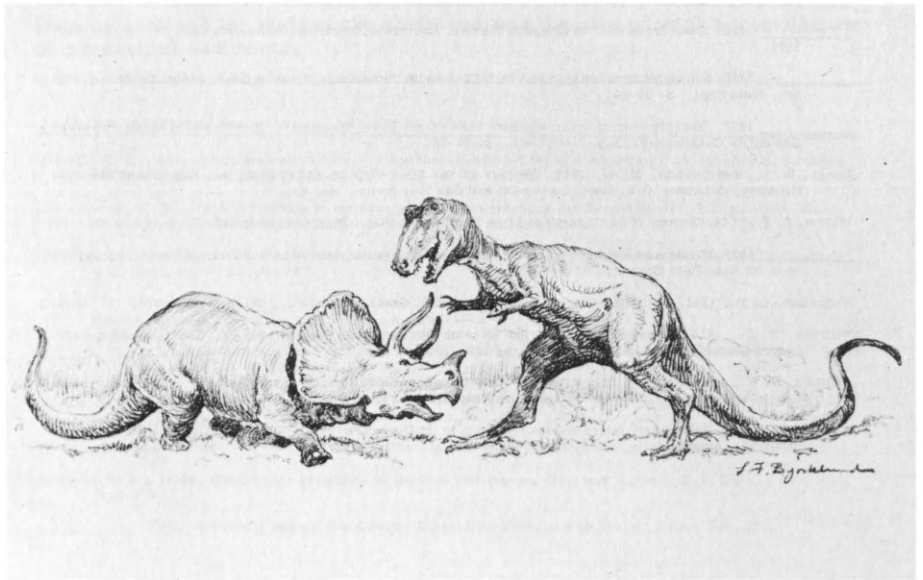
The thickness of the Cretaceous sequence ranges from 560 feet near New Harmony (Richardson, 1909, p. 385-386) to possibly 5,000 feet in the Iron Springs district (Mackin, 1947, p. 8). Bissell (1952b, p. 71) measured 4,100 feet of conglomerate and sandstone in the southeast Pine Valley Mountains. Richardson found fossils of Colorado age in the New Harmony exposures, but elsewhere fossils are generally conspicuously absent. The age relations consequently can be inferred only on the basis of stratigraphic position and lithologic similarity to Cretaceous rocks in the plateaus to the east.

This area of Utah was probably not extensively, if at all, covered by the Cretaceous seas--it lay west of the shore and was the site of thick accumulations of continental sediments.

CITED REFERENCES

- Bissell, H. J., 1952, Stratigraphy and structure of northeast Strawberry Valley quadrangle, Utah: *Am. Assoc. Petroleum Geologists Bull.*, v. 36, p. 575-637.
- Christiansen, F. W., 1951, A summary of the structure and stratigraphy of the Canyon Range: *Intermountain Assoc. Petroleum Geologists Guidebook to the Geology of Utah*, no. 6, p. 5-18.
- Clark, F. R., 1928, Economic geology of the Castlegate, Wellington, and Sunnyside quadrangles, Carbon County, Utah: *U.S. Geol. Survey Bulletin* 793.
- Cobban, W. A., and Reeside, J. B., Jr., 1951, Lower Cretaceous ammonites in Colorado, Wyoming, and Montana: *Am. Assoc. Petroleum Geologists Bull.*, v. 35, p. 1892-1893.
- _____, 1952a, Correlation of the Cretaceous formations of the western interior of the United States: *Geol. Soc. America Bull.*, v. 63, p. 1011-1044.
- _____, 1952b, Frontier formation, Wyoming and adjacent areas: *Am. Assoc. Petroleum Geologists Bull.*, v. 36, p. 1913-1961.
- Gilbert, G. K., 1877, Report on the geology of the Henry Mountains: *U.S. Geog. and Geol. Survey Rocky Mtn. Region*.
- Gregory, H. E., 1950a, Geology and geography of the Zion Park region, Utah and Arizona: *U.S. Geol. Survey Prof. Paper* 220.
- _____, 1950b, Geology of eastern Iron County, Utah: *Utah Geol. and Mineralog. Survey Bull.* 37.

- Hunt, C. B., 1946, Guidebook to the geology and geography of the Henry Mountain region: Utah Geol. Soc. Guidebook no. 1.
- _____, 1953, Geology and geography of the Henry Mountains region, Utah: U.S. Geol. Survey Prof. Paper 228.
- Hunt, R. E., 1954, South Flat formation, new Upper Cretaceous formation of central Utah: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 118-128.
- Katich, P. J., Jr., 1951, Recent evidence for Lower Cretaceous deposits in the Colorado Plateau: Am. Assoc. Petroleum Geologists, Bull., v. 35, p. 2093-2094.
- _____, 1954, Cretaceous and early Tertiary stratigraphy of central and south-central Utah with emphasis on the Wasatch Plateau area: Intermountain Assoc. Petroleum Geologists Guidebook 5th Ann. Field Conf., p. 42-54.
- _____, 1956, Some notes on the Cretaceous faunas of eastern Utah and western Colorado: Intermountain Assoc. Petroleum Geologists Guidebook 7th Ann. Field Conf., p. 116-119.
- _____, 1958, Cretaceous of southeastern Utah and adjacent areas: Intermountain Assoc. Petroleum Geologists Guidebook 9th Ann. Field Conf., p. 193-196.
- Leith, C. K., and Harder, E. C., 1908, The iron ores of the Iron Springs district, southern Utah: U.S. Geol. Survey Bull. 338.
- Mackin, J. H., 1947, Some structural features of the intrusions in the Iron Springs district: Utah Geol. Soc. Guidebook, no. 2.
- Mathews, A. A. L., 1931, Mesozoic stratigraphy of the central Wasatch Mountains: Oberlin Col. Lab. Bull., 1.
- Mitchell, J. G., 1956, Charophytes as a guide to distinguishing between Lower Cretaceous and Upper Jurassic continental sediments in the subsurface: Intermountain Assoc. Petroleum Geologists Guidebook 7th Ann. Field Conf., p. 105-112.
- Reeside, J. B., Jr., 1955, Revised interpretation of the Cretaceous section on Vermillion Creek, Moffat County, Colorado: Wyoming Geol. Assoc. Guidebook 10th Ann. Field Conf., p. 85-88.
- Richardson, G. B., 1909, The Harmony, Kolob, and Kanab coal fields, southern Utah: U.S. Geol. Survey Bull. 341, p. 379-400.
- Root, R. L., 1952, Geology of the Smith and Moorehouse-Hayden Fork area, Utah: Univ. of Utah, M.S. thesis.
- Spieker, E. M., 1946, Late Mesozoic and Early Cenozoic history of central Utah: U.S. Geol. Survey Prof. Paper 205-D, p. 117-161.
- _____, 1949, The Transition between the Colorado Plateaus and the Great Basin in central Utah: Utah Geol. Soc. Guidebook, no. 4.
- Stokes, W. L., 1944, Morrison and related deposits in and adjacent to the Colorado Plateau: Geol. Soc. America Bull., v. 55, p. 951-992.
- _____, 1952, Lower Cretaceous in Colorado Plateau: Am. Assoc. Petroleum Geologists Bull., v. 36, p. 1766-1776.
- _____, 1955, Nonmarine Late Jurassic and Early Cretaceous formations: Wyoming Geol. Assoc. Guidebook 10th Ann. Field Conf., p. 80-84.
- _____, 1957, Jurassic system of the southern flank of the Uinta Mountains: Intermountain Assoc. Petroleum Geologists Guidebook 8th Ann. Field Conf., p. 92-96.
- Stokes, W. L., and Phoenix, D. A., 1948, Geology of the Egnar-Gypsum Valley area, San Miguel and Montrose Counties, Colorado: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 93.
- Walton, P. T., 1944, Geology of the Cretaceous of the Uinta Basin, Utah: Geol. Soc. America Bull., v. 55, p. 91-130.
- _____, 1957, Cretaceous stratigraphy of the Uinta Basin: Intermountain Assoc. Petroleum Geologists Guidebook 8th Ann. Field Conf., p. 97-101.
- Weggeman, C. H., 1915, The Coalville coal field, Utah: U.S. Geol. Survey Bull., 581-E, p. 161-184.
- Williams, N. C., 1955, Laramide history of the Wasatch-western Uinta Mountains area, Utah: Wyoming Geol. Assoc. Guidebook 10th Ann. Field Conf., p. 127-129.
- Williams, N. C., and Madsen, J. H., Jr., 1959, Late Cretaceous stratigraphy of the Coalville area, Utah: Intermountain Assoc. Petroleum Geologists Guidebook 10th Ann. Field Conf., p. 122-125.
- Young, R. G., 1955, Sedimentary facies and intertonguing in the Upper Cretaceous of the Book Cliffs, Utah-Colorado: Geol. Soc. America Bull., v. 66, p. 177-202.



Paper 13 TERTIARY STRATIGRAPHY OF UTAH

by Clyde T. Hardy¹

INTRODUCTION

Four geologically distinct areas contain nearly all of the sedimentary rocks of Tertiary age in Utah. The main part of the northern Tertiary area is east of the Wasatch and Bear River Ranges and north of the Uinta Mountains; however, late Tertiary rocks are also found at places in northwestern Utah. The Uinta Basin, south of the Uinta Mountains and north of Price and Green River, Utah, is the largest area. The central area includes the Wasatch, Pavant, and Gunnison Plateaus and extends from Richfield to Thistle, Utah. The southern area is mostly between Cedar Breaks, east of Cedar City, and Bryce Canyon, although it extends northward from Cedar Breaks and northeastward from Bryce Canyon. Isolated occurrences of Tertiary rocks are found southwest of Cedar City. The relationships of important Tertiary formations are shown by means of a chart (Figure 49).

The Uinta Basin, as well as large parts of the central and southern areas, is within the Colorado Plateau. The Cenozoic history of the Colorado Plateau has been summarized by Hunt (1956). The stratigraphy of the Uinta Basin has been outlined by Abbott (1957) and that of the Book Cliffs by Fisher, Erdmann, and Reeside (1960). Many theses of Utah universities, Ohio State University, and the University of Washington contain important unpublished data. Tertiary rocks of Utah are shown on a correlation chart published by Jones, Picard, and Wyeth (1954).

NORTHERN UTAH

Rocks of early Tertiary age underlie most of northeastern Utah, east of the Wasatch and Bear River Ranges and north of the western part of the Uinta Mountains. In lower Echo Canyon, north of Coalville, Utah, the Knight formation of Eocene age overlies, with marked angular discordance, the Echo Canyon conglomerate of late Cretaceous age (Williams and Madsen, 1959). Here the Knight consists of a basal red-weathering conglomerate, 400 feet thick, overlain by about 800 feet of conglomerate, sandstone, and shale (Eardley, 1944). The Knight is also well exposed along the flanks of a broad northward-trending syncline in Morgan Valley. At this locality, it may be as much as 5,000 feet thick (Eardley, 1944). Similar rocks extend northward into the eastern part of the Bear River Range. A basal stromatolitic limestone rests on Paleozoic rocks in the area east of Logan Peak (Williams, 1948) and a thick succession of red conglomerate and shale crops out southwest and east of Bear Lake (Richardson, 1941). The Fowkes formation, formerly called the Norwood tuff, overlies the Knight formation in Morgan Valley (Eardley, 1959). It is of early Oligocene age as evidenced by vertebrate remains (Eardley, 1944).

Younger Tertiary rocks are found around the margins of Cache Valley and elsewhere in north-central and northwestern Utah. These rocks are termed the Salt Lake formation except in Cache Valley where three formations are recognized within the Salt Lake group (Adamson, Hardy, and Williams, 1955): (1) the basal Collinston

1. Associate Professor Geology, Utah State University, Logan, Utah.

AGE	NORTHERN UTAH	UINTA BASIN	CENTRAL UTAH	SOUTHERN UTAH
PLIOCENE	Mink Creek congl. Cache Valley Collinston congl.			
MIOCENE		Browns Park		
OLIGOCENE	Fowkes		Moroni	
EOCENE	Knight	Duchesne River Uinta Green River Wasatch	Crazy Hollow Green River Colton Flagstaff	Wasatch-Claron
PALEOCENE			Flagstaff North Horn (part)	

Figure 49. Generalized Chart showing Tertiary formations.

conglomerate, (2) the Cache Valley formation, and (3) the Mink Creek conglomerate. The Collinston conglomerate grades laterally into the Cache Valley formation and is best known from outcrops at the northern end of Wellsville Mountain, west of Logan, Utah. Mink Creek conglomerate overlies the Cache Valley formation along the eastern side of Cache Valley. The Cache Valley formation is of Pliocene age; however, it is possible that part of the Salt Lake group may be as old as the Powkes formation of Morgan Valley. The Salt Lake formation crops out at Rozel Point (Eardley and Slentz, 1956), in Grouse Creek Valley (Van Houten, 1956), and at other places in northwestern Utah (Felix, 1956; Mapel and Hail, 1956).

UINTA BASIN

The Wasatch formation of Eocene age overlies the Mesaverde formation of Cretaceous age in the central part of the Uinta Basin; younger Tertiary units overlap older rocks along the southern flank of the Uinta Mountains. The Green River formation of middle Eocene age is gradational with the Wasatch below and the Uinta formation above. The Duchesne River formation, late Eocene or Oligocene in age (Gazin, 1959), is conformable with the Uinta. The Browns Park formation overlies various older rocks unconformably (Hansen, Kinney, and Good, 1960). Tertiary stratigraphy of the Uinta Basin was studied by Bradley (1931) and reviewed by Abbott (1957); it is discussed in greater detail elsewhere in this volume.

CENTRAL UTAH

Tertiary rocks are well displayed in the Wasatch, Pavant, and Gunnison Plateaus. The North Horn formation, at its type locality in the eastern part of the Wasatch Plateau, is of late Cretaceous age in the lower part and Paleocene in the upper part (Spieker, 1946). The type section is 1,650 feet thick, according to Spieker (1946), and consists mostly of sandstone and shale. North Horn overlies Price River formation throughout most of the area; however, an angular unconformity separates beds identified as Price River from the North Horn in both the northeastern and southwestern parts of the Gunnison Plateau (Burma and Hardy, 1953; Hardy and Zeller, 1953). Rapid lithologic changes from sandstone and shale to conglomerate characterize the North Horn of the Gunnison Plateau. North Horn is said to intertongue with the overlying Flagstaff formation (Spieker, 1949), but in Sixmile Canyon, on the western side of the Wasatch Plateau, an angular unconformity separates it from Flagstaff. In parts of the southern Wasatch Mountains, the North Horn is not recognized and equivalent beds have been mapped as Price River formation (Baker, 1947); in the Canyon Range the North Horn is provisionally identified (Christiansen, 1952).

The Flagstaff formation of the central Wasatch Plateau consists mostly of gray limestone and shale and is 1,500 feet thick (Spieker, 1946). Southward, in the vicinity of Salina Canyon and in the Pavant Plateau, beds of red and yellow sandy limestone are prominent. The Flagstaff is believed to intertongue with the underlying North Horn formation (LaRocque, 1960; Spieker, 1949). In Sixmile Canyon, at the western margin of the Wasatch Plateau, the Flagstaff truncates North Horn and overlaps older Cretaceous rocks (Spieker, 1946). In Salina Canyon it overlaps Jurassic rocks (Gilliland, 1951). The Flagstaff of the central part of the Gunnison Plateau overlies the North Horn formation, but in the western part it rests on older Jurassic and Cretaceous rocks. The Flagstaff is of Paleocene and Eocene age (LaRocque, 1960).

The Colton formation, at its type locality near Colton, Utah, is 1,500 feet thick. Here it consists of red shale and sandstone which intertongues westward with the Green River formation (Spieker, 1946). Elsewhere in central Utah, red Colton likewise intertongues with the Green River formation. Part of the Colton formation of the Gunnison Plateau may be equivalent to Flagstaff of the Pavant Plateau (LaRocque, 1960).

The Green River formation makes prominent hogbacks along the western margin of the Wasatch Plateau and also crops out extensively in the Gunnison Plateau. It is at least 800 feet thick in central Utah (LaRocque, 1960). The Green River intertongues with the Colton formation and rests directly on Flagstaff formation in the absence of the latter. Along the eastern side of Sevier Valley, between Salina and Gunnison, Utah, Green River formation overlies Jurassic rocks (Hardy, 1952). The Green River formation is of Eocene age.

The Crazy Hollow formation unconformably overlies the Green River formation in the Sevier-Sanpete Valley area. It consists of red and gray sandstone and red sandy shale. In the type area in the lower part of Salina Canyon, it is nearly 1,000 feet thick (McGookey, 1960). The Uinta formation, possibly equivalent to the Crazy Hollow, overlies Green River formation in the southern Wasatch Mountains northeast of Thistle, Utah (Baker, 1947). Eocene volcanic sedimentary rocks are found in Long Ridge, west of the Gunnison Plateau (Muessig, 1951).

The Moroni formation, consisting of volcanic sedimentary rocks with welded tuffs in the upper part, overlies Crazy Hollow formation and older rocks in the Cedar Hills (Schoff, 1951). The Moroni is about 2,000 feet thick.

SOUTHERN UTAH

The Wasatch formation, east of Cedar City, Utah, and the equivalent Claron formation, west of Cedar City, consist of three units: (1) basal conglomerate, (2) sandstone and shale, and (3) limestone (Bissell, 1952; Cook, 1960; Gregory, 1950a). It ranges in thickness from about 500 feet to nearly 2,000 feet and forms the well-known Pink Cliffs. In Coal Creek Canyon, east of Cedar City, the Wasatch is 1,790 feet thick (Bissell, 1952). Gregory (1950b) reported a detailed section from this canyon. At Rainbow Point, Bryce Canyon, the Wasatch is mostly limestone, according to Gregory (1951), and is about 800 feet thick. The Wasatch generally rests on Cretaceous rocks and is taken to be of Eocene age; however, Bissell (1952) regarded the lower part as Paleocene.

A complex sequence of late Tertiary volcanic rocks overlies Paleozoic, Mesozoic, and Tertiary rocks in the Marysvale region (Callaghan, 1939). Volcanic rocks are also found in places westward from Cedar City to Nevada (Cook, 1960; Mackin, 1960).

CITED REFERENCES

- Abbott, Ward, 1957, Tertiary of the Uinta Basin: Intermountain Assoc. Petroleum Geologists Guidebook 8th Ann. Field Conf., p. 102-109.
- Adamson, R. D., Hardy, C. T., and Williams, J. S., 1955, Tertiary rocks of Cache Valley, Utah and Idaho: Utah Geol. Soc. Guidebook, no. 10, p. 1-22.
- Baker, A. A., 1947, Stratigraphy of the Wasatch Mountains in the vicinity of Provo, Utah: U.S. Geol. Survey Oil and Gas Inv. Prelim. Chart 30.
- Bissell, H. J., 1952, Geology of the Cretaceous and Tertiary sedimentary rocks of the Utah-Arizona-Nevada corner: Intermountain Assoc. Petroleum Geologists Guidebook, no. 7, p. 72-77.
- Bradley, W. H., 1931, Origin and microfossils of the oil shale of the Green River formation of Colorado and Utah: U.S. Geol. Survey Prof. Paper 168.
- Burma, B. H., and Hardy, C. T., 1953, Pre-North Horn orogeny in Gunnison Plateau, Utah: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 549-553.
- Callaghan, Eugene, 1939, Volcanic sequence in the Marysvale region in south-west-central Utah: Trans. Am. Geophys. Union 20th Ann. Mtg. Pt. 3, p. 438-452.
- Christiansen, F. W., 1952, Structure and stratigraphy of the Canyon Range, Central Utah: Geol. Soc. America Bull., v. 63, p. 727-728.
- Cook, E. F., 1960, Geologic atlas of Utah, Washington County: Utah Geol. and Mineralog. Survey Bull. 70, p. 36-49.
- Eardley, A. J., 1944, Geology of the north-central Wasatch Mountains, Utah: Geol. Soc. America Bull., v. 55, p. 844-846.
- _____, 1959, Review of geology of northeastern Utah and southwestern Wyoming: Intermountain Assoc. Petroleum Geologists Guidebook 10th Ann. Field Conf., p. 166-171.
- Eardley, A. J., and Slentz, L. W., 1956, Geology of Rozel Hills: Utah Geol. Soc. Guidebook, no. 11, p. 32-40.
- Felix, C. E., 1956, Geology of the eastern part of the Raft River Range, Box Elder County, Utah: Utah Geol. Soc. Guidebook, no. 11, p. 86-88.
- Fisher, D. J., Erdmann, C. E., and Reeside, J. B., Jr., 1960, Cretaceous and Tertiary formations of the Book Cliffs, Carbon, Emery, and Grand Counties, Utah, and Garfield and Mesa Counties, Colorado: U.S. Geol. Survey Prof. Paper 332.
- Gazin, C. L., 1959, Paleontological exploration and dating of the early Tertiary deposits in basins adjacent to the Uinta Mountains: Intermountain Assoc. Petroleum Geologists Guidebook 10th Ann. Field Conf., p. 137.
- Gilliland, W. N., 1951, Geology of the Gunnison quadrangle, Utah: Univ. Nebraska Studies, new ser., no. 8, p. 20-52.
- Gregory, H. E., 1950a, Geology and geography of the Zion Park region, Utah and Arizona: U.S. Geol. Survey Prof. Paper 220, p. 110-112.
- _____, 1950b, Geology of eastern Iron County, Utah: Utah Geol. and Mineralog. Survey Bull. 37, p. 58-71, 78.
- _____, 1951, The geology and geography of the Paunsaugunt region, Utah: U.S. Geol. Survey Prof. Paper 226, p. 43-54, 68.
- Hansen, W. R., Kinney, D. M., and Good, J. M., 1960, Distribution and physiographic significance of the Browns Park formation, Flaming Gorge and Red Canyon areas, Utah-Colorado: U.S. Geol. Survey Prof. Paper 400-B, p. 257-259.
- Hardy, C. T., 1952, Eastern Sevier Valley, Sevier and Sanpete Counties, Utah: Utah Geol. and Mineralog. Survey Bull. 43, p. 11-12, 31-39.
- Hardy, C. T., and Zeller, H. D., 1953, Geology of the west-central part of the Gunnison Plateau, Utah: Geol. Soc. America Bull., v. 64, p. 1269-1274.
- Hunt, C. B., 1956, Cenozoic geology of the Colorado Plateau: U.S. Geol. Survey Prof. Paper 279.
- Jones, D. J., Picard, M. D., and Wyeth, J. C., 1954, Correlation of non-marine Cenozoic of Utah: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 2219-2222.
- LaRocque, Aurele, 1960, Molluscan faunas of the Flagstaff formation of central Utah: Geol. Soc. America Mem. 78, p. 1-14, 73-84.
- Mackin, J. H., 1960, Structural significance of Tertiary volcanic rocks in southwestern Utah: Am. Jour. Sci., v. 258, p. 81-131.

- Mapel, W. J., and Hail, W. J., Jr., 1956, Tertiary stratigraphy of the Goose Creek district, Cassia County, Idaho, and adjacent parts of Utah and Nevada: Utah Geol. Soc. Guidebook, no. 11, p. 1-16.
- McGookey, D. P., 1960, Early Tertiary stratigraphy of part of central Utah: Am. Assoc. Petroleum Geologists Bull., v. 44, p. 589-615.
- Muessig, Siegfried, 1951, Eocene volcanism in central Utah: Science, v. 114, p. 234.
- Richardson, G. B., 1941, Geology and mineral resources of the Randolph quadrangle, Utah-Wyoming: U.S. Geol. Survey Bull. 923, p. 32-35.
- Schoff, S. L., 1951, Geology of the Cedar Hills, Utah: Geol. Soc. America Bull., v. 62, p. 628-636.
- Spieker, E. M., 1946, Late Mesozoic and early Cenozoic history of central Utah: U.S. Geol. Survey Prof. Paper 205-D, p. 132-149.
- _____, 1949, The transition between the Colorado Plateaus and the Great Basin in central Utah: Utah Geol. Soc. Guidebook to the Geology of Utah, no. 4, p. 26-38.
- Van Houten, F. B., 1956, Reconnaissance of Cenozoic sedimentary rocks of Nevada: Am. Assoc. Petroleum Geologists Bull., v. 40, p. 2811.
- Williams, J. S., 1948, Geology of the Paleozoic rocks, Logan quadrangle, Utah: Geol. Soc. America Bull., v. 59, p. 1144-1147.
- Williams, N. C., and Madsen, J. H., Jr., 1959, Late Cretaceous stratigraphy of the Coalville area, Utah: Inter-mountain Assoc. Petroleum Geologists Guidebook 10th Ann. Field Conf., p. 122-125.

Paper 14 THE QUATERNARY SYSTEM IN UTAH

by R. E. Marsell¹

INTRODUCTION

The Quaternary system is perhaps the most widespread and the least well known in the geological column of the state. Quaternary sedimentary deposits, largely lake beds and conglomerates, floor the intermontane valleys and desert basins of the western half of the state, lap up on the mountain flanks, and invade the canyons and major ravines in tongue-like floodplain deposits, terrace gravels, and alluvial fans. Small areas of Quaternary lavas, mainly basalts, some of which are quite recent in age, also occur.

The close relationship of Quaternary deposits to the existing topographic features of the state clearly indicates that the major reliefs were already fairly well developed in late Tertiary times, but continued to be elevated intermittently, largely by block faulting, throughout both the Pleistocene and Recent epochs--even continuing into post-Bonneville times.

On most geologic maps the Quaternary system in Utah is delineated in a pale-buff to light-yellow color and designated simply as "Quaternary alluvium," representing in the main unconsolidated materials of Recent age. Little attempt has been made in the past to distinguish stratigraphic units and determine the structure of the so-called "valley fill," but in recent years, stimulated by need of more detailed geological information in connection with the rapidly expanding use and increasing importance of the underground water resources of the state, a number of investigations have been made, largely pioneered by the State Engineer and the Ground Water Division of the U.S. Geological Survey. Several of these detailed studies have already been published, notably papers by Leggette and Taylor (1937) and Thomas (1945, 1946, and 1948). Thus, more has been learned about the Quaternary system in Utah in the past few years than in all previous time.

Investigators have met difficulty in clearly distinguishing, on the one hand, Quaternary deposits from the preceding Pliocene and, on the other, Pleistocene from Recent deposits, into which they often imperceptibly grade.

In the northern part of the state, workers have recognized the Salt Lake group of Hayden or the Salt Lake formation of Mansfield as a series of alluvial and lacustrine sediments and tuffs of late Tertiary age underlying what they have defined as the Quaternary system. Eardley, in the north-central Wasatch Mountains, assigned beds of this group (Salt Lake) to the late Eocene on the basis of vertebrate fossils, and renamed the deposits the Norwood Tuff (now the Fowkes formation). J. Stewart Williams, on the other hand, is pretty well convinced, on the basis of fossils found by him in the beds of the Salt Lake group in Cache Valley, that here at least in part the beds are of Pliocene age. It seems likely, therefore, that when these Tertiary beds are studied more widely and completely in Utah, they may be found to embrace deposits ranging all of the way from late Eocene to late Pliocene in age. Two outstanding features seem to distinguish the sediments assigned to the Salt Lake group: one, the presence of pumiceous ash and tuffaceous sandstone; the other,

1. Professor Emeritus of Geology, University of Utah, Salt Lake City, Utah.

steep dips reflecting mild deformation rather than initial inclination of the sediments. By contrast, the Quaternary system generally lacks pyroclastics, except locally in the Fillmore area as reported by Maxey (1946, p. 244), and shows little evidence of tectonic disturbance other than minor dislocations by fault movements. In Cache Valley, where beds of the Salt Lake group are exceptionally well exposed, Williams (1958) has described fanglomerates, limestone, and tuffs, aggregating nearly 9,000 feet. By comparison, the Quaternary system, as interpreted mainly from deep well logs in the basins where the most complete sections are preserved, is generally under 1,000 feet in thickness, the average being closer to one-half that figure. Oolitic limestone appears to be absent from the Pleistocene lacustrine deposits, but is prominent in the Recent sediments of Great Salt Lake, as described by Eardley (1938) and others.

The Lake Bonneville deposits, in a restricted sense (Gilbert, 1890), are found to constitute but a small fraction of the total Pleistocene deposits mantling the basin floors. In fact, except for a coarse shore facies, the Bonneville "lake bottom beds" of Hunt, Varnes, and Thomas (1953), Bissell (1948, unpublished thesis), and Thomas (1948) are but a thin veneer laid over a succession of pre-Bonneville fanglomerates, playa beds with occasional intercalated layers of peat, thick lake clays, and stream channel gravels and sands. Thus, it would appear that Lake Bonneville and its more recent analogue "Lake Provo" (as defined by Antevs, 1948) are but the last of a series of lakes that occupied parts of western Utah during Quaternary times. The sediments, as revealed by deep well samples, show wide fluctuations of strandlines in the more remote past, like those known in more recent times for Utah Lake (Hansen, 1934) and Great Salt Lake (Wooley, 1946), and evidence also of longer times of probable complete desiccation of the basin. The major "lake intervals" are generally regarded (Nolan, 1943) as being closely associated with several pluvial and glacial stages of the Pleistocene epoch. Atwood (1909) found evidence of two well-defined glacial stages and a suggestion of a third in the Wasatch and Uinta Mountains; more recently, Marsell (1946), working in the central Wasatch Mountains, has found evidence of four flacial stages.

Since much of the same topography has prevailed during Quaternary times as that in existence today, Quaternary sediments that have remained in closed basins, or have been left due to lack of sufficient precipitation to maintain outflowing streams, reveal a wide variety of types in harmony with the complexity of the landscapes of the region.

Sedimentary deposits range from coarse detritus, such as bouldery moraines, blocky taluses, landslide debris, and mudrock "cloudburst" flood deposits, through typical alluvial fanglomerates to shore gravels and the finer sands, silts, and clays of lake origin. Dune sands and some loessial soils are also present.

Chemical deposits include algal tufa, abundant on the Provo and younger terraces of Lake Bonneville, and in long, reef-like masses in present Great Salt Lake (Eardley, 1938). Both lake chalk and diatomite are common in Pleistocene deposits in the state, and oolitic sand is accumulating at present along certain parts of the shore and near-shore zones in Great Salt Lake (Eardley, 1938). Evaporites and precipitates occur, such as salt, gypsum, and "mirabilite" (sodium sulphate); the latter is present in a considerable deposit along the southeast shore of Great Salt Lake (Bell, 1948). Large spring-terrace deposits of travertine of Quaternary age, resembling those at Mammoth Springs in Yellowstone, are known in Utah, notably those in Blacksmith Fork Canyon in the Bear River Range and those in an area west of Kanosh (Maxey, 1946). Three small travertine deposits occur

near the Jordan Narrows, south of Salt Lake City, where Marsell (1932) found teeth of an early Pleistocene camel, along with the well preserved lower jaw and teeth of a horse of late Pliocene age, embedded in the travertine at a depth of sixty feet below the present surface. In the latter locality, the hot-springs responsible for the deposit are extinct, but warm-spring waters are known in the vicinity.

SEDIMENTARY ROCKS

Detrital Deposits

Alluvium: On most geologic maps of the state the Quaternary unconsolidated deposits are grouped together and designated simply as "alluvium"; included are such detrital deposits as moraines, talus and landslide debris, fanglomerates and associated "mudrock flows" (Thomas, 1948), river terrace and flood plain gravels and sands, lake accumulations of gravel, sand, silt, and clay, and sand dunes. On the four quarters of the colored geologic map of Utah (Stokes, et al., Northeast Quarter, 1961), alluvial deposits, gravel surfaces, land slides, dunes, moraines, outwash, and covering deposits are separately indicated.

Glacial Deposits: The Quaternary glacial deposits of Utah consist of bulky terminal and lateral moraines left at the mouths and along the margins of the major canyons of the loftier mountain ranges and plateaus of the state. These morainal deposits are often accompanied by deep valley trains and thick fan-like accumulations of outwash cobbles and gravels. The bulk of the coarser sediments that ultimately found lodgement in the lake basins along the eastern margin of the Great Basin had their origin in the "glacial mills" that once were present in the heads and upper portions of many of the adjacent mountain valleys (Blackwelder, 1948). Since Atwood's (1909) early report on the glaciation of the Uinta and Wasatch Mountains, glacial deposits have been recognized in many parts of the state, notably in the Wasatch, Fish Lake, and Aqueous Plateaus of the High Plateau district in south-central Utah, in the La Sal Mountains (Richmond, 1952), near the southeastern margin of the state, in the Deep Creek, Stansbury, and Oquirrh Mountains in the western part, and in the Bear River Range, east of Cache Valley in the northern part of the state.

The oldest moraines are represented merely by large, scattered, deeply-weathered residual erratic blocks, stranded high on valley walls and ridge spurs. Other moraines, intermediate in age, retain something of their original topographic form, though deeply trenched by trunk streams and considerably gullied by erosion. In these moraines visible boulders are scarce, and weathering has proceeded to depths of several feet. Where granite boulders are embedded in these intermediate moraines, they are generally deeply stained and discolored in the weathered zone; many of the smaller cobbles of granite are so completely decomposed that they can be readily crushed in the hand. On the other hand, visible boulders are very abundant in the younger moraines, and little weathering or topographic modification of their original morainal form is evident.

The moraines and their associated gravel terraces and outwash deposits freely absorb snow meltwater and direct precipitation in the form of rain, and, thus, provide underground reservoirs that feed springs and seepages, and also serve as recharge areas for ground-water aquifers. The combined moraines locally have a thickness in excess of one thousand feet.

Talus and Landslide Debris: Coarse talus blocks mantle most of the higher crestal ridges and summits above timber line on the loftier mountains and plateaus, and steep talus cones flank the bases of the cirque walls in glaciated areas. In fact, the cirques at lower elevations that were occupied by ice only during the earlier and more intensive glacial stages have a greatly softened and subdued form because the rising mantle of talus has largely buried the cliffy basin walls.

Certain quartzite formations in Utah seem to promote the development of talus streams, cones, and even a general talus mantle; notable in this connection are the Precambrian and Cambrian quartzites and similar rocks in the Weber and Oquirrh formations of Pennsylvanian age.

Landslides are frequently associated with the bold fault scarps of the Great Basin section of the state and also with the steep erosional escarpments on the sandstones of the plateau country. Examples of the former are mentioned by Eardley (1932) and also by Thomas (1946a); the latter, in describing landslide breccias of considerable extent along the west face of the Kolob Plateau south of Cedar City, says in part:

The most prominent landslide in the region is about 2 miles south of Cedar City, where an area about 2 miles long and as much as half a mile wide is covered by a breccia consisting chiefly of blocks and rubble derived from the Cretaceous sandstone that caps the plateau farther east... The breccia, which has been deposited upon strata of Triassic and Jurassic age, has interrupted the drainage of one of the smaller streams, so that a small pond, Green Lake, is formed about 2,000 feet above the base of the plateau.

Just as certain formations favor the development of talus, as previously mentioned, others are especially susceptible to landslide action. The thick, coarse, red Echo Canyon (formerly Almy) conglomerate of probable Late Cretaceous age (Williams and Madsen, 1959) gives rise to conspicuous landslide topography in Echo Canyon and along the west margin of the Echo Reservoir on Weber River in Summit County, and the Cretaceous sandstones in the plateau country collapse by sapping of the soft shales below them. The topographic freshness of most of these landslide masses suggests that they are of late Quaternary age.

Fanglomerates and Mudrock Flows: Throughout much of Tertiary time and much of the Quaternary, including the present, the desert basins in western Utah and their piedmont margins have been the site of accumulation of a considerable thickness of so-called "alluvium" or "valley fill," which consists mainly of coarse to fine debris that has been eroded from neighboring highlands and deposited by streams as alluvial cones and fans, which, by confluence from parallel ravines along mountain and plateau fronts, form gently sloping "bajadas" or alluvial piedmont plains. A minor amount of the finest material accumulates in the lowest parts of the basins as playa deposits of ephemeral lakes; and when larger and more permanent bodies of water occupied the basins, some of the alluvium of the piedmont areas was reworked and redeposited by waves and currents. As revealed in abundant well logs, the "valley fill" of the basins largely consists of such alluvial deposits alternating with lake silts and clays.

The "fanglomerates," as the alluvial fan deposits are commonly called, display a notable lack of sorting in a size of material with the coarse boulders and gravel in channels and at the apices of the fans and finer material towards their margins. On this point, Thomas (1946a) comments as follows:

Deposition of these alluvial materials is highly irregular, however, for coarse detritus may be transported several miles down the slopes of the fan by a stream at flood stage, and silt and clay may be left near the apex during the decline from the flood stage. Because of continual changes in stream-carrying power as well as in the positions of stream channels, the alluvial gravel, sand, and silt are characteristically deposited in continuous lenticular beds of variable thickness and areal extent.

The nature and structure of these fanglomerates is of the utmost importance in the utilization of ground-water supplies that occur within them. The intensive study given to these deposits in recent years will yield sufficient data on their nature and structure to greatly reduce the hazard of sinking "dry holes" in the search for water.

The large number of huge boulders (Utah Governor's Comm. Rept. 1931) incorporated in the fanglomerates, both ancient and recent, indicate that torrential "cloud-burst" storms have contributed "mudrock flow" debris to the alluvial fan deposits. That such torrential deposits, with their attendant large boulders, were of common occurrence in Pleistocene times, as well as during the relatively short period of human occupation of the region, is aptly demonstrated by a recent exposure along the west base of the Wasatch Mountains in Salt Lake County opposite Neffs Canyon in a deep trench excavated for the Salt Lake Aqueduct. Here 40 feet of pre-Provo stage "Alpine" (Hunt, Varnes, and Thomas, 1953) lake beds are underlain by a coarse fanglomerate, whose upper portion contains many Cambrian and Precambrian quartzite boulders several feet in diameter (one measured 9 feet 6 inches in longest dimension) that occur out on the piedmont, nearly a mile from the mouth of the steep ravine that was their source. Similar "mudrock flow" deposits with huge boulders have been encountered beneath lake gravels and sands in several gravel pits in the vicinity. Directly overlying the lake beds in the same Neffs Canyon locality are younger "post-lake" tongue-like "mudrock flows" containing abundant and even larger boulders. These torrential deposits are partially buried in soil of both aeolian and slope-wash origin; thus, the Pleistocene lake beds are bracketed by "mudrock flows," all older than the brief period of human occupation. At the mouth of a steep ravine on the northwest slope of Mt. Olympus, in the same locality, the uppermost shoreline of the ancient Pleistocene Lake Bonneville lies buried and concealed by the ridge-like apex of a bouldery fan, whose most recent "mudrock flow," although pre-occupation in age, is so young that no soil whatever covers the mass of huge, largely angular quartzite blocks. Although fire, de-forestation, overgrazing, and similar impairment of the plant cover resulting from human occupation has unquestionably aggravated the situation so that now a storm of lesser magnitude will produce destructive "mudrock flows" in such denuded areas, the abundant evidence at Neffs Canyon and elsewhere (Crawford and Thackwell, 1931) would indicate that Pleistocene "mudrock flows" occurring beneath Lake Bonneville deposits must be attributed to causes unrelated to human occupation of the region.

In the southern Wasatch Mountains, Eardley (1932) describes a Pleistocene fanglomerate, referred to as the Salt Creek formation, which he describes in part as follows:

The Salt Creek formation is composed of a mixture of large and small angular rock fragments, rudely sorted, with a matrix of red earthy material. Cementation is usually poor. Stratification is rough and channeled. In most places the formation is a fanglomerate... (which) rests on an old, mature, valley floor which has since been incised to a depth of about two

hundred feet where the fanglomerate occurs. The rejuvenation is due to block-faulting of Basin and Range age, which has lowered the base of deposition of Salt Creek.

So far as is known to the writer, this is one of the first examples of the application of stratigraphic principles and terminology to the Quaternary alluvial deposits of Utah.

Fanglomerates of pre-Bonneville age are also described by Bissell (1948, unpublished thesis), Hunt, Varnes, and Thomas (1953), Maxey (1946), Thomas (1946, 1948), and others; and well logs in piedmont areas reveal their general presence to considerable depths, interbedded with lake sediments.

River Terrace Gravels: River terrace and flood-plain gravels, although widespread and conspicuous, have been largely neglected in spite of their significance in connection with Pleistocene and recent physiographic history. Most of the major stream channels in the Middle Rocky Mountain province in Utah and many in both the Great Basin and Colorado Plateau are bordered by one or more river terraces. In some instances, these terraces constitute merely a thin gravel capping on a planed bedrock surface, but in others, especially in those drainages with thick, bouldery valley trains of "glacio-fluvio" origin, the terraces are developed wholly in such deep valley fill. With the advent of air-photo coverage and better maps, it is expected that these important deposits will soon receive the attention their importance deserves.

Lake Deposits: In western Utah an area about the size of Lake Michigan, or about one-fourth of the total area of the state, was occupied by Pleistocene Lake Bonneville and its predecessors; gravels, sands, silts, and clays deposited in these lakes floor the desert basins and flank the bases of the mountain ranges. In fact, lake deposits are still accumulating in the same region, but greatly restricted in area, in such bodies as Utah Lake and Great Salt Lake, the former studied in considerable detail by Bissell (1948, unpublished thesis), and the latter by Eardley (1938). Since Quaternary lake deposits have received considerable detailed study in the past few years (Bissell, 1948, unpublished thesis; Hunt, Varnes, and Thomas, 1953; Thomas, 1948; and Williams, 1958, the present brief survey of the Quaternary system in Utah will not reiterate these excellent papers. Therefore, only a general statement will be presented.

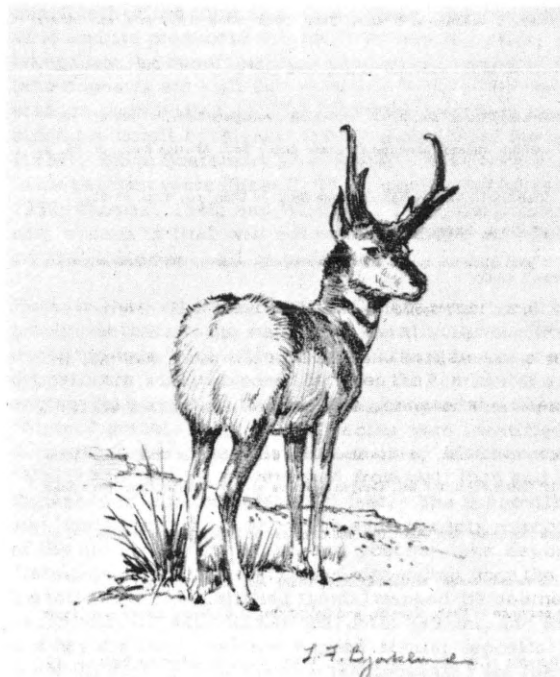
Hunt, in the northern end of Utah County, was the first investigator to apply stratigraphic methods to the mapping of the alluvium mantling the valley floor. He introduced the term "Alpine" formation for the oldest deposits of Lake Bonneville. These deposits are widely exposed between the Bonneville and the Provo shorelines of the ancient lake and also underlie the younger lake deposits beneath the valley floor. "Alpine" gravel, sand, and silt facies were identified and separately mapped. The dominant facies is mostly silt, in thin, distinct, nearly horizontal layers. The "Alpine" formation, as revealed from well logs and surface exposures, attains a thickness of approximately 300 feet. The Bonneville formation is largely gravel and limited to various shoreline embankments associated with the highest terrace of the old lake. The Provo and younger lake deposits are similarly separately distinguished into several facies, depending upon the coarseness of the sediments. Bissell (1948, unpublished thesis) mapped the southern end of Utah County, using essentially the same formational units as Hunt, and Thomas (1948) in Davis County, and has distinguished and mapped similar deposits in the Bountiful area. In the latter district, pre-Bonneville fanglomerates are reached by practically all of the artesian wells in the basin. These fanglomerates may attain a thickness varying

from 700 feet to 1,200 feet and are underlain by beds of the Salt Lake group. Characteristically, the pre-Bonneville deposits are poorly sorted alluvial debris in irregular, discontinuous, and lenticular bodies with occasional interbedded gravel, sand, silt, and clay; the silt and clay thickening appreciably away from the mountain front. Decomposed, peat-like plant material, probably the remains of buried swamps, is generally encountered in the deeper wells and may be the source of the methane gas discharged by these wells. In the western part of the Bountiful area, geologic sections prepared by Thomas from well logs and well samples indicate that the lake bottom sediments (including Alpine, Provo, and younger lake deposits) average about 120 feet in thickness and rest upon pre-Bonneville alluvial deposits that in color and coarser texture and lack of sorting are readily distinguished in well logs.

CITED REFERENCES

- Antevs, Ernst, 1948, The Great Basin, with emphasis on glacial and postglacial times: Univ. of Utah Bull. 38, no. 20, p. 167-191.
- Atwood, W. W., 1909, Glaciation in the Uinta and Wasatch Mountains, Utah: U.S. Geol. Survey Prof. Paper 61.
- Bissell, H. J., 1948, Geology of the Bonneville Basin, southern Utah County: Iowa State Univ., Ph.D. thesis.
- Blackwelder, Eliot, 1928, Mudflow as a geologic agent in semiarid mountains: U.S. Geol. Survey Prof. Paper 257-B.
- _____, 1948, The Great Basin, with emphasis on glacial and post-glacial times: Univ. of Utah Bull. 38, no. 20, p. 3-16.
- Crawford, A. L., and Thackwell, F. E., 1931, Some aspects of the mudflows north of Salt Lake City, Utah: Utah Acad. Sci., Arts, and Letters Proc., v. 8.
- Eardley, A. J., 1932, Stratigraphy of the southern Wasatch Mountains, Utah: Mich. Acad. Sci., Arts, and Letters Papers, v. 18 (1933).
- _____, 1936, Oil and gas possibilities of the Great Salt Lake Basin: Utah Acad. Sci., Arts, and Letters Proc., v. 3.
- _____, 1938, Sediments of Great Salt Lake, Utah: Am. Assoc. Petroleum Geologists Bull., v. 22, no. 10.
- _____, 1944, Geology of the north-central Wasatch Mountains, Utah: Geol. Soc. America Bull., v. 55, p. 819-894.
- _____, 1952, Wasatch hinterland: Utah Geol. Soc. Guidebook to the Geol. of Utah, no. 8, p. 52-60.
- Gilbert, G. K., 1890, Lake Bonneville: U.S. Geol. Survey Mon. 1.
- Hansen, G. H., 1934, An interpretation of past climatic cycles from observations made of Utah Lake sediments: Utah Acad. Sci., Arts, and Letters Proc., v. 11.
- Hunt, C. B., Varnes, H. D., and Thomas, H. E., 1953, Geology of northern Utah Valley, Utah: Lake Bonneville, U.S. Geol. Survey Prof. Paper 257 (1953).
- Leggette, R. M., and Taylor, G. H., 1937, Geology and ground water resources of Ogden Valley, Utah: U.S. Geol. Survey Water-Supply Paper 796-D.
- Marsell, R. E., 1931, Salient geologic features of the Traverse Mountains, Utah: Utah Acad. Sci., Arts, and Letters Proc., v. 8.
- _____, 1932, Geology of the Jordan Narrows region, Traverse Mountains, Utah: Univ. of Utah, M.S. thesis.
- _____, 1946, Relations of the Little Cottonwood and Bell Canyon glaciers to Lake Bonneville: Utah Acad. Sci., Arts, and Letters, Proc., v. 23.
- _____, 1953, Geology of the Wasatch front near Salt Lake City: The Compass of Sigma Gamma Epsilon, v. 31, no. 1, p. 2-22.
- Maxey, G. B., 1946, Geology of part of the Pavant Range, Millard County, Utah: Am. Jour. Sci., v. 244.
- Nolan, T. B., 1943, The Basin and Range province in Utah, Nevada, and California: U.S. Geol. Survey Prof. Paper 197-D.
- Richmond, G. M., 1952, Quaternary stratigraphy of the La Sal Mountains, Utah: Geol. Soc. America Bull., v. 63, no. 12, pt. 2, 1368.

- _____ in press, Cenozoic stratigraphy of the La Sal Mountains, Utah: U.S. Geol. Survey Prof. Paper 324.
- Thomas, H. E., 1945, The Ogden Valley artesian reservoirs, Weber County, Utah: Utah State Eng. Tech. Pub. 2.
- _____ 1946a, Geology and ground-water resources of Cedar City and Parowan Valleys, Iron County, Utah: U.S. Geol. Survey Water-Supply Paper 993.
- _____ 1946b, Ground water in Pavant Valley, Millard County, Utah: Utah State Eng. Tech. Pub. 3.
- _____ 1946c, Ground water in Tooele Valley, Tooele County, Utah: Utah State Eng. Tech. Pub. 4.
- _____ 1948, Ground water in the east shore area, Bountiful district, Davis County, Utah: Utah State Eng. Tech. Pub. 5.
- Williams, J. S., 1958, Geologic Atlas of Utah--Cache County: Utah Geol. and Mineralog. Survey Bull. 64.
- Williams, N. C., and Madsen, J. H., Jr., 1959, Late Cretaceous stratigraphy of the Coalville area, Utah: Inter-mountain Assoc. Petroleum Geologist Guidebook 10th Ann. Field Conf., p. 122-125.
- Wooley, R. R., 1946, Cloudburst floods in Utah: U.S. Geol. Survey Water-Supply Paper 994.
- Wooley, R. R., and Marsell, R. E., 1946, Great Salt Lake: Am. Geophys. Union Trans., v. 27, no. 1.



Paper 15 IGNEOUS ROCKS OF UTAH

by Paul Dean Proctor¹ and Kenneth Bullock²

INTRUSIVE ROCKS

Distribution

Intrusive igneous rocks, widely distributed throughout western Utah, are present in three localities in the southwestern part of the state (Figure 50). The intrusives lie in belts or clusters, and the masses in the individual group commonly show genetic relationships. One includes the Mineral Mountain, Bull Valley, Hard-scrabble Hollow, Big Mountain, Iron Mountain, Granite Mountain, and Three Peaks intrusives in Washington and Iron Counties. Another lies just to the east and includes the Pine Valley and Stoddard Mountain igneous masses. A third belt includes the Frisco, Beaver Lake, Rocky, Starr, Mineral Range, Tushar, Monzonite Hill, Central, and Sevier Plateau intrusives, and the somewhat isolated Notch Peak and Crystal Peak intrusives to the north in western Millard County.

A fourth major belt includes the Ibapah, Gold Hill, Granite Range, Drum, Desert Mountain, Sheeprock, West Tintic, Sunrise Peak, and Silver City stocks. A fifth belt includes the Mercur, Bingham, Little Cottonwood, Alta, Clayton Peak, and Park City bodies. Finally, a northeasterly trending intrusive belt in northwestern Utah includes the Pilot, Silver Island, Newfoundland, Grouse Creek, and Raft River stocks.

In the southeastern part of the state, as exemplified by the Henry, Abajo, and La Sal Mountains, the intrusives are grouped in clusters rather than elongated belts.

Structural Relations of Intrusive Rocks

The intrusives of the state are considered to have invaded other rocks by one or a combination of three mechanisms: by (1) assimilation of the rocks they invade; (2) forcing the country rocks bodily upward and aside; (3) recrystallization of pre-existing rocks.

The geological relationships of the largest intrusives suggest that all three mechanisms have operated but possibly the dominant mode has been accomplished by displacement of the country rocks. The principal types, formed largely by displacement, are intrusive arches or domes, laccoliths, bysmaliths, stocks, cupolas, dikes, and sills. No batholiths are exposed.

Sedimentary rocks overlying laccolithic bodies are raised as a dome over the thicker portion of the lens-like intrusives, and, in general, dip quaquaversally away from the intrusives. Some laccoliths in the Henry Mountains are surrounded by exceptionally steeply-dipping sedimentary rocks, suggesting upfaulted laccoliths or bysmaliths. Other domal structures, such as Navajo Mountain and possibly the San Rafael Swell, suggest the presence of unexposed intrusive bodies.

1. Chairman, Dept. of Geology, Missouri School of Mines, Rolla, Missouri.

2. Chairman, Dept. of Geology, Brigham Young Univ., Provo, Utah.

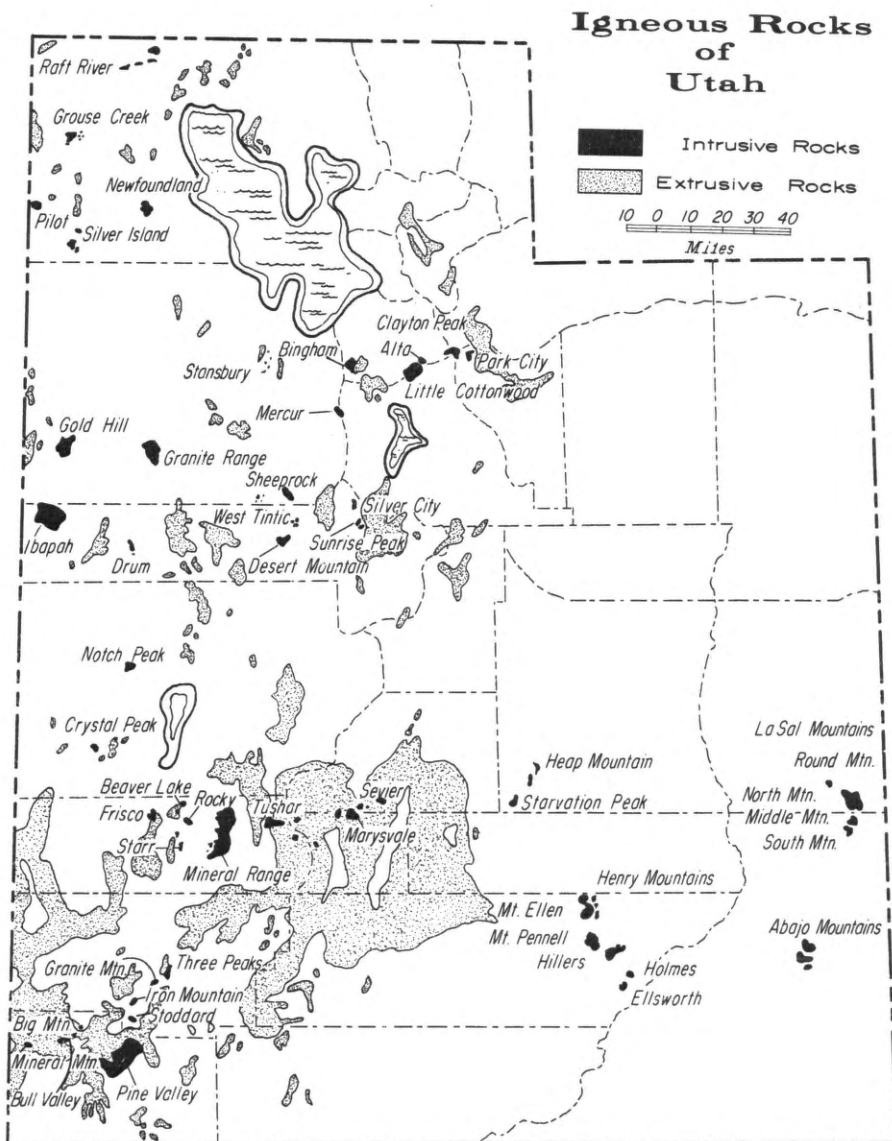


Figure 50. Index Map

Laccoliths, best developed in southeastern Utah, are exposed in the Henry, Abajo (Blue), and La Sal Mountains. Bysmaliths, sheets, and dikes also are present. Intruded into Triassic to Cretaceous sedimentary rocks, they range from a few feet to hundreds of feet in thickness. Stocks occur in the center of the structural domes associated with the Henry and La Sal Mountains (Hunt, 1953, 1958); laccoliths and bysmaliths are nested around them. Future studies may indicate a stock in the Abajo Mountains.

Dikes, sills, and cupolas are present in many localities. Some of the largest sills are represented by Heaps Mountain and Starvation Peak in southwestern Emery County (Figure 50).

Stocks are distinctly cross-cutting bodies, and doming cannot account for all the rock displaced. In the Tintic and Park City districts, cross-cutting masses possibly have forced blocks of earlier rocks bodily before the intruding mass (Butler, and others, 1920). There is also evidence that stocks have made room for themselves by stoping and assimilation, and in part by granitization. Stringham (1953) has shown that granitization has played a part in the development of the Bingham stock. Other stocks in western Utah show similar features, such as Mineral Range (Condie, 1960).

Major intrusives of the western part of the state are regarded as intrusive arches or domes, stocks, or plug domes. Wells (1938) suggested both stocks and plugs are present in the Bull Valley district. Blank's (1959) detailed study of the Bull Valley, Hardscrabble Hollow, and Big Mountain intrusives indicated they are stocks and intrusive domes. In the Iron Springs district, Leith and Harder (1908) suggested the intrusives were laccoliths, but Butler (1920) questioned the presence of laccoliths and regarded them as stocks. Mackin (1954, 1960) interpreted the Stoddard Mountain, Iron Mountain, Granite Mountain, and Three Peaks masses in the Iron Springs district as intrusive arches or domes. Cook (1952) interpreted the Pine Valley Mountains as a laccolith that has arched or domed the overlying rocks. This forms the largest intrusive body in Utah.

The intrusives of Washington and Iron Counties invade various stratigraphic horizons. The intrusive masses of the Bull Valley and Iron Springs districts probably intrude between the Navajo sandstone and the Jurassic Homestake (Carmel) limestone; the Stoddard Mountain mass between the Cretaceous Iron Springs and Eocene (?) Claron formations; the Pine Valley igneous body between the Claron and the overlying volcanic igneous rocks.

Crystal Peak in Millard County is regarded as a plug dome (Dunn, 1958). Most all other intrusive masses of western Utah are interpreted as stocks.

The stocks of western Utah invade rocks from Precambrian to Tertiary in age. Some intrude nearly all formations lying between these ages. Thus, the stocks of the Cottonwood-Park City region intrude Precambrian to Triassic rocks; those of the San Francisco and adjacent regions intrude Cambrian to Triassic rocks. The largest stocks are generally associated with the older rocks. This is true of the Little Cottonwood and Granite Range stocks, which are intruded into Cambrian and Precambrian rocks. The Ibapah stock of Deep Creek Range intrudes rock from the Precambrian into the Carboniferous (Nolan, 1935). A large stock in the Mineral Range, however, cuts Carboniferous and possibly Lower Triassic rocks.

Composition of Intrusive Rocks

The texture of the major intrusives of southwestern and southeastern Utah is porphyritic. In some the groundmass is fine; in the larger bodies it is coarsely crystalline, even granitoid. The laccolithic bodies are primarily diorite porphyries, whereas the intrusive domes and arches are primarily quartz monzonite porphyries. (See Table VIII).

The stocks of western and northwestern Utah, even within many individual intrusives, range from granitoid to porphyritic. The large stocks of Ibapah, Little Cottonwood, and Granite Range are characterized by large feldspar phenocrysts. The smaller bodies, and those intruded nearest the surface, tend to be porphyritic, the larger and deeper seated to have a granitoid texture. Primarily intermediate in composition, they range from granite, quartz monzonite, granodiorite through quartz diorite, and from syenite, monzonite through diorite.

EXTRUSIVE ROCKS

General Distribution

In Utah these rocks are absent in most of the Colorado Plateau. Most prominently exposed near its western edge, their most extensive distribution is in the Marysvale region in the south-central part of the state. Here they cover several thousand square miles within which erosional and fault-block windows of Cenozoic, Mesozoic, and Paleozoic rocks crop out locally.

Extensive disconnected outcrops occur in the Basin and Ranges where local accumulations of volcanic flows and pyroclastics may approach 10,000 feet. A broad area outcrops west of Cedar City; others crop out south of Hurricane, extend north and west to Leeds, thence west as an almost solid outcrop-area to the state line. In the Escalante Desert area, east of Modena, alluvium covers extensive areas of extrusive igneous rocks similar to those exposed near the town and northward. Smaller areas occur near Frisco, Gold Hill, in the Fish Springs Range, in the Thomas, Drum, and Cedar Mountains, in the Tintic district near Eureka, near Nephi in the Traverse Mountains north of Provo, and east and north of Park City.

In the northwestern part of the state prominent accumulations are reported in the Pilot Mountains, south of the Raft River Mountains, and near the northern shores of Great Salt Lake at Monument and southwest of Rozel. The index map (Figure 50) shows their general distribution. Other small areas crop out as isolated masses around the margins of the Great Salt Lake Desert. Butler (1920) suggests that the northern part of the state may once have been largely covered by volcanic rocks which have since been partly removed by erosion, or that younger sediments may cover extensive masses.

Age determinations range from Eocene to Recent. Absolute age determinations, from 19 million to 49 million years, suggest that volcanism was active during most epochs of the Tertiary period.

Origin, Composition, and Character of Extrusive Rocks

Extrusive materials arrived at the surface in one or more of three possible ways. (1) The molten lava and/or fragmental materials were extruded and/or ejected from a central feeding neck, such as a volcano. This, in its broadest sense, includes

part of the nuee ardente type of eruption. (2) The lava issued through fissures, appearing as separate flows, or coalescing from various fissure sources to form large flow areas. Fissures may also have acted as channelways for nuee ardente eruptions on a much grander scale than has heretofore been considered. The former origin would be similar to that attributed to many of the Columbia River basalt flows of the northwestern United States. The latter may be a source of many of the widespread ignimbrites of the western part of the state. (3) A combination of central and fissure eruptions, with their variations. Varieties of these extrusive processes are recognized and some eruption centers have been outlined by recent, detailed work.

The volcanic rocks include rhyolites, trachytes, minor phonolites, quartz latites, latites, dacites, andesites, basalts, nepheline basalts, volcanic glasses, abundant andesitic-latic pyroclastics, and ignimbrites of rhyolitic to latitic composition. Those of intermediate composition are the most abundant. Basalts, less abundant, generally are associated with younger eruptions. Recent central eruption flows occur near Fillmore, west of Hurricane, east on the Colorado Plateau in local areas, northward in the Great Basin, and northwest of St. George.

A large portion is of fragmental texture, though abundant lava flows are present. Tuff breccias and ignimbrites, especially characteristic of the southern part of the state, commonly occur near the base of the extrusive series. Results of recent field work in the Marysvale and Iron Springs-Pine Valley-Bull Valley areas suggest the presence of greater quantities of ignimbrites than have heretofore been recognized. These are proving to be valuable key horizons in unraveling volcanic sequences in western Utah and elsewhere in the Great Basin.

Extrusive Rocks of Specific Areas

Discussed from south to north a brief summary is presented of the important volcanic areas.

Cedar City area: Leith and Harder (1908) described a relatively thick section in the Iron Springs area that ranges from trachyte to andesite, and varies from felsitic to porphyritic with included fragmental types. An aggregate of 1,700 to 2,500 feet is given. The lower part was spread over an essentially flat surface of Claron fluvial and lacustrine deposits. A late Miocene age is suggested.

Mackin (1954, 1960), Mackin, et al., (1954), and Cook (1953) added details to this area. Rocks formerly described as flows are now considered ignimbrites, although interbedded lavas and explosive breccias are still recognized. These workers suggested use of the widespread ignimbrites for regional correlation of volcanic sequences.

Near the Pine Valley Mountain, Cook (1957) indicated a similar sequence possibly exceeding 6,000 feet. Deposition was believed to have followed the Eocene (?) Claron formation. Several unconformities are present. He identified an earlier volcanic group, separated by an erosional unconformity from later Tertiary sequences. Younger basalt flows lie unconformably on the latter.

A few miles to the west, Wells (1938) recorded "several thousand feet of lavas and tuffs that range in composition from basalts to rhyolite." An older group, largely flows, and a distinctly younger group, mainly rudely stratified pyroclastics capped by rhyolitic tuffs and flows, were also described. Younger basalts overlie the latter. Numerous ignimbrites have since been recognized by Blank (1959).

Mackin (1960) dated the early volcanism as "certainly Eocene or Oligocene." The earliest units in the Pine Valley Mountains and Bull Valley area may be correlative.

TABLE VIII. COMPOSITION OF INTRUSIVE IGNEOUS ROCKS OF UTAH

INTRUSION	COMPOSITION	COUNTY	AUTHOR
La Sal Mountains:			
Round Mountain	Diorite Porphyry	Grand	Hunt, 1958
North Mountain	" "	Grand and San Juan	" "
Middle Mountain	" "	San Juan	" "
South Mountain	" "	" "	" "
Abajo Mountains:			
North and Horsehead Peaks	Porphyritic Hornblende Latite	San Juan	Gregory, 1938
Mt. Linnaeus and South Peaks	" "	" "	" "
Johnson Creek	" "	" "	" "
Henry Mountains:			
Mt. Ellen	Diorite Porphyry	Garfield and Emery	Hunt, 1953
Mt. Pennell	" "	Garfield	" "
Mt. Hilliers	" "	" "	" "
Mt. Holmes	" "	" "	" "
Mt. Ellsworth	" "	" "	" "
Heap Mountain	Diabase and Syenite	Emery	Gilluly, 1927
Starvation Point	" "	" "	" "
Mineral Mountain	Granite Porphyry	Washington	Bullock, this report
Bull Valley	Quartz Monzonite Porphyry	" "	Blank, 1959
Hardscrabble Hollow	" "	" "	" "
Big Mountain	" "	" "	" "
Pine Valley Mountain	" "	" "	Cook, 1957
Stoddard Mountain	Quartz Monzonite Porphyry	Iron	Mackin, '47, '54, '60
Iron Mountain	" "	" "	" "
Granite Mountain	" "	" "	" "
Three Peaks	" "	" "	" "
San Francisco Mountains	Quartz Monzonite	Beaver	Butler, 1913
Beaver Lake Mountains	" "	" "	Barosh, 1959
Star Range	" "	" "	Butler, 1913
Rocky Range	Granodiorite Porphyry	" "	" "
Mineral Mountain	Quartz Monzonite	" "	Condie, 1960
Tushar Mountains	" "	Beaver and Piute	Callaghan, 1939
Marysville area:			
Monzonite Hill	Quartz Monzonite	Sevier and Piute	Kerr, 1957
Central	" "	" "	" "
Sevier Plateau	" "	Sevier	Callaghan, 1939
Crystal Peak	Rhyolite	Millard	Dunn, 1958
Notch Peak	Quartz Monzonite	" "	Gehman, 1958
Ibapah	Granodiorite	Juab	Bick, 1958
Drum Mountains	Granite	" "	Davis, 1959
Desert Mountain	" "	" "	Butler, 1920
West Tintic	Monzonite and Granite	" "	Groff, 1959
Sunrise Peak	Monzonite Porphyry	" "	Lindgren, 1919
Silver City	Monzonite	" "	" "
Gold Hill	Quartz Monzonite	Tooele	Nolan, 1935
Granite Range	Granite	" "	Butler, 1920
Simpson Mountains	Granodiorite and Monzonite	" "	Thomas, 1958
Sheeprock Mountains	Granite	" "	Cohenour, 1959
Stansbury Mountains	Andesite and Diabase	" "	Davis, 1959
Mercur	Monzonite	Tooele and Utah	Gilluly, 1932
Bingham	Granite	Salt Lake	Stringham, 1953
Little Cottonwood	Quartz Monzonite	Salt Lake and Utah	Calkins, 1943
Alta	Granodiorite	Salt Lake	" "
Clayton Peak	Diorite	Salt Lake, Wasatch	" "
Park City	Quartz Diorite Porphyry	Wasatch	Boutwell, 1912
Pilot Range	Granite	Box Elder	Butler, 1920
Silver Island Range	Quartz Monzonite	" "	Anderson, 1957
Newfoundland Mountains	" "	" "	Paddock, 1956
Grouse Creek Mountains	" "	" "	Baker, 1959
Raft River Mountains	Granite	" "	Felix, 1956

Absolute ages by lead-alpha age determinations (Jaffe, et al., 1959) of pre-intrusive Leach Canyon tuff yielded 28 million years, the Three Peaks intrusives 22 million years, and a post-intrusive white tuff (Kane Point) 19 million years. These considerably post-date the earliest volcanism in the area. The youngest volcanism extends into recent time. Practically uneroded volcanic cones are well developed near Veyo to the south. Tables IX and X show portions of Mackin's correlative section (1960, p. 90). More absolute age datings are needed.

Marvysvale area: Butler and Gale (1912), Callaghan (1938, 1939), Kerr, et al., (1957) and Callaghan and Parker (1961) and Willard and Callaghan (1962), described at least three periods of volcanism that have been dated as early to middle Tertiary, late (?) Tertiary, and late Pliocene or early Pleistocene. Distinct erosional surfaces separate them. The cumulative thickness approaches 9,000 feet, but each group shows a considerable range in thickness. Greatest continuity of individual beds is expressed by pyroxene andesites and biotite latites. The rocks range from rhyolites to basalts, from glasses to tuff breccia and agglomerates. Ignimbrites will undoubtedly be recognized as important units as detailed studies continue.

The early to middle Tertiary Bullion Canyon series approximates 4,000 feet in thickness (Kerr, et al., p. 1957). These lie on folded, deeply eroded pre-Tertiary rocks, and on Wasatch (?) formation. Latite flows, agglomerates, hornblende and pyroxene andesites, tuffs, and ignimbrites comprise this series. They are warped, faulted, intruded, and deeply eroded.

The earliest Bullion Canyon volcanics were apparently deposited before Green River (middle Eocene) time was completed (Lautenschlager, 1954). This corresponds to age data from the Tintic district. Mackin (1960, p. 102) tentatively suggests that the Needle Range formation is equivalent to part of Callaghan's Bullion Canyon group and the Isom formation is part of the Dry Hollow latite. Absolute age dating by Bassett and Kerr (1960) suggested a much younger age (28 million years) for at least part of the Bullion Canyon series. More work is needed to resolve this problem.

A cumulative thickness of approximately 4,670 feet of latites, glasses, rhyolites, and tuffs, termed the Mt. Belknap series, was deposited upon the eroded surface of the older igneous rocks. These, too, have been warped, faulted, and eroded. (Absolute age dating by Bassett and Kerr (1960) yields a cluster about 15-19 million years, or late Miocene in age). Mackin (1960, p. 98), through the work of Blank, reported similar lithology and position in the section for rocks equivalent, in part, to the Page Ranch formation. An absolute age determination of the Kane Point tuff member of this formation yields 19 million years.

The youngest igneous rocks include tuffs and basalt flows deposited on the Sevier River formation of late Pliocene (?) age. Table X summarizes the known sequence of volcanic rocks in this and two other well-studied areas of Utah.

Tintic district: Lindgren and Loughlin (1919), Lovering, et al., (1949), Proctor (1951, 1956), and Morris (1957) studied an extensive sequence of flows and pyroclastics. Separated by erosion surfaces, three periods of volcanic activity are noted: (1) probable pre-mid-Eocene, (2) mid-Eocene, and (3) post-mid-Eocene, pre-Bonneville. Part of this dating is based on Muessig's (1951) discovery of plant fossils in marly limestone of mid-Eocene Green River formation, interbedded in agglomerates similar to those in the Tintic district. Absolute age determinations by Jaffe, et al., (1959) of intrusive rocks in the district yield ages of 39 to 43 million years (depending on mesh size of zircon) for a stock in East Tintic and 49 to 50 million years for the Silver City stock. The stocks are related to known volcanic rocks in the district. Elsewhere, igneous rocks dated by the Green River

Table IX. Generalized Volcanic Rock Sequence Pine Valley Mountains, Utah. (Modified after Cook, 1957.)

SYSTEM	SERIES	FORMATION		LITHOLOGY		THICKNESS		
Quaternary	Recent	Alluvium		Sand, silt, gravel		0-200		
		Unconf.						
	Pleistocene	High level gravel		Coarse, poorly sorted gravels		0-200		
		Basalt		Basalt		0-200		
	Pleistocene (?)	Unconf.						
		Parunuweap (?) formation		Silt, sand, fine gravel, locally cemented		0-200		
	Pliocene (?)	Eight Mile dacite	Culbert breccia	Porphyritic hornblende dactite	Mudflow breccia	500	0-150	
		Unconf.						
	Tertiary		Pine Valley latite		Augite-biotite latite porphyry with well developed platy parting. Intrus. ? Basal glass 10-150 ft. thick		2000±	
			Unconf.					
Page Ranch formation			Crystal biotite-dacite ignimbrite on bedded tuff-breccia		0-600			
Unconf.								
Atchinson formation			Rudely bedded breccia overlying augite andesite flows and breccia. Tuff breccia locally at base		0-500			
Unconf.								
Grass Valley formation			Vitric-crystal rhyolite ignimbrite, foliated		0-500			
			Vitric-crystal rhyolite ignimbrite with lithic fragments		0-700			
			Augite andesite lava, amygdaloidal		0-50			
Unconf.			Lacustrine limestone		0-100			
Quichapa Group		or thrust						
		Rencher formation		Latite breccia top, air-fall tuff, volcanic sandstone, dacite porphyry breccia, biotite ignimbrite, crystal-vitric dacite ignimbrite containing quartzite pebbles, basal conglomerate, limestone		0-600		
		Unconf.						
		Tv-3		Crystal biotite dacite ignimbrite		0-550		
		Tv-2		Vitric rhyolite ignimbrite, foliated		0-180		
		Tv-1		Crystal vitric rhyolite ignimbrite with lithic fragments		0-800		
	Disconf.							
	Eocene	Claron formation	Lacustrine limestone, biotite tuff near top; near base a black ls. pebb. conglomerate.		0-1000			
Calcareous sandstone and sandy limestone								
Quartzite cobble conglomerate and sandstone								

163

*N.S. Not Stated
**Ignimbrite or includes ignimbrites

TABLE XI. LEAD-ALPHA AGE DETERMINATIONS OF IGNEOUS ROCKS OF UTAH*

Sample Number	Rocky Type Locality	Accessory Mineral	Lead-Alpha Age in Millions of Years	Cited Geologic Age of the Rock
14	Granite, Sheep Rock Range, SW1/4 Sec. 22, T-10-S, R-6-W, Tooele Co.	Zircon Monazite	20 15	No published data. T. S. Lovering.
15	Rhyolitic welded tuff, W. side of Thomas Range, Juab County	Zircon	20	No published data. Tertiary (?) W. J. Carr.
16	White tuff, post-intrusive volcanics, Iron Springs district	Zircon	19	Middle Tertiary (Oligocene?) J. H. Mackin. Miocene, Gregory, 1945.
17	Three Peaks intrusive, Iron Springs district	Zircon	22	Same as above.
18	Lower tuff, pre-intrusive volcanic rocks, Iron Springs district	Zircon	28	Middle Tertiary (Oligocene?) J. H. Mackin. Miocene, Gregory, 1945.
19	Syenite porphyry, W. shoulder of Mineral Mountain, LaSal Mountains	Zircon	25	Tertiary, Hunt, 1956; p. 42. Waters, 1955.
20	Monzonite porphyry, S. edge of intrusive, W. central part of North Mountain, La Sal Mtns.	Zircon	55 51	Same as above
21	Diorite porphyry, Middle Mountain La Sal Mountains	Zircon	386	Same as above
22	Diorite porphyry, S. side of Miner's Basin, North Mountain, La Sal Mountains	Zircon	490	Same as above
23	Diorite porphyry, N.W. end of North Mountain, La Sal Mtns.	Zircon	419	Same as above.
38	Porphyritic quartz monzonite, Little Cottonwood stock, Temple granite quarry, Wasatch Mountains	Zircon	46	No published data. M. Crittenden.
39	Diorite, Clayton Peak stock, head of Big Cottonwood Canyon Wasatch Mountains	Thorite Zircon	40 48	Same as above.
40	Granodiorite, Alta stock, head of Big Cottonwood Canyon, Wasatch Mountains	Zircon	54	Same as above.
42	Quartz monzonite, North Lily stock, East Tintic district	Zircon	43	Middle Eocene (Green River). Brown and Pecora, 1949.
43	Quartz monzonite, Silver City stock, Tintic district	Zircon	49 50	Same as above.

*Modified table from data by Jaffe, Howard W., and others, 1959, Lead-alpha age determinations of accessory minerals of igneous rock (1953-1957): U.S. Geol. Survey Bulletin, 1097-B, p. 71-73, 75-76.

Table XII. Age Relationships of Cenozoic Igneous Rocks of Utah.

Locality	Type	Source	Eocene	Oligocene	Miocene	Pliocene	Pleisto.
		<i>Kulp J.L. 1960</i>	<i>59 m.y.</i>	<i>36 m.y.</i>	<i>25 m.y.</i>	<i>12 m.y.</i>	<i>1 m.y.</i>
<i>Colorado Plateau</i>	<i>Intrusive</i>	Jaffe 1959	■		■		
<i>Rozel Hills</i>	<i>Volcanics</i>	Stentz & Eardley '56				▨	
<i>Raft River</i>	<i>Volcanics</i>	Felix 1956				▨	▨
<i>Goose Creek</i>	<i>Volcanics</i>	Mapel & Hail 1956				▨	
<i>Thomas Range</i>	<i>Volcanics</i>	Jaffe 1959			■		
<i>Gold Hill</i>	<i>Volcanics</i>	Nolan 1935				▨	
<i>Park City - Wasatch</i>	<i>Volcanics</i>	Butler '20 Eardley '52		▨			
	<i>Intrusive</i>	Williams '54 Jaffe '59	■ ■ ■ ■				
<i>Stockton - Fairfield</i>	<i>Volcanics</i>	Gilluly 1952		▨			
<i>Tintic</i>	<i>Volcanics</i>	Morris 1957	▨			▨	
	<i>Intrusive</i>	Jaffe et al 1959	■ ■ ■				
<i>Marysvale</i>	<i>Volcanics</i>	Lautenschlager '54		■			
	<i>Intrusive</i>	Callaghan '39	▨				▨
		Bassett et al '60			■		
<i>Iron Springs</i>	<i>Volcanics</i>	Mackin '60 Jaffe '60	▨	▨	■		
	<i>Intrusive</i>	Jaffe			■		
<i>Pine Valley</i>	<i>Volcanics</i>	Mackin '60 Jaffe '60		▨	▨	▨	▨
	<i>Intrusive</i>	Cook 1957			■		▨

E X P L A N A T I O N

■ Absolute age (Radioactive) ▨ Fairly certain age ▨ Uncertain age

formation (middle Eocene) yield 46 million years for an absolute age (Jaffe, et al., 1959), again a rather close correlation for these determinations.

The thickness of the volcanic sequence is not known, but its cumulative total probably exceeds 5,000 feet. Tuffs, vitrophyres, massive latite flows, andesites and trachyandesites, and agglomerates are included. These units, as elsewhere in the state, show considerable lateral variation in thickness.

Morris (1957) subdivides the older sequence into the Packard quartz-latite and Fernow quartz-latite series, the younger into the Latite volcanic series. He also records a much later basalt. The oldest series exceed 3,100 feet in thickness, locally, and is deposited on a surface of relief similar to that now existing.

Units in the Packard group include, from oldest to youngest, basal tuff, lower vitrophyre, massive flow, and upper vitrophyre. The Fernow includes a basal tuff, a vitrophyre and/or porphyritic quartz latite flow. They are gently inclined away from their main centers of accumulation. They are considered pre-mid-Eocene in age.

The latite volcanic series, separated from the older by a disconformity, probably exceeds 2,000 feet in thickness. Main rock types are: a basal tuff, lower flow series, intermediate tuff and agglomerate, upper flow series of latite, andesite and trachyandesite, and a thick agglomerate. These are considered mid-Eocene.

A basalt, in excess of 75 feet, ranging from dense to scoriaceous, occurs to the northeast of the main volcanic area. The exact age is unknown, but it post-dates the Latite volcanic series and pre-dates Lake Bonneville sediments.

Stockton-Fairfield area: Gilluly (1932) described a thick sequence of late Eocene or Oligocene flows, tuff-breccias, and tuffs in the Traverse Range and along the east flank of the Oquirrh Range east of Bingham. Deposited on an erosion surface, some of the old valleys have 1,000 feet of relief within a mile's distance. The sequence includes latites and quartz latite, with minor flows of basalt, rhyolite obsidian, and nepheline basalt. Breccia is the common texture.

The volcanic rocks are chiefly latite and quartz latites. These, however, are subordinate in quantity to the pyroclastics. At least 1,900 feet of latite breccia, with less abundant lavas overlain by not less than 1,000 feet of lava and subordinate breccia, are noted. Total thickness for the series is estimated at probably more than 3,000 feet. These volcanic rocks probably correlate with similar rocks in the Lake Mountains (Bullock, 1951) and the Latite volcanic series in the Tintic district, as noted above.

Park City area: An area exceeding 200 square miles lies east, north, and south of Park City. The extrusives, composed of andesitic flows and pyroclastics, dip gently east. The rocks have been deposited on an erosion surface of some relief.

Gray to yellowish-gray tuffs, a conspicuous portion of the volcanic sequence near Park City, resemble a fine sandstone which is gradational to argillaceous rock containing larger grains. Some included particles vary greatly in size.

Age relationships of the intrusive and extrusive rocks are not known exactly, but Butler (1920, p. 299) suggests at least one porphyry intrusive may have been emplaced, deeply eroded, then covered with andesitic volcanics. The andesites rest upon Eocene (?) sedimentaries, and the lower tuffs grade into them. Eardley (1952, p. 59) suggested a late Eocene age. Fossils in the interbedded tuffs within the volcanic sequence (Williams, personal communication, 1954) suggest a possible Oligocene age for at least part of the activity.

Other areas: The described areas above represent those for which detailed geologic data are available. They include those districts in which the thickest volcanic rock accumulations are known. Other areas within the state also show considerable thickness and broad areal distribution of these rocks, e.g., the Frisco area, margins of the Great Salt Lake Desert, and others.

In the Raft River Mountains, basalts are exposed on their north flanks, and in low buttes and hills to the southwest, which are scarred by wave-cut cliffs and terraces of Lake Bonneville. A late Tertiary (Pliocene) age is suggested. Several hundred feet of white volcanic ash and reddish-brown welded tuffs in the Salt Lake formation, late Miocene and early Pliocene, are known near Goose Creek (Mapel and Hail, 1956).

Near the Rozel Hills, alternating basalt flows and limestone beds are presumed to be part of the Salt Lake group (Slentz and Eardley, 1956). Total thickness is unknown, but exceeds several hundred feet. Age is considered Miocene-Pliocene.

To the west near Gold Hill, Nolan (1935) described small areas covered by lavas or pyroclastics which range from rhyolite to basalt. Total thickness is unknown. Nolan indicated that they are younger than Eocene (?), and are thought to be younger than Pliocene (?), but older than Lake Bonneville sediments. Because they are separated from the latter by a period of considerable erosion, Nolan concluded a late Pliocene age.

AGE OF IGNEOUS ROCKS OF UTAH

Igneous rocks in Utah range from Eocene to Recent. At least two and usually three series of volcanic rocks are recognized: a pre-mid-Eocene or early Tertiary series; later Tertiary, probably Miocene series; and a much later basalt series of possibly late Pliocene (?) or early Pleistocene age. Absolute ages suggest volcanism in Eocene, Oligocene, and Miocene times. Cinder cones and lava flows of post-Bonneville age are conspicuous in the southern and west-central part of the state.

The age of the intrusive rocks cannot be definitely ascertained from stratigraphic relationships in most areas in Utah. The intrusives of Nevada are regarded as late Jurassic or early Cretaceous. The intrusives of the Plateau region are assigned to the Tertiary. In western Utah, where sedimentary formations later than Carboniferous are absent, definite data are lacking for determining whether the intrusive rocks should be correlated with the intrusives of Nevada or with those of the Plateau country.

Absolute age determinations (Jaffe, et al., 1959) assist in age relationships. The absolute dating by lead-alpha age determinations yield 19-28 million years in the Iron Springs district; 20 million years in the Thomas Range. Absolute age dating of intrusive igneous rocks include: Sheep Rock Range, 15-20 million years; Three Peaks intrusive, 22 million years; La Sal Mountains, 25, 51-55, 386-419 million years; Little Cottonwood, Alta, and Clayton Peak stocks, 40-54 million years; North Lily and Silver City stocks, 43-50 million years (Table XI).

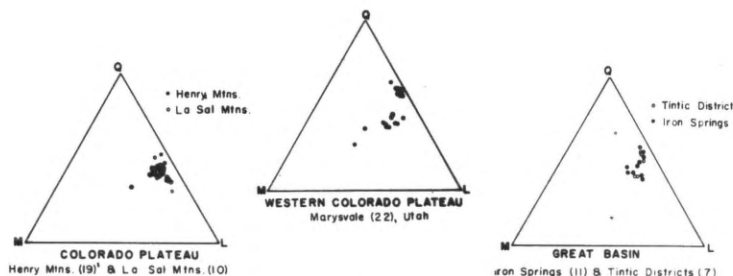
Absolute age determinations made by Jaffe show disparities. Particularly the assignment of 386-419 million years for intrusive masses in the La Sal Mountains is erroneous, since they cut Mesozoic strata. Though only in the embryonic stage, the need is indicated for more studies by this method in all the major igneous rock areas of Utah. Dependable absolute age data will permit a solution to many of the difficult problems of dating igneous activity.

A compilation of the age relationships of Cenozoic igneous rocks of Utah is attempted in Table XII. Uncertainties, fair certainties, and absolute ages, with their known variations, are shown for the major areas in the state. The wide spread of the more certain data suggests volcanic activity throughout a good portion of Tertiary period, starting in Eocene time and continuing into the present.

POSSIBLE RELATION TO OIL ACCUMULATIONS

The volcanic rocks of Utah offer little promise of being reservoir rocks for the accumulation of oil. However, the unique discovery of oil in volcanic debris in eastern Nevada requires that they not be eliminated from consideration. Igneous rocks may cover possible oil traps in the sedimentary rocks below, and structures formed since the volcanic rocks were deposited, can be mapped. Thus, imposed anticlinal folds or faults in the volcanics should be reflected in the sediments below. Such structures have been mapped in the Plateau Province where both broad warps and faults occur in the volcanic sequences. Since several thousand square miles of the Plateau and Basin and Range Provinces are covered by extrusives of Eocene to late Pliocene or Pleistocene age, fault and/or fold structures post-dating these ages can be mapped.

Superimposed structures must be distinguished from primary structures such as those formed with strato-volcanoes, compaction features over buried topography, etc. Remnants of these structures may be present even after much of the original land form has been eliminated by erosion. These might be mistaken for superimposed structures. If oil has accumulated in true folds of Eocene or later age, or is trapped against faults of similar age, these rocks should bear a more careful investigation in the future.



¹Refers to number of published chemical analyses used in determining QLM values

QLM VALUES (Niggli) OF SOME IGNEOUS ROCKS OF UTAH (1961-After Kennedy and Proctor)

QLM values of Niggli (Burri and Niggli, 1945, p. 9-97), computed from chemical analyses of 50 igneous rocks in Utah from the Colorado Plateau and the Great Basin, demonstrate possible differences in the rock types (Figure 50a) (Kennedy and Proctor, 1961, personal communication).

Thus: Q: quartz. L: leucocrate base group--kaliophillite (potassium aluminosilicate), nepheline, calcium aluminosilicate molecules. M: melanocrate base group--calcium orthosilicate, forsterite, fayalite molecules. Q, L, and M positions represent 100% of each group.

On the QL side of the triangle point Q=40 is the position of the feldspars: orthoclase, albite, anorthite. On the QM side pyroxenes lie at Q=25. Amphiboles and biotites, within the triangle, their positions determined by these Q:L:M ratios, further modify the plotted position. Thus, one point may represent a rock analysis, and at a glance ready comparison is possible for a large number of rocks.

Colorado Plateau rocks: Q values range from 32-47, L, 44-57, M, 5-14. Near Marysvale two distinct clusters are present: the Bullion Canyon series with Q values 36-45, L, 40-49, M, 8-20, and the more acidic Belknap series with Q at 50-56, L, 37-42, and M, 0-4.

Variations at Iron Springs and Tintic indicate a group intermediate between two Marysvale groups, but more acidic than those of the Colorado Plateau. Q values range from 40-59, L, 36-48, and M, 4-18.

CITED REFERENCES

- Anderson, W. L., 1957, Geology of the Northern Silver Island Mountains, Box Elder County, Utah: Univ. of Utah M.S. thesis.
- Baker, W. H., 1959, Geologic setting and origin of the Grouse Creek plutons, Box Elder County, Utah: Univ. of Utah Ph.D. thesis.
- Barosh, P. J., 1959, Geology and ore deposits of the Beaver Lake Mountains, Beaver County, Utah: Utah Geol. and Mineralog. Survey Bull. 68.
- Bassett, W. A., Kerr, P. F., and others, 1960, K-Ar ages, Marysvale, Utah--Tertiary Volcanic rocks: Geol. Soc. America Program, 1960 Annual Meetings, p. 54.
- Bick, K. F., 1958, Geology of the Deep Creek Mountains, Utah: Yale Univ., Ph.D. thesis.
- Blank, H. R., 1959, Geology of the Bull Valley District, Utah: Univ. of Washington, Ph.D. thesis.
- Brown, R. W., and Pecora, W. T., 1949, Paleocene and Eocene strata in the Bearpaw Mountains, Montana: Science, v. 109, p. 487-489.
- Bullock, K. C., 1951, Geology of Lake Mountain, Utah: Utah Geol. and Mineralog. Survey Bull. 41.
- Burri, Conrad, and Niggl, Paul, 1945, Die jungen Eruptivgesteine des mediterranen Orogens: Zurich, 654 p.
- Butler, B. S., 1913, Geology and ore deposits of the San Francisco and adjacent districts, Utah: U.S. Geol. Survey Prof. Paper 80.
- Butler, B. S., and others, 1920, The ore deposits of Utah: U.S. Geol. Survey Prof. Paper 111, p. 88.
- Calkins, P. C., and others, 1943, Geology and ore deposits of the Cottonwood-American Fork area, Utah: U.S. Geol. Survey Prof. Paper 201.
- Callaghan, E., 1938, Preliminary report on the alunite deposits near Marysvale, Utah: U.S. Geol. Survey Bull. 886-D, p. 91-134.
- _____, 1939, Volcanic sequence in the Marysvale region in southwest-central Utah: Trans. Am. Geophys. Union, p. 438.
- Callaghan, Eugene, and Parker, R. L., 1961, Geology of the Monroe quadrangle, Utah: U.S. Geol. Survey Geologic Quadrangle Map 155.
- Cohenour, R. E., 1959, Geology of the Sheeprock Mountains, Utah: Utah Geol. and Mineralog. Survey Bull. 63.
- Condie, K. C., 1960, Petrogenesis of the Mineral Mountains Pluton, southwestern Utah: Univ. of Utah M.S. thesis.
- Cook, E. F., 1952, Geology of the Pine Valley Mountains: Intermountain Assoc. Petroleum Geologists Guidebook, no. 7, p. 92-100.
- _____, 1953, Structural transition zone between Colorado Plateau and Basin and Range provinces in southwestern Utah (abs.): Geol. Soc. America Bull. 12, v. 64, p. 1501.
- _____, 1957, Geology of the Pine Valley Mountains, Utah: Utah Geol. and Mineralog. Survey Bull. 58.
- Davis, B. L., 1959a, Geology of the Drum Mountains, Utah: Unpublished geologic map.
- _____, 1959b, Petrology and petrography of the igneous rocks of the Stansbury Mountains, Utah: Brigham Young Univ. Research Studies, Geol. ser., v. 6, no. 2.
- Dunn, D. E., 1958, The geology of the Crystal Peak area, Millard County, Utah: Southern Methodist Univ. M.S. thesis.
- Eardley, A. J., 1952, Wasatch Hinterland: Utah Geol. Soc. Guidebook, no. 8, p. 52-60.
- Felix, C., 1956, Geology of the eastern part of the Raft River Mountains: Utah Geol. Soc. Guidebook, no. 11.
- Gehman, H. M., Jr., 1958, Notch Peak intrusive, Millard County, Utah: Utah Geol. and Mineralog. Survey Bull. 62.
- Gilluly, J., 1927, Alkaline diabase and related alkaline syenite from Utah: Am. Jour. Sci., 5th ser., v. 14, p. 199-211.
- _____, 1932, Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U.S. Geol. Survey Prof. Paper 173.
- Gregory, H. E., 1938, The San Juan Country, a geographic and geologic reconnaissance of southeastern Utah: U.S. Geol. Survey Prof. Paper 188.
- Groff, S. L., 1959, Geology of the West Tintic Range and vicinity, Utah: Univ. of Utah, Ph.D. thesis.
- Hunt, C. B., 1946, Geology and geography of the Henry Mountain region, Utah: Utah Geol. Soc. Guidebook, no. 1.
- _____, 1953, Geology and geography of the Henry Mountain region, Utah: U.S. Geol. Survey Prof. Paper 228.
- _____, 1956, Cenozoic geology of the Colorado Plateau: U.S. Geol. Survey Prof. Paper 279.
- _____, 1958, Structure and igneous geology of the La Sal Mountains, Utah: U.S. Geol. Survey Prof. Paper 294-I.
- Jaffe, H. W., Gottfried, D., Waring, C. L., Worthing, H. W., 1959, Lead-Alpha age determinations of accessory minerals of igneous rocks (1953-1957): U.S. Geol. Survey Bull. 1097-B, p. 65-148.
- Kerr, P. F., and others, 1957, Marysvale, Utah uranium area: Geol. Soc. America Spec. Paper 64.
- Lautenschlager, H. K., 1954, The geology of the central part of the Pavant Range, Utah: Ohio State Univ., Ph.D. thesis.
- Leith, C. K., and Harder, E. C., 1908, The iron ores of the Iron Springs district, southern Utah: U.S. Geol. Survey Bull. 338, p. 47.
- Lindgren, W., and Loughlin, G. F., 1919, Geology and ore deposits of the Tintic mining district, Utah: U.S. Geol. Survey Prof. Paper 107, p. 42.
- Lovering, T. S., 1949, Rock alteration as guide to ore--East Tintic district, Utah: Econ. Geology Mon. 1.
- Mackin, J. H., 1947, Some structural features of the intrusions in the Iron Springs district: Utah Geol. Soc. Guidebook no. 2.
- _____, 1954, Geology and iron ore deposits of the Granite Mountain area, Iron County, Utah: U.S. Geol. Survey Mineral Inv. Field Studies Map MF 14.
- _____, 1960, Structural significance of Tertiary volcanic rocks in southwestern Utah: Am. Jour. Sci., v. 258, p. 81-121.
- Mackin, J. H., Cook, E. F., and Threet, R. L., 1954, Stratigraphy of early Tertiary volcanic rocks in southwestern Utah (abs.): Geol. Soc. America Bull., v. 65, pt. 2, p. 1280.
- Mapel, W. J., and Hail, W. J., Jr., 1956, Tertiary stratigraphy of the Goose Creek district, Cassia County, Idaho, and adjacent parts of Utah and Nevada: Utah Geol. Soc. Guidebook to the Geology of Utah, no. 11, p. 1-16.
- Morris, H. T., 1957, General geology of the East Tintic Mountains, Utah: Utah Geol. Soc. Guidebook, no. 12, p. 30-34.
- Nolan, T. B., 1935, The Gold Hill mining district, Utah: U.S. Geol. Survey Prof. Paper 177, p. 43.
- Paddock, R. E., 1956, Geology of the Newfoundland Mountains, Box Elder Co., Utah: Univ. of Utah, M.S. thesis.
- Proctor, P. D., 1951, Geological projections under volcanic cover, East Tintic, Utah: Geol. Soc. America Bull., no. 12, v. 62, p. 1470.
- _____, 1956, Preliminary geologic map of the Allen's Ranch quadrangle, Utah: U.S. Geol. Survey Mineral Inv. Field Study Map MF 45.
- Slentz, L. W., and Eardley, A. J., 1956, Geology of the Rozel Hills: Utah Geol. Soc. Guidebook, no. 11, p. 32-40.
- Stringham, B., 1953, Granitization and hydrothermal alteration at Bingham Utah: Geol. Soc. America Bull., 64, p. 945-992.
- Thomas, G., 1958, Geology of the Indian Springs quadrangle, Utah: Brigham Young Univ. Research Studies, Geol. ser., v. 5, no. 4.
- Waters, A. C., 1955, Volcanic rocks and the tectonic cycle: Geol. Soc. America Spec. Paper 62, p. 703-722.
- Wells, P. G., 1938, The origin of the iron ore deposits in the Bull Valley and Iron Springs District, Utah: Econ. Geology, v. 33, p. 447-507.
- Willard, M. E., and Callaghan, Eugene, 1962, Geology of the Marysvale quadrangle, Utah: U.S. Geol. Survey Geologic Quadrangle Map 154.

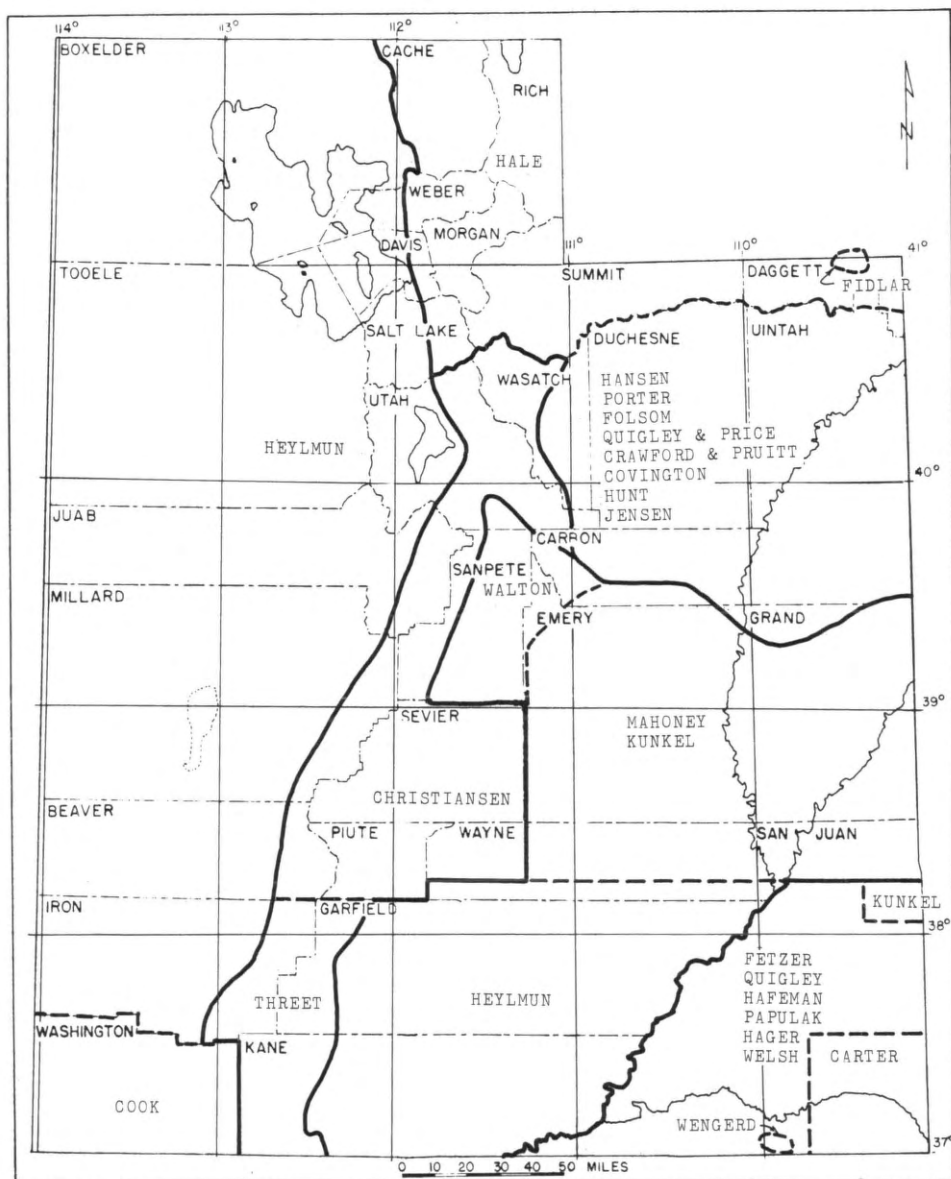


Figure 51. Index map showing areas treated by symposium authors.

PART III
EVALUATION
BY
AREAS

EXPLANATORY NOTE

In PART III, EVALUATION BY AREAS, written by the best-informed specialists, Utah has been divided into natural physiographic provinces (Figure 2), then subdivided along county boundaries, major highways, or other lines of demarkation. However, in the Paradox Basin a "layer-cake" treatment of the Desert Creek and Ismay sedimentary horizons was found to be the best means to concisely summarize our present knowledge for this area.

The Index Map (Figure 52), page 170, shows the authors of the areal papers for Part III. Four general areas are evaluated in the following order:

- A. Northeastern Utah - the areas east of the Wasatch Front, north of Utah and Wasatch Counties, and all of the Uinta Basin.
- B. The Great Basin Sector and the Southwestern Corner of Utah.
- C. The Transition Zone between the Great Basin and the Canyon Lands.
- D. The High Plateaus.

The Index for each section shows the organization of subject matter. By referring to these indices the sequence of treatment can be more fully seen and appreciated.

— A —
NORTHEASTERN UTAH
AND
THE UINTA BASIN

Index to Section A

<u>Paper</u>		<u>Page</u>
16	THE UINTA BASIN -- STRUCTURE, STRATIGRAPHY, AND TECTONIC SETTING, by Alan R. Hansen	175
	Structure	175
	Regional Stratigraphy	175
	Tectonic Associations	176
	Cited References	176
17	CLAY BASIN GAS FIELD, DAGGETT COUNTY, UTAH, by M. M. Fidler	177
	Structure	180
	Economic Geology	180
	Cited References	182
18	NORTHERN UTAH, by Lyle A. Hale	183
	Introduction	183
	Major Structural Elements	183
	Coalville Anticline	187
	Cited References	191
19	STRATIGRAPHY AND OIL POSSIBILITIES OF THE GREEN RIVER FORMATION IN THE UINTA BASIN, UTAH, by Livingstone Porter, Jr.	193
	Depositional History	193
	Structural History	194
	Green River Facies Definitions	195
	Facies Distribution and Oil Occurrence	195
	Oil Possibilities of the Green River Formation	197
	Drilling Activity	198
	Summary	198
20	ECONOMIC ASPECTS OF UINTA BASIN GAS DEVELOPMENT, by L. W. Folsom	199
	History of Development	199
	Pipeline Outlets	199
	Geological Considerations	200
	Economic Considerations	202
	Summary and Conclusions	205
	Cited References	206
21	GREEN RIVER OIL SHALE POTENTIAL IN UTAH, by M. D. Quigley and J. R. Price	207
	Oil Shale Environment	208
	Stratigraphy	209
	Recent Developments and Economics	209
	Oil Shale Reserves in the Uinta Basin	211
	Cited References	213
22	GILSONITE AND OTHER BITUMINOUS RESOURCES OF CENTRAL UINTAH COUNTY, UTAH by Arthur L. Crawford and Robert G. Pruitt	215
	Introduction	215
	Gilsonite	215
	Gilsonite Mining and Markets	221
	Other Bituminous Resources	221
	Cited References	224
23	BITUMINOUS SANDSTONE AND LIMESTONE DEPOSITS OF UTAH, by Robert E. Covington	225
	Introduction	225
	Asphalt Ridge Area	225
	Whiterocks Area Bituminous Sandstones	237
	Sunnyside Area Bituminous Sandstones	239
	Miscellaneous Localities	241
	Cited References	247
24	COMPOSITION AND ORIGIN OF THE UINTA BASIN BITUMENS, by John M. Hunt	249
	Introduction	249
	Occurrence of the Bitumens	249
	Composition of the Bitumens	255
	Identification of Source Beds	269
	Change in Bitumen Type with Depositional Environment	271
	Formation of the Vein Deposits	271
	Cited References	273
25	THE BEARING OF SULFUR ISOTOPES ON COLORADO PLATEAU URANIUM AND PETROLEUM DEPOSITS, by Mead LeRoy Jensen	275
	Introduction	275
	Basic Concepts	275
	Fractionation of Sulfur Isotopes	276
	Results	278
	Cited References	284

Paper 16 THE UINTA BASIN — STRUCTURE, STRATIGRAPHY AND TECTONIC SETTING¹

by Alan R. Hansen²

STRUCTURE

The Uinta Basin is a broad asymmetrical syncline. As described by Walton (1944), "Its axis trends roughly east, but bends gently toward the north. The topographic low of the basin is not coincident with the axis of the syncline, but parallels it throughout its length about 10 to 15 miles to the south."

For structural and topographic reasons, the Uinta Basin has been divided into basins of minor distinction. The easternmost in Colorado is designated the Piceance Creek basin (Figure 67). The division is expressed by three domal uplifts forming a north-south line approximately along the boundary between Utah and Colorado. From north to south, this line of uplifts is composed of the Raven Park fold, Douglas Creek uplift, and, to the south, the Uncompahgre plateau. Together, these elements nearly separate the Tertiary stratigraphy of the Utah portion from that of Colorado. Associate features of these anticlinal structures are the oil-and-gas-producing areas of Rangely oil field and the Douglas Creek gas field.

The south flank of the Uinta Mountains is dissected by prominent faulting. Huddle and McCann (1947) recognized one fault of major displacement that is traceable along the greater portion of the mountain front. This fault, known as the South Flank fault, is expressed by strong south dips (80°) along the fault plane, and all along the mountain front, beds of Paleozoic and Mesozoic age stand almost in vertical position. Along the south flank of Blue Mountain, the writer observed such beds to be overturned.

Oligocene and younger strata are only gently undulating, even where such strata lie close to the mountain front and unconformably overlies older upturned Tertiary beds. Childs (1950) mentions that the axial plane of the syncline shown in the Duchesne River formation continues downward with a progressive decrease of dip. This evidence has led many to believe that the vertical fault planes at the surface tend to flatten with depth, and that the Uinta Mountains are the products of ramp-thrusting. Such a mechanism could develop the asymmetry noted in the Uinta Basin. Walton (1944) asserts that faulting has been unimportant in establishing the structure of the basin, but the writer believes that north-south compression has served to impress asymmetry upon a broad down-warp established during the period of deposition.

REGIONAL STRATIGRAPHY

Paleozoic

Along the south flank of the Uinta Mountains, nearly 7,000 feet of Paleozoic rocks have been noted. Nearly half of this total is represented by metamorphosed quartzitic sandstone of which Cambrian shales and quartzites comprise 3,400 feet of strata. This sequence is directly overlain by a limestone-dolomite unit of questionable Ordovician age. Rocks of Silurian and Devonian ages are unknown in the Uinta Basin and probably were never deposited there. (See Papers 3, 7, and 8).

1. Adapted from a Yale University thesis.

2. Geologist, Sun Oil Company.

Mississippian, Pennsylvanian, and Permian rocks are not well exposed, but drilling has indicated such beds within the basin. Lithology suggests deposition in a vast marginal shelf area with rapid, lateral-facies changing from littoral to epineritic sedimentary types. (Refer to Paper 9).

Mesozoic

Mesozoic sedimentation, dominantly clastic, is a continuation of Paleozoic deposition, with no unconformable relationships known between the two. Sediments were derived from the Ancestral Rockies on the east and the Mesocordilleran geanticline on the west. The former were progressively buried and have relatively little effect after Morrison time, the latter prominent during middle and late Mesozoic, furnished vast quantities of sediment (Paper 10).

Cenozoic

As the vast Cretaceous seas silted-up and disappeared, the ensuing orogenic uplifts served to isolate basins of thick Tertiary deposition throughout the Rocky Mountain region within the Uinta Basin. Tertiary sedimentation probably exceeds 13,000 feet. With the exception of the fresh-water Green River formation, there is a monotonous series of deltaic, lacustrine, and fluvial deposits (Williams, 1950). Shales predominate, but intervals of sandstone (subgraywackes), and mudstone indicate varying conditions of erosion and deposition. Major relative subsidence is dominantly Tertiary, and these basinal sediments are super-imposed upon previous sequences of essentially shelf-type sediments. Quaternary alluvium and recent river fill have done little to alter the Tertiary picture.

TECTONIC ASSOCIATIONS

Throughout the greatest part of its tectonic history the Uinta Basin has behaved as a great shelf or foreland area lying east of an extensive geosynclinal trough (Childs, 1950). But in the Cenozoic the Uinta Mountains rose from early Paleocene to Oligocene, with the main uplift occurring during Eocene time (Eardley, 1951). This uplift is synonymous with deposition that began with the Price River and ended with the Green River formations.

Forrester (1937) indicates three major periods of diastrophism, which were responsible for a maximum vertical uplift of about 45,000 feet in the center of the range: (1) Deformation of the Uinta Mountain and Wasatch Mountain geosynclines during the Laramide revolution. (2) Vertical uplift and large scale faulting in late Eocene, (3) Continental uplift of the general plateau area in late Pliocene or early Pleistocene.

CITED REFERENCES

- Childs, O. E., 1950, Geologic history of the Uinta Basin: Intermountain Assoc. Petroleum Geologists Guidebook, no. 5, p. 49-59.
- Eardley, A. J., 1951, Structural geology of North America: New York, Harper Bros., publishers, p. 331-332.
- Forrester, J. D., 1937, Structure of the Uinta Mountains: Geol. Soc. America Bull., v. 48, p. 631-666.
- Huddle, J. W., and McCann, F. T., 1947, Pre-Tertiary geology of the Duchesne River area, Duchesne and Wasatch Counties, Utah: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 75.
- Walton, P. T., 1944, Geology of the Cretaceous of Uinta Basin: Geol. Soc. America Bull., v. 55, p. 91-130.
- Williams, M. D., 1950, Tertiary stratigraphy of the Uinta Basin: Intermountain Assoc. Petroleum Geologists Guidebook, no. 5, p. 101-114.

Paper 17 CLAY BASIN GAS FIELD DAGGETT COUNTY, UTAH

by M. M. Fidler¹

The following summary is a condensed and updated version of the 1949 description of the Clay Basin gas field, the first large gas field discovered in Utah (Fidler, 1949).

The field lies in T-3-N, R-24-E at the base of the north flank of the Uinta Mountains in extreme northeastern Daggett County. Some 50 miles south of Rock Springs, Wyoming, and 140 miles east of Salt Lake City, Utah, it is serviced by graded roads that lead northward to Rock Springs, southward to the Browns Park ranch area, and westward to Linwood, Utah. Operated by Mountain Fuel Supply Company, it is the site of modern homes and service buildings constructed by the operator for the use of personnel employed in the field.

Bounded on the north and east by sheer bluffs of Mesaverde sandstone, on the south and west by the maroon and gray Precambrian foothills of the Uinta Mountains, Clay Basin, for which the field was named, is a striking topographic feature eroded in soft, gray Mancos shales exposed on the crest of the westerly-trending Clay Basin anticline (Figure 52). Deep drilling on the crest of this structure has revealed a normal stratigraphic section down to the Weber sandstone (Figure 53). The reconstructed stratigraphic section is as follows:

	Thickness in Feet
Tertiary: Wasatch formation	
Unconformity	
Cretaceous (Upper)	
Mesaverde group	900
Mancos shale	6,400 ±
Frontier formation (minor gas sands)	120
Aspen shale	185
Dakota sandstone (principal gas sands)	110
Fuson (?) shale	65
Lakota (?) sandstone	15
Unconformity	
Jurassic	
Morrison formation	600
Curtis formation	175
Entrada formation (water)	100
Carmel formation	110
Nugget sandstone (water)	775
Unconformity	
Triassic	
Chinle formation	230
Shinarump conglomerate (water)	25
Moenkopi formation	895
Probable Unconformity	
Permian	
Phosphoria (Park City)	325
Pennsylvanian	
Weber sandstone (noncombustible gas)	330+
Morgan formation	unknown
Mississippian	
Madison limestone	unknown
Possible older Paleozoic sediments	unknown
Precambrian: Red Creek quartzite	undetermined

1. President, Mountain Fuel Supply Company.

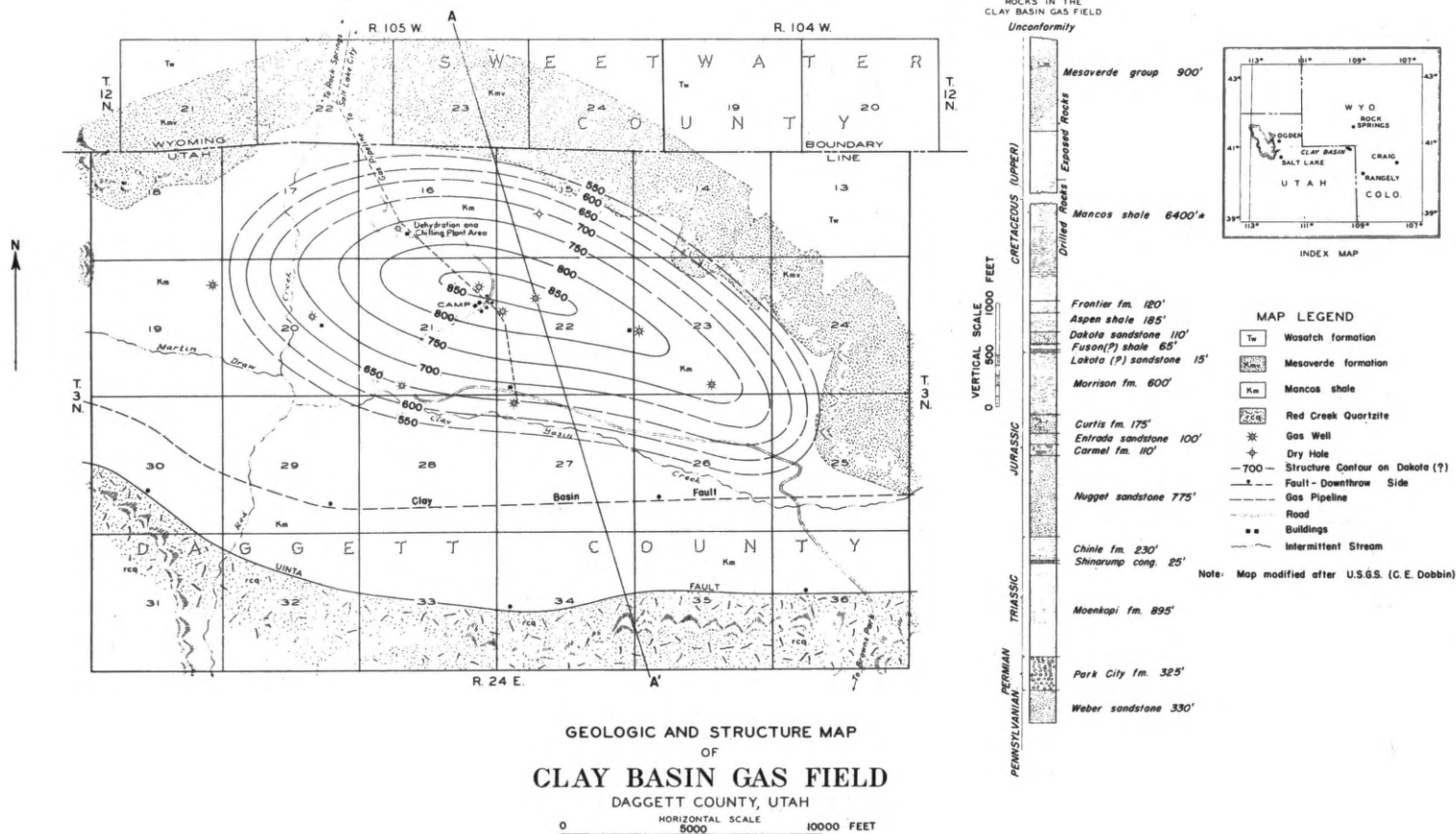


Figure 52.

R.D. MURPHY
WELL NO. 6-W

CLAY BASIN FAULT

UINTA FAULT

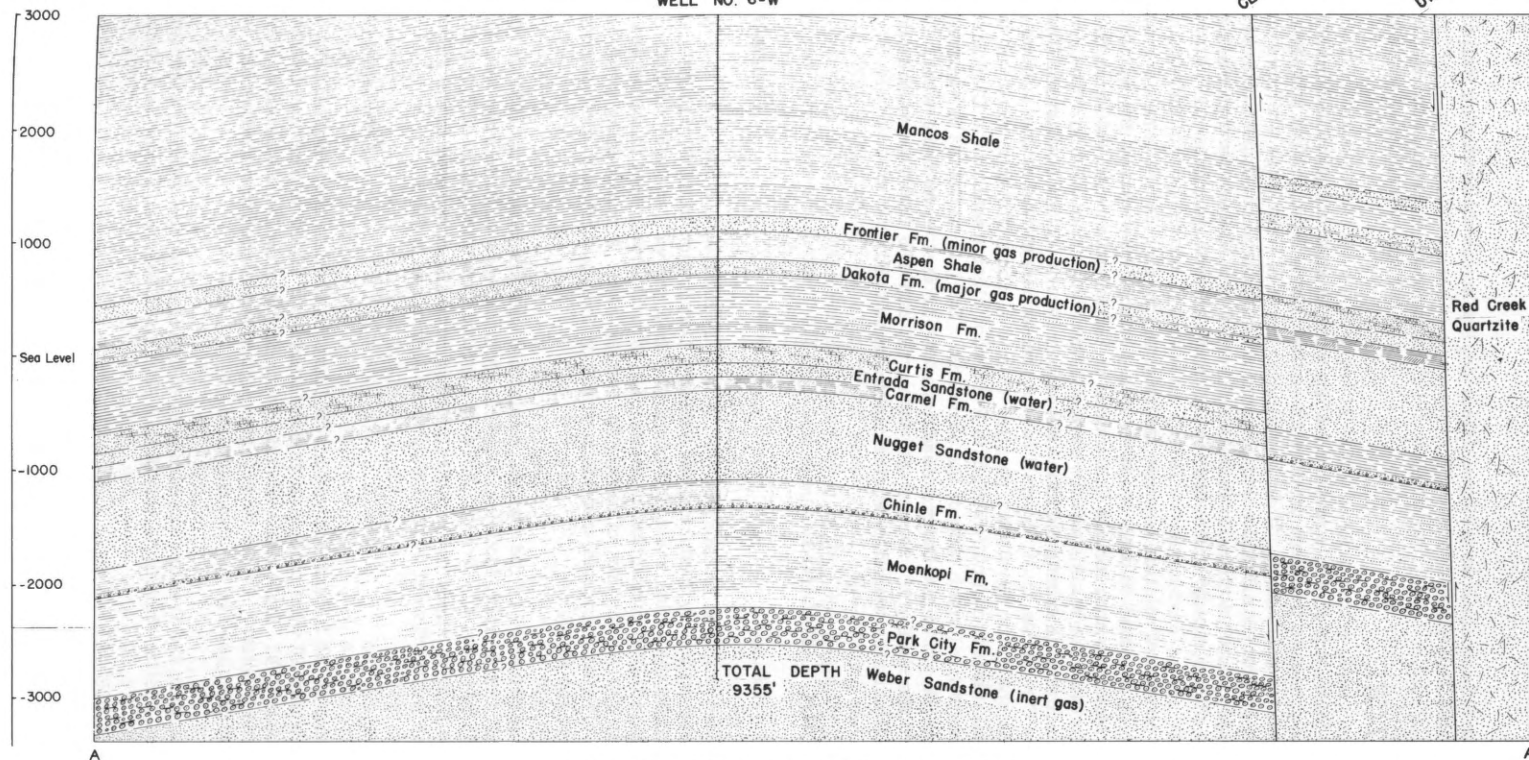


Figure 53. Ideal Cross Section A-A' of Clay Basin Gas Field.

Of the above formations the most persistent key horizon in the producing wells is the top of the Dakota sandstone.

STRUCTURE

The Uinta fault, a high angle reverse feature with an apparent throw of more than 18,000 feet, bounds the Uinta Mountains on their north flank and the Clay Basin anticline on its south flank. It strikes slightly north of west, dips sharply south and throws Precambrian Red Creek quartzite on the south against Upper Cretaceous Mancos shale on the north. North of the gas field the Mesaverde and Wasatch formations plunge rapidly northward toward the Red Creek syncline.

A genetic structural relation between faulting and folding in the area is rather well established, and folding probably was accomplished during the uplift of the Uinta Mountain arch in Late Cretaceous or Early Tertiary age. Wasatch beds exposed north of the basin probably were not involved in this folding. The producing structure is a closed anticline developed parallel to and against the Uinta fault. The Clay Basin fault, a small reverse feature identified at the surface in the Mancos shales is developed parallel to and a short distance north of the Uinta fault. Surface structure suggests a 400-foot closure against the Clay Basin fault on the critical south side of the anticline. Drilling indicates a structural reversal on the top of the Dakota sandstone of 450 feet toward the west, 220 feet toward the south, 150 feet toward the north, and 100 feet toward the east. Figure 52 illustrates the various relationships involved.

ECONOMIC GEOLOGY

Discovery

The discovery well, R. D. Murphy Well No. 1, in the NW 1/4 sec. 22, T-3-N, R-24-E, was drilled by Producers and Refiners Corporation in 1927. Drilled only a few feet into the Aspen shale and completed as a gas well in the Frontier sandstone with an initial production capacity of 3,276,000 cubic feet of sweet gas a day, it was shut-in for lack of market for natural gas. In succeeding years the structural area was unitized and Mountain Fuel Supply Company took over the operation of the field.

The large gas reserve in the Dakota sandstone was discovered in 1935 in the second well in the field, Mountain Fuel Supply Company's R. D. Murphy Well No. 2 in the NE 1/4 sec. 21, T-3-N, R-24-E. Drilled to a total depth of 6,799 feet to test the Entrada sandstone, it was plugged back and completed in the Dakota zone for an initial flow of 32,000,000 cubic feet of gas a day.

Development

Development of the field to the end of 1961 has resulted in the completion of 11 wells, of which 10 were producing gas wells and one failed to find gas in commercial quantities. Eight wells are now producing from the Dakota sandstone and two from the Frontier. Of the latter, one originally produced from the Dakota, but has been recompleted in the Frontier zone.

Average depth to the Frontier sandstone is 5,400 feet, to the Dakota sandstone 5,760 feet. Collar elevations vary from 6,279 to 6,659 feet above sea level.

Initial production has been variable. The smallest producing well had an initial capacity of 3,276,000, and the largest of 32,000,000 cubic feet a day. Average initial rock pressure approached 2,175 pounds per square inch. All the wells produce condensate with the gas.

A dehydration plant was constructed in 1938. A refrigeration plant, built in 1951, chills the dry gas to remove the liquid hydrocarbons. A compressor plant, put in operation in 1956, delivers gas from all wells to the main transmission line.

Most wells stopped in the Dakota or upper Morrison, but in 1935 the Dakota gas discovery well was drilled into the Entrada sandstone 6,799 feet, where it found water. Lower zones were not tested until 1947. After geophysical surveys indicated that folding reaches at least as far below the surface as the Weber sandstone, a deep 9,335-foot test, R. D. Murphy Well No. 6-W, was drilled on the crest of the structure in the NW 1/4 sec. 22, T-3-N, R-24-E. It penetrated 330 feet of Weber sandstone, and after drillstem tests demonstrated that the Weber contained an accumulation of valueless noncombustible gas, 82 per cent nitrogen and 15 per cent carbon dioxide, the well was plugged back and completed as a gas well in the Dakota sandstone.

Production History

A 23-mile pipeline was completed in 1937 to connect the Clay Basin field with an existing pipeline system from fields in northwestern Colorado which were producing gas for distribution in Great Salt Lake Valley. Gas production from the Clay Basin wells was started the same year. The annual and cumulative production of gas into the Salt Lake pipeline from the Clay Basin field are shown in the following tabulation (15.025 psia pressure base):

Year	Production During Year (cu. ft.)	Cumulative Production (cu. ft.)
1937	1,935,614,000	1,935,614,000
1938	3,708,681,000	5,644,295,000
1939	4,132,529,000	9,776,824,000
1940	4,264,725,000	14,041,549,000
1941	4,689,464,000	18,731,013,000
1942	4,384,394,000	23,115,407,000
1943	3,864,741,000	26,980,148,000
1944	6,202,185,000	33,182,333,000
1945	6,651,871,000	39,834,204,000
1946	4,294,920,000	44,129,124,000
1947	6,036,372,000	50,165,496,000
1948	6,609,774,000	56,775,270,000
1949	6,125,730,000	62,901,000,000
1950	3,949,875,000	66,850,875,000
1951	3,670,529,000	70,521,404,000
1952	2,833,450,000	73,354,854,000
1953	3,536,556,000	76,891,410,000
1954	2,628,518,000	79,519,928,000
1955	3,242,999,000	82,762,927,000
1956	2,540,462,000	85,303,389,000
1957	1,877,445,000	87,180,834,000
1958	1,817,909,000	88,998,743,000
1959	2,165,186,000	91,163,929,000
1960	1,815,962,000	92,979,891,000
1961	1,950,353,000	94,930,506,000

Remaining reserves of gas in the Frontier and Dakota sandstone reservoirs in the field as of January 1, 1962, were estimated to be approximately 32,000,000,000 cubic feet. Both producing formations appear to be gas-expansion type reservoirs, as the reservoir pressure has declined in a regular manner as gas production continued.

CITED REFERENCES

Fidlar, M. M., 1949, Clay Basin Gas field, Daggett County, Utah: Oil and Gas Possibilities of Utah, Utah Geol. and Mineralog. Survey, publisher.

Paper 18 NORTHERN UTAH¹

by Lyle A. Hale²

INTRODUCTION

The subject area (Figure 54), consisting of Daggett, Summit, Morgan, and Rich Counties and the mountainous portions of Cache, Weber, Davis, and Salt Lake Counties, is famous for its wealth of critical geologic data that is ideally exposed for examination by the geologist. The central part of the region has been aptly termed the "transitional" area. In this area two major north-south trending structural elements, the Idaho-Wyoming thrust belt and the Wasatch Mountains, merge with the east-west trending Uinta Mountain arch. These uplifted areas are composed of, or flanked by, several thousands of feet of sedimentary strata that reveal a transition from miogeosynclinal sedimentation to shelf-type deposits. For details of the areal geology, the reader is referred to the Northeast Quarter of the Geologic Map of Utah, compiled by W. L. Stokes, 1961³.

The region is bounded on the west by the Basin and Range province, on the northeast by the Wyoming extension of the overthrust belt and adjacent Green River Basin, and on the south by the Uinta Basin and the southern Wasatch Range. To the petroleum geologist this region of Utah is unique in that, with the single exception of the Clay Basin gas field, more hydrocarbons are being injected into than are being extracted from underlying strata.

MAJOR STRUCTURAL ELEMENTS

Uinta Mountain Arch

The east-west aligned Uinta Mountain arch is a unique and anomalous segment of the dominantly north-south trending Rocky Mountain chain. The axis of the arch extends east to west across Daggett County, then curves and plunges southeasterly as it passes into Colorado. Approximately 35,000 feet of strata, ranging from Precambrian quartzites and phyllites in the mountainous core to Late Cretaceous on the outer flanks, are involved in the uplifted area. The arch is strongly asymmetric. Dips on the north flank exceed thirty degrees and in areas of thrust faulting are vertical to strongly overturned; whereas, on the south flank, dips into the Uinta Basin range between fifteen and twenty degrees. The northward asymmetry and axial convexity of the arch are the result of strong compressive forces acting from the south. Eardley (1961) postulates vertical uplift with subsequent gravity flow northward over the adjacent Green River Basin. Ritzma (1959) dates the major growth period of the Uinta arch as occurring between late Paleocene and early Eocene. Later folding with subsequent normal or relax faulting occurred at the close of Tertiary Miocene. Two thrust faults on the north flank, the Henry's Fork and Uinta, are planes along which some 30,000 feet of vertical uplift occurred. The magnitude of horizontal movement or thrust over the adjacent Green River Basin is unknown.

1. The writer is grateful to the management of Mountain Fuel Supply Company for permission to publish this report.

2. Staff Geologist, Mountain Fuel Supply Company, Salt Lake City, Utah.

3. Available through the Utah Geological and Mineralogical Survey.

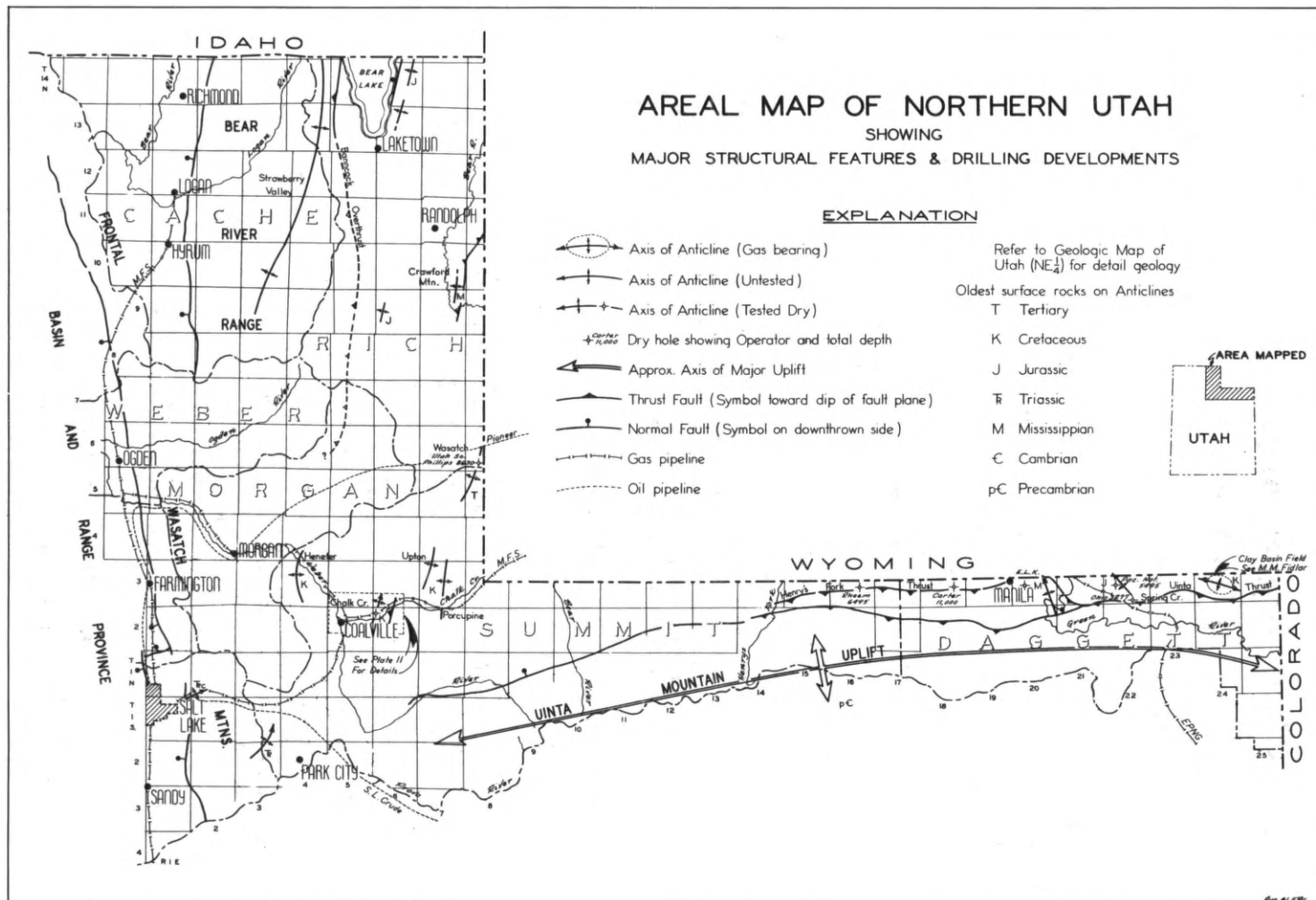


Figure 54.

Even though the Uinta arch is an anticlinal fold of considerable magnitude, it is considered a negative area to the petroleum geologist due to the extensive erosion which has exposed crystalline rocks of its Precambrian core.

Wasatch Mountains

The salient feature of the Wasatch Range is the Northern Utah Highland, described by Eardley (1939, p. 1286). This feature is an ancient positive element, the core of which is composed of sharply folded and distorted metamorphic rocks of Precambrian age. It extends northward from Salt Lake City to near Brigham City and east-west between Morgan Valley and Bird Island in the Great Salt Lake. Numerous open anticlines and synclines have been mapped north and south of the Highland in flanking Paleozoic and Triassic rocks in the Wasatch Range. These folds, most notably the Strawberry Valley anticline of the Bear River range, were developed during the Laramide orogeny. Subsequently, the folded strata were elevated by faulting into the mountainous blocks that make up the Wasatch Range. Perched anticlines of this type are considered unlikely prospects for the entrapment of oil or gas.

Idaho-Wyoming Overthrust Belt

A third major structural element, which occupies most of Rich County, is a part of the southern extension of the Idaho-Wyoming overthrust belt. Richardson (1941) shows the extension of two major thrust faults into north-northeastern Utah. The Bannock thrust, well known from Mansfield's (1927) studies, enters the state along the west shore of Bear Lake. Generally unexposed in the map area, the Bannock thrust can be observed as far south as southern Rich County, where erosion has cut "windows" through the unconformably overlapping Wasatch formation. The maximum southern limits of the Bannock thrust cannot be ascertained from surface studies; however, judging from the relative structural position of the strata comprising the central Wasatch Range and those in foothill areas around Coalville, it appears likely that the Bannock thrust may be genetically related to the Charleston thrust and others described by Baker (1959, p. 153) in the Heber Valley area. The Bannock and Charleston thrust faults are the planes along which the main Wasatch Mountain masses have moved upward to their present high structural position. The magnitude of eastward thrust along the faults is not presently known.

A second major thrust enters Utah east of Randolph, skirts the east margin of Crawford Mountain, and is the plane along which the Paleozoic rocks have been thrust upward and complexly folded. The Crawford Mountain thrust, like the Bannock, is a southern extension of the Idaho-Wyoming thrust belt. This thrust is obscured by Tertiary and recent alluvial cover, but strikes toward and may be related to the thrust faulting in the Coalville area described below.

As mentioned above, most of the area lying east of the Wasatch Mountains, principally Rich County and eastern Morgan County, is covered by Tertiary strata (Knight, Fowkes, and others). Since the principal episodes of deformation antedate deposition of the Tertiary strata, the age and structure of the underlying formations cannot be ascertained from surface study. It is evident, however, that compressional stresses generated by the eastward movement along the Bannock Thrust have developed linear north-south trending folds east of the mobile thrust block. Two such folds, visible through Tertiary cover, are indicated on Figure 54. One is located north of Laketown on the east side of Bear Lake and the other southwest of Randolph. Undoubtedly, others are present beneath the

Tertiary cover elsewhere in Rich County. Determination of such subsurface structure through seismic or magnetometer surveys could lead to the delineation of significant oil and gas traps.

Green River Basin

The extreme southern limits of the Green River basin of Wyoming extend into northern Summit and Daggett Counties. Three important folds, genetically related to the growth of the Uinta Mountain arch, are classified as belonging to the Green River Basin. These folds are, from east to west, the Clay Basin, Spring Creek, and Linwood anticlines.

Clay Basin Anticline: The Clay Basin anticline is a doubly-plunging anticline with 400 plus feet of closure. The axial trend of west-northwest is developed parallel to the Uinta thrust. Details on the geology and production history of this field are presented by M. M. Fidler elsewhere in this publication.

Spring Creek Anticline: This fold is a minor northwest-plunging anticlinal nose expressed in Mesozoic strata. The fold closes against, and presumably passes beneath, the hanging wall of the Uinta thrust. Oldest rocks on the axis are Nugget sandstone in fault contact with Precambrian. Two oil and gas tests have been drilled on the Spring Creek fold in recent years. The initial test, drilled by the Ohio Oil Company in 1956, spudded in lower Mancos shale and bottomed in Weber sandstone of Pennsylvanian age at a depth of 3,277 feet. Cores of the Weber contained shows of dead oil and were water saturated. Other sands were also barren of oil or gas. In December, 1960, Pacific Natural Gas Exploration Company completed a second well that reached a depth of 5,495 feet in rocks of Triassic age. Large volumes of fresh water were recovered from all sands tested.

Linwood Anticline: This feature is a northwest-plunging anticlinal nose developed en echelon to the Spring Creek nose. The fold involves rocks ranging in age from Pennsylvanian-Weber sandstone to Mesaverde of Late Cretaceous age. It terminates down plunge at the Henrys Fork thrust and closes up dip against a large normal fault. In December, 1961, the E.L.K. Oil Company drilled a stratigraphic test on the Linwood fold in Sec. 20, T-3-N, R-20-E. The well reached a total depth of 2,000 feet, but no other data has been released.

Carson Peak Area: This area, located in the northeast corner of Daggett County, was drilled by Carter (Humble) Oil Company in 1954. The well spudded in Tertiary Green River formation and, according to published well information, bottomed in Mesaverde formation of Late Cretaceous age at a depth of 11,200 feet. Based on the character of sediments at total depth, the writer believes the well may have bottomed in rocks of early Tertiary age. This opinion is based on the lithology of the rocks penetrated and in part on the observation that the deeper parts of the Green River Basin which received Tertiary deposits are adjacent to the steeper flanks of the enclosing mountain ranges. The exploratory methods involved in the selection of this prospect are unknown to the writer. It was probably based on seismic data.

Widdop Peak Area: This area, located in the extreme northeast corner of Summit County, was drilled in 1954, by Rheem Manufacturing Company. The well reached a depth of 6,495 feet in the Tertiary Fort Union formation. No oil or gas shows were reported. The prospect was based on seismic surveying which delineated an east-west fold north of and parallel to the Henry's Fork fault.

COALVILLE ANTICLINE

Introduction

Because of its obvious structural configuration and proximity to pipelines and market area, the Coalville anticline has been a frequent target for exploratory drilling. Since 1921, six tests have been drilled on various structural segments of the anticline. However, minor oil and gas shows were encountered only in wells drilled on the apex of the anticline in Sec. 6, T-2-N, R-6-E. As early as 1954, Mountain Fuel Supply Company considered the suitability of the structure as a gas storage prospect, and a preliminary geologic structural study was made. Gas storage is needed to assist in satisfying the seasonal fluctuations of market demands in the Salt Lake Valley.

The initial phase of this program consisted of structural and stratigraphic studies of the prospect by Mountain Fuel Supply Company personnel. A summary of this work completed in December, 1959, follows:

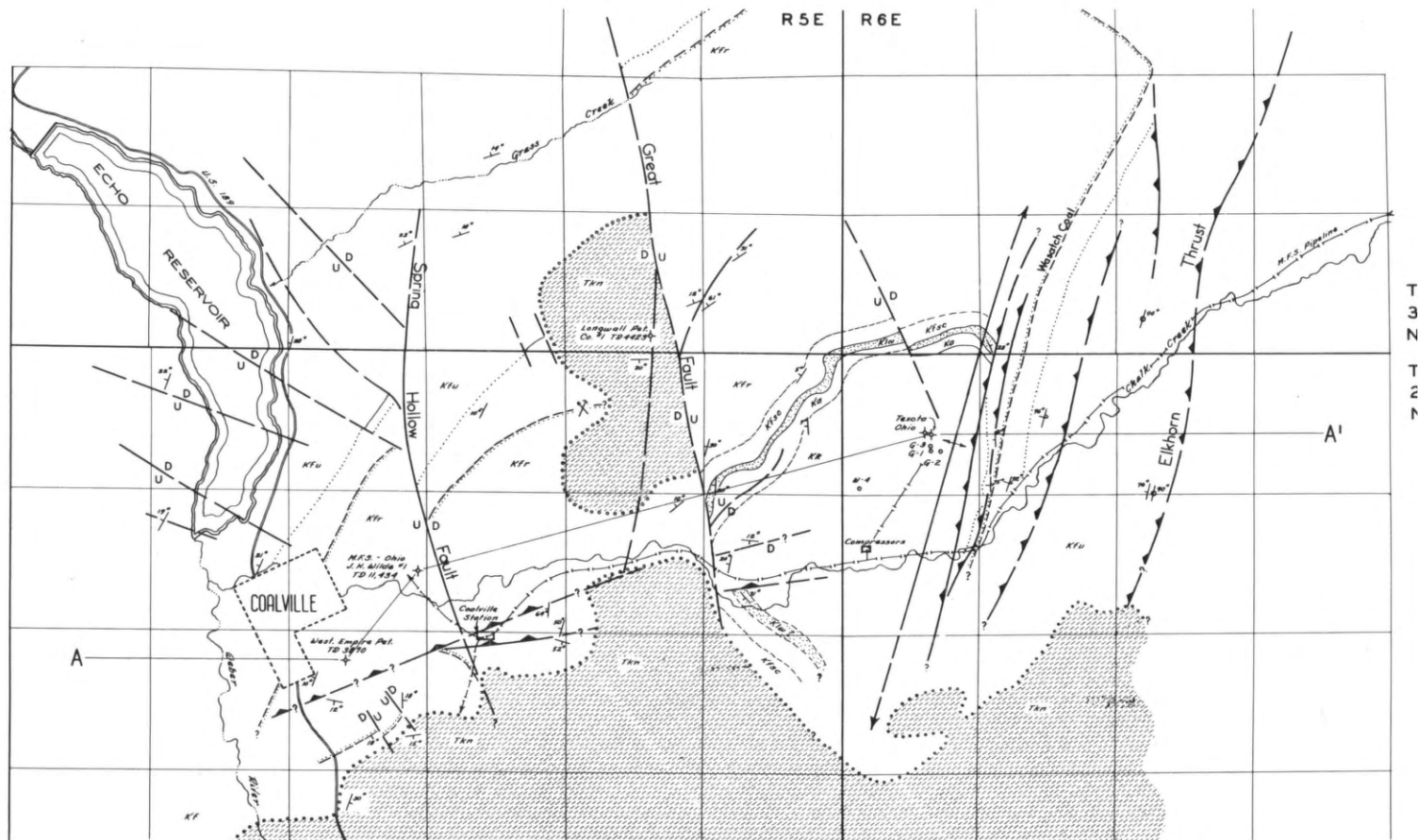
Stratigraphy

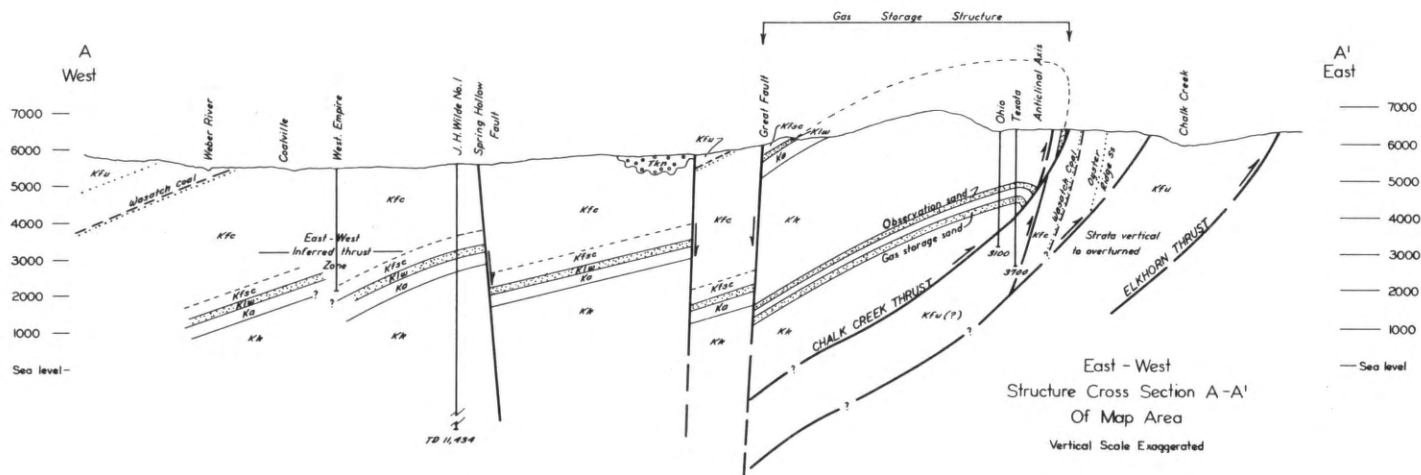
The stratigraphy of the Coalville area has been described by several writers dating back to Stanton (1893) and Wegemann (1915). The most recent published description (Hale, 1960) presented significant revisions, particularly of the Frontier formation. To present the same here would be needless repetition; therefore, a general summary of the stratigraphic section is given below. This is followed by a more detailed description of the rocks involved in the gas storage program.

		Feet
EOCENE	Knight formation--redbeds, conglomerate, sandstone, claystone	2000
	--Unconformity--	
UPPER CRETACEOUS (?)	Echo Canyon conglomerate--conglomerate, massive, nonmarine	3000
UPPER CRETACEOUS	Henefer formation--sandstone, claystone, carbonaceous at base, nonmarine	2450-2500
	Upton sandstone member--regressive marine sandstone (early Niobrara)	450
	Judd shale member--marine shale tongue of the Hilliard (early Niobrara)	350(W)-760(E)
	Grass Creek member--mixed marine and nonmarine sandstone and shale	875(E)-1025(W)
	Dry Hollow member*--basal conglomerate, middle nonmarine sandstone and shale and conglomerate, Dry Hollow coal zone and upper white sandstone hogback (early Niobrara).	1000-1220 (varies locally)
UPPER CRETACEOUS	--Unconformity-- (Hiatus spans middle and late Carlile)	
	Oyster Ridge member--basal regressive marine "Oyster Ridge" sandstone; upper part nonmarine shale and sandstone (early Carlile)	200-280 (varies locally)
	Allan Hollow shale member--marine shale (early Carlile)	780
	Coalville member--"Wasatch" coal overlying and underlying marine sandstone (late Greenhorn)	175(E)-223(W)
	Chalk Creek member--nonmarine redbed facies; pink to red claystone, coarse sandstone and conglomeratic sandstone (possibly Belle Fourche to late Greenhorn)	3150
LOWER CRETACEOUS (?)	Spring Canyon member*--carbonaceous shale, sandstone and thin coals (possibly Mowry or Belle Fourche)	350
	Longwall sandstone member--regressive marine sandstone (possibly Mowry age)	70(W)-100(E)
LOWER CRETACEOUS	Aspen (?) shale--dark gray shale and tan sandstone with interbedded light gray shale containing Teleost fish scales	210
	Kelvin formation--nonmarine redbeds: shale and sandstone, lenses of conglomerate	2500

* Member names not cleared by U.S. Geological Survey Geologic Names Committee.

Figure 55.





EXPLANATION

TERTIARY	
	Knight formation
	Unconformity
UPPER CRETACEOUS	
	Frontier formation
Kfu	Upper (several members)
	Oyster ridge sandstone
	"Wasatch" Coal
Kfc	Chalk Creek member (red bed facies)
LOWER CRETACEOUS (?)	
Kfsc	Spring Canyon (carb. shale)
Klw	Longwall sandstone
LOWER CRETACEOUS	
Ka	Aspen (?) shale
Kk	Kelvin formation

LEGEND

	Thrust fault
	Normal fault
	Dashed where inferred
	Dip component
	Dip and strike of strata
	Vertical strata
	Overturned strata
	Dry hole
	Gas injection or observation well
	Water withdrawal well

RECONNAISSANCE GEOLOGIC MAP

COALVILLE ANTICLINE (Gas Storage Project Area) SUMMIT COUNTY, UTAH

BY L. A. HALE
August 1961

On the accompanying map (Figure 55) only the areal distribution of the Kelvin formation and of the basal members of the Frontier formation is indicated. Those members of the Frontier lying above the Oyster Ridge sandstone are shown as Frontier "undivided", which roughly corresponds to the Wanship of Williams and Madsen (1959). The mapping project did not include younger formations. Key mapping horizons used in the structural survey were the "Wasatch" coal and associated sandstones, the Oyster Ridge sandstone, and the Longwall sandstone.

Kelvin formation: The name Kelvin formation was first used in publication by Eardley (1944) in the Peoa-Wanship area southeast of Coalville. It includes a lower sequence of conglomerates and shales up to 350 feet thick and an upper variegated shale and sandstone sequence 2,000 feet or more in thickness. About 4,200 feet of variegated shales and coarse-grained to conglomeratic sandstones were penetrated by the Ohio Oil Company deep test in Sec. 9, T-2-N, R-5-E. This section, encountered between 2,650 and 6,840 feet, is nearly twice the average normal thickness. Wells later drilled on the structural crest have penetrated about 2,300 feet of Kelvin above a thrust fault. Adding this to the estimated 850 feet of exposed section above the wells gives a thickness of 3,150 plus feet. The Kelvin is considered of Early Cretaceous age and equivalent to the Bear River and Beckwith, or Gannett formations, in Wyoming.

A water-bearing sandstone encountered at a depth of about 1,768 feet in Mountain Fuel Supply Company's Government Well No. 1 is currently being used as a gas storage reservoir. An upper sand drilled between 1,360 feet and 1,500 feet is being used as an observation sand.

Structure

The structural pattern of the Coalville anticline has evolved from two principal orogenies. The initial movements of the Laramide orogeny began in early Montanan and culminated at the close of Late Cretaceous with uplift and complex thrust faulting. With the waning of compressional stresses, the structural configuration was further complicated by north-trending normal faults. There ensued a period of extensive erosion which breached the Coalville anticlinal area and produced a rather extensive drainage pattern.

Further uplifting of a western mountain mass and increased rate of sedimentation buried the early Tertiary drainage system with coarse conglomerates of Eocene Knight formation. A subsequent orogeny of probable Miocene age further accentuated the structure of the area. A more detailed review of the geologic history of the general area is outlined by Eardley (1959 and earlier).

The Coalville anticline is an elongate, asymmetrical, doubly-plunging anticline with an axial trend of about North 15 East across Townships 2 and 3 North, Ranges 5 and 6 East in Summit County (Figure 55). Dips on the west limb average about 20 degrees. The structure rises to the east from Coalville and culminates in a sharp reversal in Sec. 6, T-2-N, R-6-E. The east flank is overturned and broken by west-dipping thrust faults into a complex imbricate structure. Structural configuration of the south plunge is largely obscured by unconformably overlapping rocks of the Knight formation. The west flank is modified by two large normal faults. These faults, named the "Great" Fault (after Wegemann, 1915) and the Spring Hollow fault, have together formed a deep graben two miles in width. A small area of apparent closure developed west of the graben was drilled by Mountain Fuel Supply Company in 1938 to a depth of 5,538 feet. Ohio Oil Company deepened the well to 11,434 feet in 1959 without finding oil or gas.

Following an analysis of geological data, Mountain Fuel Supply Company began experimental work on the crest of the Coalville anticline late in 1960 to test the feasibility of using the structure as an underground gas storage area.

Initially, Mountain Fuel Supply Company drilled its Government No. 1 (G-1 on Figure 55) to a total depth of 2,349 feet. The Chalk Creek thrust was encountered at 2,299 feet and the well penetrated 50 feet of west-dipping (possibly overturned) Frontier formation. After an analysis of all well data, a sand between 1,783 and 1,870 feet was selected as the gas storage reservoir and the well was completed for gas injection. The abandoned Ohio Oil Company Government No. 1 and Texota Oil Company Federal "L" Well No. 1 were re-entered and completed in the storage sand as gas injection and/or withdrawal wells. Government No. 2 (G-2) and Government No. 3 (G-3) wells were completed as observation wells to check possible vertical migration of gas from the underlying storage sand.

Upon completion of the five wells, surface facilities for the injection and withdrawal of gas were installed. The facilities consist of a six-inch spur line from the main transmission line, a 550-horsepower compressor, and a four-inch high pressure line connecting the compressor to Government Well No. 1 (G-1). A dehydration unit with a capacity of 6,000 Mcf gas per day at a pressure of 1,000 psig was installed downstream from Government Well No. 1 (G-1). Testing operations began on November 23, 1960, with the injection of about 4,000 Mcf gas per day into the storage sand. As injection continued, it became apparent there was no escape route for the water trapped in the storage sand. As a means of increasing the storage capacity of the sand, Government Well No. 4 (W-4) was drilled down structure as a water withdrawal well. After a period of simultaneous gas injection and water withdrawal, water was finally displaced by gas down structure to the level of the No. 4 well.

As of February 26, 1962, the stored inventory of gas reached 495,000,000 cubic feet. Withdrawals during the winter of 1961-1962 during period of cold weather reached a maximum of 30,000 Mcf gas per day to help meet the peak demands for natural gas in the market area. Each withdrawal is followed by gas injection during periods of warmer weather.

The Coalville gas storage program is rather unique in that the geology is unusually complex for a storage prospect, and the structure was not conclusively proven as an effective trap for accumulation of indigenous hydrocarbons. Although the proven and potential storage is not as large as desired, the project, nevertheless, has proved beneficial in meeting the fluctuating demands for natural gas in the Utah areas served by Mountain Fuel Supply Company.

CITED REFERENCES

-
- Baker, A. A., 1959, Faults in the Wasatch Range near Provo, Utah: Intermountain Association of Petroleum Geologists 10th Ann. Field Conf., p. 153-158.
- Bardley, A. J., 1939, Structure of the Wasatch-Great Basin Region: Geol. Soc. America Bull., v. 50, p. 1277-1310.
- _____, 1944, Geology of the Northcentral Wasatch Mountains, Utah: Geol. Soc. America Bull., v. 55, p. 821-893.
- _____, 1959, Review of geology of northeastern Utah and southwestern Wyoming: Intermountain Assoc. Petroleum Geologists Guidebook 10th Ann. Field Conf., p. 166-171.
- _____, 1961, Relation of uplifts to thrusts in Rocky Mountains: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 3, p. 407.
- Hale, L. A., 1960, Frontier formation, Coalville, Utah, and nearby areas of Wyoming and Colorado: W.G.A. 15th Ann. Field Conf. Guidebook, p. 137-146.

- Mansfield, G. R., 1927, Geography, Geology, and Mineral Resources of part of southeastern Idaho: U.S. Geol. Survey Prof. Paper 152.
- Richardson, G. B., 1941, Geology and Mineral Resources of the Randolph Quadrangle, Utah-Wyoming: U. S. Geol. Survey Bull. 923.
- Ritzma, H. R., 1959, Geologic Atlas of Utah--Daggett County: Utah Geol. and Mineralog. Survey Bull. 66.
- Stanton, T. W., 1893, The Colorado formation and its invertebrate Fauna: U.S. Geol. Survey Bull. 106.
- Wegemann, C. H., 1915, The Coalville Coal Field, Utah: U.S. Geol. Survey Bull. 581-E, p. 161-184.
- Williams, N. C., and Madsen, J. H., 1959, Late Cretaceous stratigraphy of the Coalville area, Utah: Intermountain Assoc. Petroleum Geologists Guidebook, 10th Ann. Field Conf., p. 122-125.

Paper 19 STRATIGRAPHY AND OIL POSSIBILITIES OF THE GREEN RIVER FORMATION IN THE UINTA BASIN, UTAH

by *Livingstone Porter, Jr.*¹

DEPOSITIONAL HISTORY

The Uinta Basin (Figure 56) first appeared in Paleocene time as a depression between the Uinta Mountains and the San Rafael and Uncompahgre highlands. Lake Uinta began as a relatively small lake surrounded by broad floodplains of low relief. During this early stage the Wasatch formation was deposited. Thick deposits of fluvial sands, silts, and mud accumulated on the floodplains, and lacustrine limestones and shales were deposited in the axial lake.

The beginning of Green River formation deposition was marked by the relatively rapid growth of Lake Uinta to its maximum size. The lake extended far beyond the present boundaries of the Uinta Basin, covering the Piceance Basin to the east, and probably was continuous with Goshute Lake on the north side of the Uinta Mountains in southwestern Wyoming. The lake may have covered a large part of western Utah, but erosion has removed critical deposits which held the key to the relationship of contemporaneous lacustrine sediments in this area to those of Lake Uinta. The balance of this discussion will concern only the portion of Lake Uinta and its sediments which fall within the present Uinta Basin.

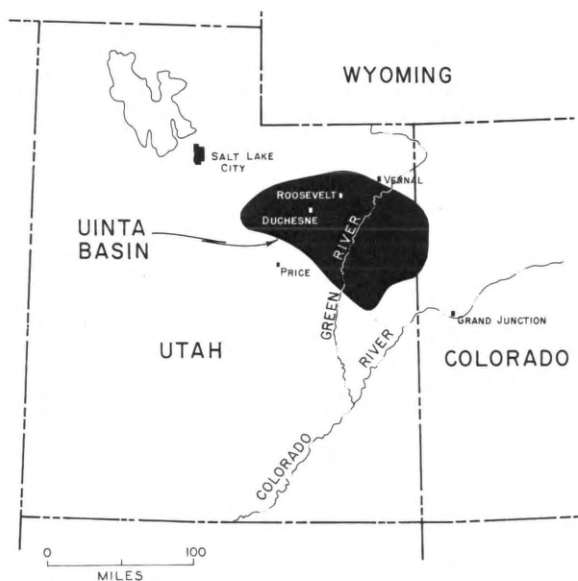


Figure 56. Index map to Uinta Basin.

1. Senior Evaluations Geologist, California Oil Company, Denver, Colorado.

During the remaining Green River deposition Lake Uinta underwent many changes in extent, but generally decreased in size as time went on. It finally became a closed basin in which the Uinta formation was deposited, and the deposition of the fluvial Duchesne River formation marked the end of the lacustrine depositional environment in this area.

STRUCTURAL HISTORY

The Uinta Basin is at present an asymmetric basin (Figure 57), with a very gently dipping south flank and a more steeply dipping north flank. This condition apparently existed throughout Green River deposition. The dominant tectonic

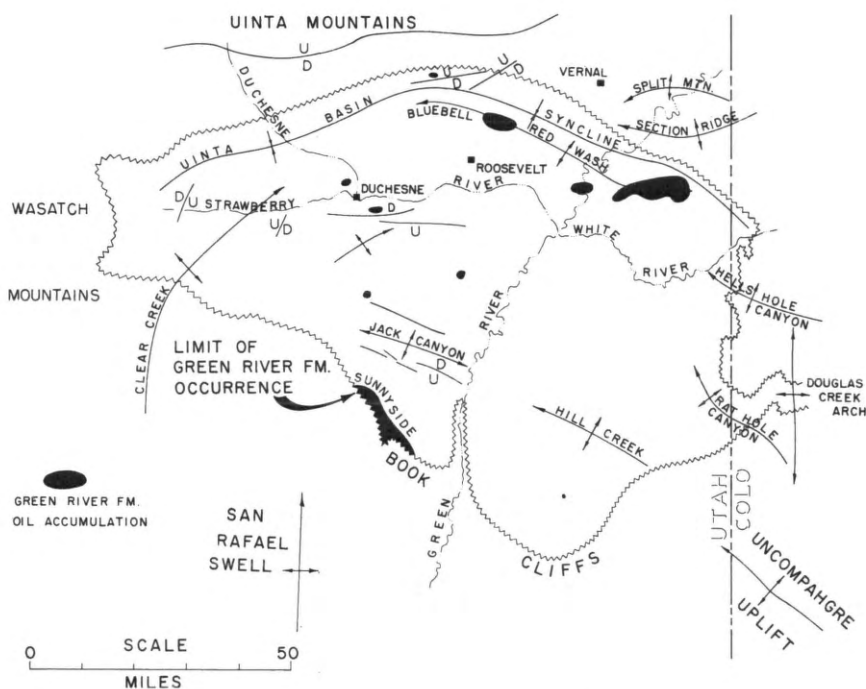


Figure 57. Structural features of the Uinta Basin.

activity throughout the life of Lake Uinta was a steady axial subsidence combined with a relative uplift of the Uinta Mountains on the north. There were several positive areas within the basin which subsided less rapidly than their surroundings, and had some influence on facies distribution within the Green River formation. Among the most important of these was the Bluebell Arch. The depositional axis of the basin centered along the present course of the Strawberry and Duchesne Rivers in the western and central parts of the basin, and more or less along the present White River to the east. The structural axis lay some miles to the north, but was masked by the rapid influx of sediment from the Uinta Mountains, which were closer to the basin and relatively higher than the source areas to the south.

Following Green River deposition the Douglas Creek arch was rejuvenated, the Uinta Mountains continued to rise, and the entire basin underwent a slight northward tilt, so that the present structural axis lies as much as twenty miles north of the indicated depositional axis. Minor crumpling, probably due to compressional forces related to continued folding of the basin, produced a number of subtle noses, such as the Red Wash-Roosevelt trend in the northeastern part of the basin and several noses plunging northwesterly off the Douglas Creek arch. The Uncompahgre uplift apparently did not subside as much as the axial and northern parts of the basin, leading to the development of the Jack Canyon and Hill Creek anticlines as drape folds on the south flank of the basin.

Tensional forces, perhaps related to regional uplift, are evidenced by a well developed northwesterly-trending fracture pattern throughout the basin. The many gilsonite veins in the basin occur as fillings in these fractures. Tensional faults of up to several hundred feet displacement appear at the surface, most notably along the Duchesne fault zone, just south of the town of Duchesne, and paralleling the Jack Canyon anticline. Subsurface information also indicates high angle reverse faulting along the north flank of the basin north of Roosevelt.

GREEN RIVER FACIES DEFINITIONS

The various facies of the Green River formation intertongue and grade into one another so that a sharp definition is not always practical. However, the following major types of depositional facies will include practically all the Green River sediments occurring in the Uinta Basin:

The fluvial facies consists of lenticular conglomerates and sandstone and vari-colored siltstones and shales. Piedmont fans along the northern margin of the basin are included in the fluvial facies. The presence of some lacustrine sediments distinguishes the marginal lacustrine delta facies from the above fluvial facies. This facies contains conglomerates, conglomeratic sandstones, siltstones, and shales. The nearshore lacustrine sandstone facies consists of locally conglomeratic delta, beach, bar, and spit sandstones; algal and oolitic limestones, and light colored siltstones and shales. The offshore lacustrine facies is similar to the above, but also contains some marl and oil shale. The axial lacustrine facies consists of oil shales, marls, dense, fine-grained, muddy limestones, and dark colored shales, and contains no coarse clastics. Finally, the mud flat-deltaic facies is composed of gray-green shales, siltstones, and thin sandstones, interbedded with thick, lenticular, cross-bedded channel sandstones and shallow water oolitic and algal limestones.

FACIES DISTRIBUTION AND OIL OCCURRENCE

The following discussion of facies distribution does not necessarily hold true for any one horizon within the Green River formation, but rather considers the areas in which each facies is predominant (Figure 58).

Rocks deposited in the fluvial environment are only partially represented along the north flank of the Uinta Basin. Post-depositional uplift and erosion have removed many of these basin margin deposits, and overlap by younger Tertiary deposits makes their mapping difficult. Although abundant oil shows have been found in the sandstones and conglomerates of this facies both in wells and at surface outcrops, the individual lenses of reservoir rock are of restricted lateral

extent, and to date have not offered encouragement as exploratory objectives. The sediments of the fluvial facies grade into those of the marginal lacustrine delta facies along the shoreline of Lake Uinta.

The conglomeratic deposits of the marginal lacustrine delta facies accumulated where the swift streams coming off the Uinta Mountains emptied into the lake, and the water could not transport the pebbles and cobbles any farther. The gravel benches found along the Wasatch front at the mouths of present day canyons represent similar deposits of Lake Bonneville. Oil production was obtained from conglomerates and sandstones of this facies at the Starr Flat field, but proved subcommercial due to limited reservoir extent. This facies grades rapidly into the nearshore lacustrine sandstone facies.

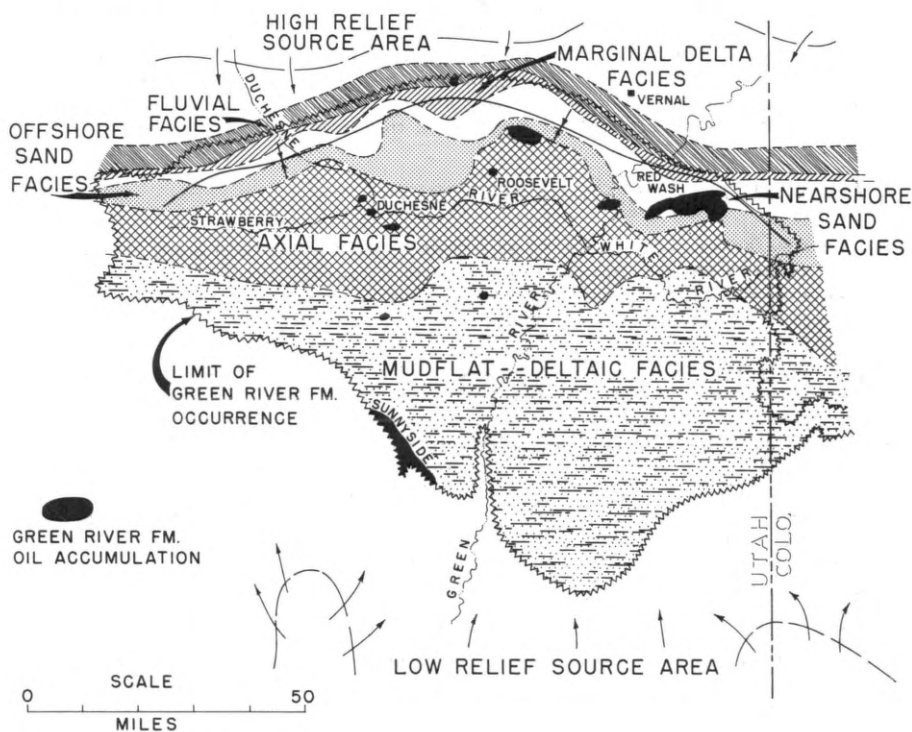


Figure 58. Green River formation facies distribution.

The nearshore lacustrine sandstone facies includes sandstones of delta, beach, bar, and spit type, which are most favorable environments for development of reservoir sandstones. The Red Wash field, so far the major oil field in the basin, produces from beach and delta sands of this facies. The accumulation is essentially stratigraphic, localized on a westward-plunging structural nose. The facies extends westward from Red Wash and is believed to occur in a continuous band of varying width all along the north flank of the Uinta Basin. Because the present location of the Uinta Basin synclinal axis is far to the north of the depositional axis, the nearshore lacustrine sandstone facies grades into the much shalier offshore and axial facies in a southerly up-dip direction along practically the entire north side of the basin.

The offshore lacustrine facies is a transitional deposit between the nearshore sandstone facies and axial lacustrine beds. This facies occurs in a band from two to ten miles wide along the entire length of the Uinta Basin. Sandstones of this facies are generally thin, fine-grained, and silty. They are, however, capable of hydrocarbon production, as evidenced by gas production in the Red Wash field and fractured sandstone oil production at the Roosevelt field.

The axial lacustrine facies occurs in the depositional axis of the Uinta Lake basin. It forms an east-west trending band which crosses the Douglas Creek arch from the east and extends entirely across the Uinta Basin to the present outcrop edge on the west in a zone varying between 8 and 20 miles wide. Fracture production has been obtained from shales of this facies in the Roosevelt field, and also from several wells near Duchesne. Oil shales of this facies contain tremendous amounts of oil. The axial lacustrine facies interfingers southward into the mud-flat deltaic facies.

The mud flat-deltaic facies occurs along the southern margin of the basin and represents an area of low relief and very gentle slope, where material derived from the San Rafael and Uncompahgre highlands to the south accumulated in shallow water. Oil has been found in this facies in the outcrop near Sunnyside, at Chokecherry Canyon and most recently at Mountain Fuel Supply Co. Wells Draw Unit No. 1. Oil shows have been noted in a number of wells in this facies, and the saturated sands outcropping near Sunnyside were once a major oil field. The Jack Canyon accumulation in upper Wasatch sands of a similar facies is structurally controlled, and the other known accumulations in this facies apparently are trapped by updip pinchouts of the particular sand involved.

OIL POSSIBILITIES OF THE GREEN RIVER FORMATION

The oil shales of the Green River formation indicate the presence of a remarkable source of hydrocarbons, and shows or production have been found in rocks of every facies of the Green River formation. It therefore seems almost inconceivable that the one major oil field discovered to date will turn out to be the only important commercial Green River accumulation in the Uinta Basin. Let us then review the types of accumulations which may occur in the different parts of the basin.

In the southern part of the basin, where the mud flat-deltaic facies is predominant, oil will probably be found in isolated sand lenses which are not open updip. Any local variations in the regional depositional trends which might have caused the deposition of a number of such sands over a period of Green River time in one area could cause a concentration of such individual accumulations into a commercially attractive oil field. Any purely structural traps, such as folds, or faults which could interrupt updip migration, could localize accumulations in a number of different sand bodies.

The central part of the basin appears to have potential in fractured shale and sandstone production. Results to date have not been encouraging because of high drilling costs and rapid production declines; however, this has been the history in many areas of fracture production where, nevertheless, several fields with good profitable production have been found.

The northern part of the basin appears to offer an attractive potential for the occurrence of oil accumulations. Onlap and truncation of Green River sandstones of the marginal lacustrine delta facies are known to occur north of the Uinta

Basin syncline, providing stratigraphic trap possibilities. Faulting and structural nosing may concentrate stratigraphic accumulations in local areas.

South of the syncline the updip gradation of nearshore lacustrine sandstones toward the axial shale facies offers classic stratigraphic accumulation conditions. Localization of oil accumulations may be accomplished by variations of the limits of sandstone deposition from the general east-west trend.

DRILLING ACTIVITY

Only about 50 significant wildcat wells have been drilled in the one hundred-odd townships west of the Green River. Some of these wells are grouped fairly close together, and one can count about 60 townships in this area which contain no significant wells. In the smaller area east of the Green River drilling has been considerably denser. However, one township adjacent to the Red Wash field has only one Green River test, and another only two, indicating that even here there is room for more oil to be found.

SUMMARY

In summary, it appears that oil accumulations in the Green River formation will be found in stratigraphic traps, dependent to some extent on local structural and depositional variations from the regional trends. Finding such accumulations will not be easy, because of the scattered geologic control available. On the other hand, the very presence of large untested areas in a proven oil province provides a challenge to imaginative geologists.

Paper 20 ECONOMIC ASPECTS OF UINTA BASIN GAS DEVELOPMENT¹

by L. W. Folsom²

Early exploratory drilling in the Uinta Basin was largely confined to the search for oil. Many of the early-drilled wells had substantial amounts of gas, having only nuisance value because of marketing difficulties.

Oil, even when discovered in remote areas and inaccessible to a pipeline, is adaptable to various other methods of transportation. The operator may suffer a transportation-cost penalty, but he can still be fairly certain of selling his product within a reasonable length of time; but the unique character of natural gas demands transportation by pipeline. Consequently, years of effort and an outlay of millions of dollars may be required before sufficient gas reserve can be developed to justify a pipeline into a market area. Moreover, where inter-state transmission is required to reach a market area, Federal Power Commission regulation becomes involved and operators face the risk of exploration and development expenditures being unproductive of a return on investment for a long period of time before the Commission authorizes connection of the wells--this without the certainty of any reliable estimate of the price the F.P.C. will finally approve.

HISTORY OF DEVELOPMENT

Minor gas production was established in the Uinta Basin in 1929-1941. In the search for oil during the following ten years, many excellent shows of natural gas were encountered in the Tertiary and Cretaceous sediments. With later rumors of pipeline planning, a further boost was given to the exploratory effort for natural gas, and the late 1950's saw unprecedented activity: 21 wildcat wells being drilled in 1960; 39 in 1961; and a projected 75 to 100 wildcats in 1962. In the 62 year period of drilling history, over 500 wells have been drilled. It is estimated that at least half of these have been drilled for gas and that the overall success ratio is 1 to 2.6. In 1961 alone, the wildcat success ratio was 1 to 3 or 33-1/3 per cent. Moreover, many of the wells failing in commercial completion, have had significant shows that have led to later discoveries.

PIPELINE OUTLETS

The Uinta Basin is now served by three pipeline outlets (Figure 2): The Rangely-Salt Lake (crude oil) pipeline, the Pacific Northwest Pipeline-El Paso Natural Gas line, and the Mountain Fuel Supply-El Paso Natural Gas line. The second line is available to only a small northeast segment of the basin. The Mountain Fuel-El Paso line furnishes the first accessible major outlet to market for Uinta Basin natural gas.

1. Condensed from a paper presented before the Intermountain Assoc. Petroleum Geologists, Salt Lake City, Utah, April 16, 1962, and the Rocky Mountain Section of the American Association of Petroleum Geologists, Salt Lake City, Utah, April 24, 1962. Published through the courtesy of Mountain Fuel Supply Company.

2. Manager, Exploration Division, Mountain Fuel Supply Company.

GEOLOGICAL CONSIDERATIONS

General

The geology of the area has been comprehensively covered by collective authors in this volume, recent field conference guidebooks (particularly Intermountain Assoc. Petroleum Geologists Guidebooks for 1956 and 1957), and other references which are prolific.

Stratigraphy

Minor gas production occurs from the Cretaceous Mesaverde and Dakota formations and from the Eocene Uinta formation. Associated gas is produced from the Green River-Wasatch transition zone in the Red Wash-Walker Hollow oil field. The main production, however, is from stratigraphic traps in the fluvialite, red bed sequence, generally considered as the Wasatch formation, here termed LOWER TERTIARY UNDIVIDED (Figures 59 and 60). This part of the section is here referred to as a fluvialite sequence rather than a shallow-lake (bar, patch, and barrier) deposit as proposed by Hendel (1960), whose sound geologic reasoning strongly supports his ideas. Figure 61 shows the over-all relationship of the Lower Tertiary to the formations of late Cretaceous and early Tertiary age.

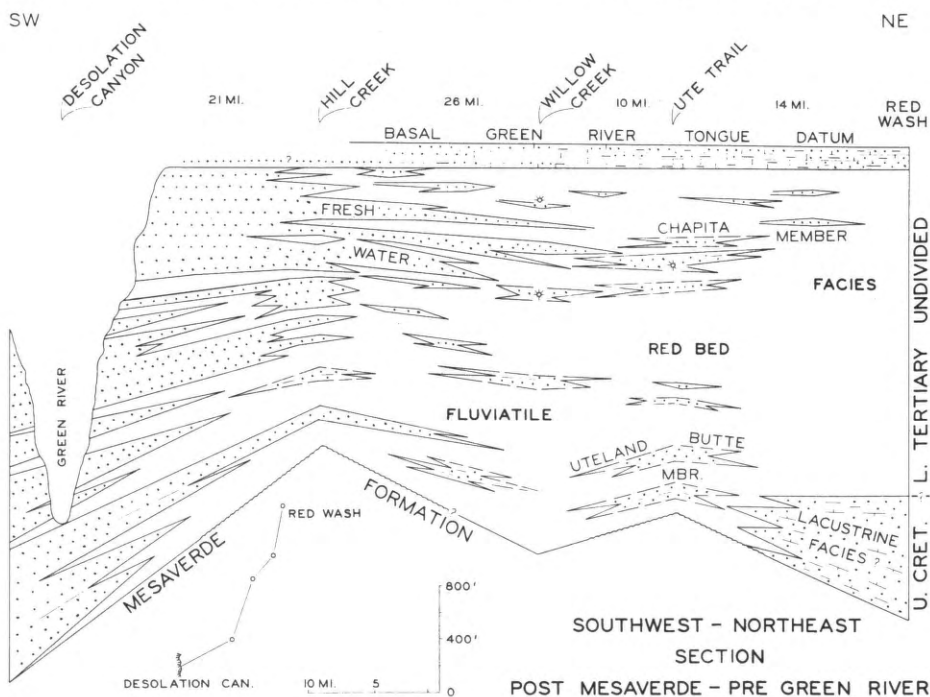


Figure 59.

Two productive zones occur within the "Wasatch" portion of the undivided lower Tertiary in the basin. The upper of these is commonly referred to as the Chapita sandstone or member, and the lower is herein referred to as the Uteland Butte member (Figures 59 and 60).

The Chapita member, named for its occurrence in wells drilled in the vicinity of the Chapita Wells field, is a zone of about 400 to 500 feet composed of lenticular sands interbedded with shales. The top of this zone occurs at about 500 feet below the top of the Wasatch--that is below the basal Green River tongue. Fields from which the main gas production is from this zone include Chapita Wells, Ute Trail, Uintah, Island, Southman Canyon, and Rock House (Figure 1) .

The Uteland Butte member occurs in the lower part of the undivided lower Tertiary. This member, like the Chapita member, is 400-500 feet thick and composed of lenticular sands interbedded with shales. The Uteland Butte field's gas production, the Sinclair Oil and Gas Company's recently completed oil well in the west Sweetwater Creek area, and the Rainbow Unit (Shamrock's Unit No. 4) are producing from this zone.

Fossil evidence published by Swain (1956) and La Rocque (1960) shows that the "Wasatch" of the basin is the time equivalent of the basal Green River, the Colton, and the Flagstaff to the southwest of the basin. Abbot (1957) correlates the lower Wasatch as a time equivalent of part of the North Horn formation to the west and possibly of the Tuscher formation to the southeast. Thus, as indicated on the generalized stratigraphic section (Figure 61), the Chapita member may be a shoreward facies of part of the Flagstaff, and the Uteland Butte member is possibly a time equivalent of part of the North Horn and the Tuscher formations to the northwest and southeast, respectively, and conceivably might be in part of late Cretaceous age. Hale (personal communication) supports this interpretation.

Stratigraphic and Geographic Distribution of Hydrocarbons

The Wasatch formation is the most economically important gas producing zone in the east-central portion of the basin. The possibility of oil or natural gas occurrence in horizons other than the Wasatch decidedly lowers the risk factor of any exploratory drilling. These objectives include the Tertiary Uinta, Green River, and the Cretaceous Tuscher and Mesaverde formations. Marginal to the basin, the Cretaceous Mancos (Emery), Dakota, and Cedar Mountain formations are important gas-bearing horizons as are the Jurassic Morrison and Entrada and the Permo-Pennsylvanian Phosphoria and Weber.

Uinta formation wells have produced some gas at the Bend field, Red Wash-Walker Hollow field, and at Chapita Wells. These wells are relatively shallow, but pressures and volumes appear low and the reserve is not great.

The Green River formation has produced both gas and oil but is more important as an oil-producing formation. The Roosevelt and Gusher fields produce oil from the Green River formation. The Red Wash-Walker Hollow field also produces considerable associated gas from sandstone lenses in the lower Green River formation, actually the transition zone of the Green River-Wasatch formations. Nonassociated gas is produced in the Red Wash-Walker Hollow field from the same part of the stratigraphic section, mainly at the east end of the field. The transition zone is productive in the Peters Point-Jack Canyon field as well. The Recent oil discovery in the Wells Draw Unit by Mountain Fuel Supply Company is in this same general transition zone.

The Mesaverde formation has shown some oil production at Chapita Wells and Southman Canyon fields. The Castlegate sandstone member has shown some gas occurrences in areas marginal to the basin. The Mesaverde formation is one of the most promising potentially productive formations and should contain a sizeable reserve that remains to be tapped.

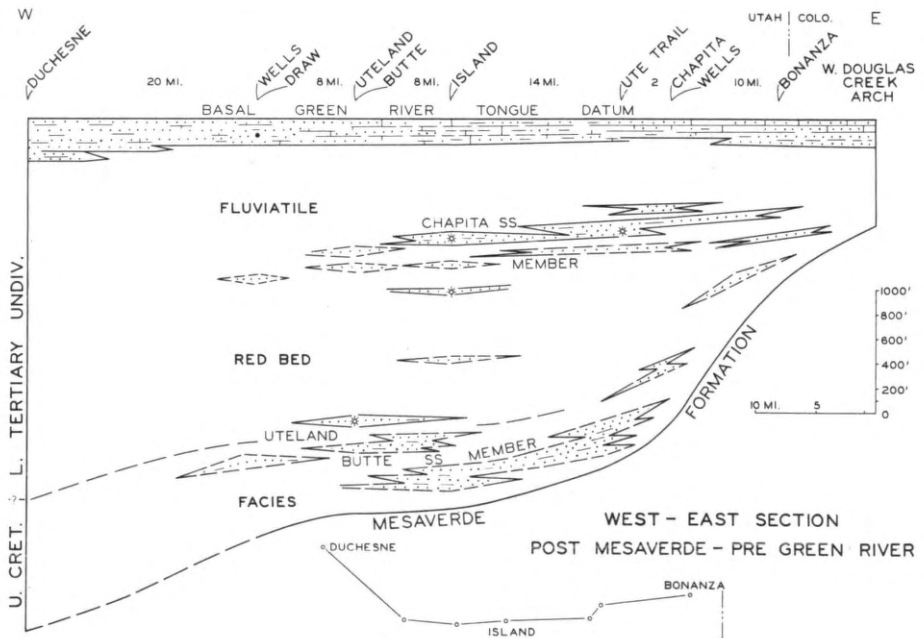


Figure 60.

ECONOMIC CONSIDERATIONS

At the outset of any economic discussion on the Uinta Basin, it should be pointed out that production into pipeline is still too new and, hence, data on depletion, pressure decline, water encroachment, and other variables is inadequate to make any reliable, long range projections as to life of production and ultimate reserves. It is necessary, therefore, to place somewhat arbitrary limits on economic factors of gas development. These limits make estimation of reserves difficult and, consequently, there is a wide variance in estimates and a distinct chance for inherent and unintentional error on the part of any estimator. It is, moreover, difficult to compare statistics with those given nationally for the gas industry because of unique factors influencing the economics of this area but generally nonexistent in other gas producing provinces. For one, at the present time there is a single reasonable market area to be served (Mountain Fuel Supply Company's service area) and a single pipeline purchaser for the

major portion of the Uinta Basin gas; therefore, perhaps competitive bidding for price is limited. It seems quite unlikely that this situation will change within the foreseeable future. It is not anticipated that the Rock Springs-Thistle portion of the proposed El Paso-Colorado Interstate, California system line will be accessible to the basin nor increase the outlet for gas from this area. However, the intrastate nature of the Uinta Basin Pipeline outlet avoids F.P.C. regulation and some of the obvious disadvantages of this type of control. Moreover, should a surplus reserve be developed in the future, there is a distinct possibility of other pipeline outlets.

Market

Customer growth rate as indicated by population increase is the usual basis for analysis for future market demands for energy supplies. Between 1955 and 1960, the population in Mountain Fuel Supply Company's service area increased by 128,000 (from 560,000 in 1955 to 688,000 in 1960). The population of the state of Utah during the same period increased by 103,627. There was actually a population shift, therefore, into the market area. The percentage increase of the market area population compared to the state population increased from 71.1 per cent to 76.9 per cent. The number of firm load customers served, that is the new customer connections made, increased by nearly 50,000 (49,653), an average of about 10,000 each year. In the last year (1961), 9086 new customers were added to Mountain Fuel's distribution system.

Based on total annual gas requirements in the service area since 1955, a forecast can be made as to the total requirements by 1966. This is tabulated below:

ANNUAL GAS REQUIREMENTS M²cf @ 12.85 Psia

<u>Historical</u>	<u>Forecast</u>
1955 - 58,955	1961 - 90,119
1956 - 66,421	1962 - 96,944
1957 - 67,807	1963 - 104,719
1958 - 64,474	1964 - 112,179
1959 - 65,398	1965 - 117,202
1960 - 81,076	1966 - 122,983

This increase in over-all demand reflects the total of firm requirements plus industrial fuel requirements. It also reflects a fairly steady proportional relationship between population growth and the need for industrial fuel. Actually, there is a slight progressive increase in the proportion of industrial fuel requirements to over-all requirements. The increase is the result of influencing factors, such as technological advances, centralization of industry, loss of competitive position by coal, convenience, and many others. As population increases and is followed by greater centralization of industry, it is anticipated that this proportion of industrial demand to total demand will progressively continue to become greater.

Market area projections indicate initial requirements of 26 million cubic feet per day from the Uinta Basin area. By 1964, 73 million cubic feet per day will be required, increasing to 100 million cubic feet by 1966.

Reserves

It has been estimated that the Uinta Basin contains from 1.25 trillion (Osmond, personal communication) to 2 trillion cubic feet (Pruitt, 1961) of recoverable gas reserve. These estimates were made before any sustained production was established and were, therefore, based only on examination of logs and drill stem tests. Evidence now used to make estimates is subject to change. Only a reasonable estimate of gas recoverable from that already discovered in place can be made. The reserve, thus estimated, as of December 31, 1961, is 1,080 M³cf (one trillion eighty billion cubic feet).

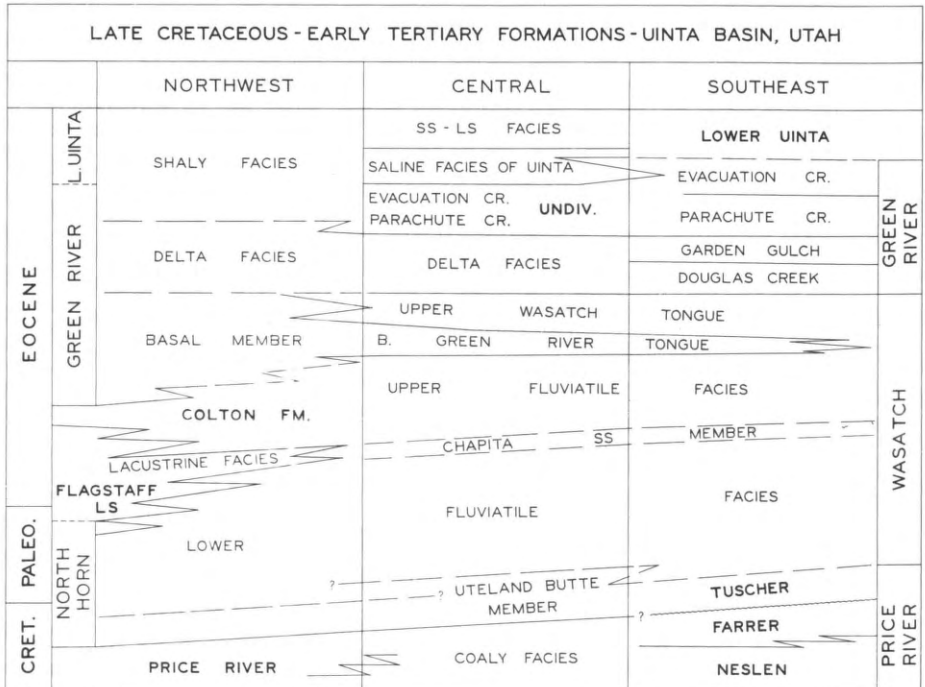


Figure 61.

The Tertiary Green River-Wasatch formation transition zone and Wasatch formation proper account for about 75 per cent of the estimated reserve. The Cretaceous Dakota and Jurassic Entrada, on the south flank of the basin where they occur at reasonable drilling depths, account for about 15 per cent of the total estimated reserve. Of this, about 5 per cent of the total reserve is low Btu gas from the Entrada sandstone. The Cretaceous Mesaverde now accounts for about 6 per cent for the reserve in the Uinta Basin. This group has a much greater potential productive capacity than has been proved to date, and it is anticipated that important reserves in this group will be tapped in the near future.

Field Price

The price currently being paid in the area by Mountain Fuel Supply Company and Utah Natural Gas Company is 16-1/2 cents a thousand cubic feet. Escalation of 1 cent each five years is provided so that ultimately the field price will reach 19-1/2 cents a thousand cubic feet.

Under the above terms of gas sales agreements, reserves developed under an area in excess of 600,000 (about 675,000) acres are committed to the Uinta Basin Pipeline. Over twenty separate operators and/or producers in over fifteen fields and areas have committed their reserves to this line and now have an outlet to market for their reserves.

Drilling Costs, Completion Procedures, and Deliverability

The average depth of wells drilled in the basin to test through the productive Wasatch formation sands is about 6,000 feet. There is considerable variation, of course, from the deeper portions of the basin outward toward the flanks. Completed well costs in excess of \$20 per foot are to be expected at these average depths. As exploratory drilling goes to deeper objective horizons, such as the Mesaverde at projected average depths of 8,000-9,000 feet, per foot drilling costs increase by at least one-third. An increase in drilling depths below the 10,000 foot range double or triple completed well costs. If increased gas reserves per unit of porosity and depth should be encountered, such deeper drilling might be economical.

Such increase in reserve per unit of depth is generally the exception throughout the Rocky Mountain area, however, because of the progressive loss of effective porosity with depth. It would be extremely risky at this stage of drilling history to predict what might eventually prove to be optimum drilling depths in the Uinta Basin. Drilling costs have been reduced by the use of gas as the circulating medium, but this method is not without risk, because of the random occurrence of formation water. It is reasonable to expect greater use of gas drilling techniques in the future with consequent reductions in per-foot drilling costs.

Artificial stimulation of the lower Tertiary producing zones has decidedly increased the potentials of numerous wells, in some cases many times over. This has now become nearly standard completion procedure and certainly should be a continuing practice. Experience seems to indicate that an oil-base frac is preferable to a water-base frac and that initial potential and deliverability is increased by the use of diesel-oil as a frac fluid. A few of the wells recently drilled have shown very low or no deliverability against pipeline pressure. It is possible that stimulation or restimulation, in some cases, might be a remedy.

SUMMARY AND CONCLUSIONS

Currently, the largest percentage of gas reserve has been developed in stratigraphic traps in the lower Tertiary sediments. Further exploratory drilling should tap additional Cretaceous Mesaverde gas, and this formation is considered an attractive objective whose full potential remains to be revealed. Deeper objectives offer untested potentials around the fringes of the basin where drilling depths are not prohibitive. The "bonus potential" of oil and/or condensate in the lower Tertiary and upper Cretaceous sediments add incentive to exploratory drilling throughout the area.

Continuing improvement of drilling and completion techniques will increase potentials and deliverability of wells and will hold the line on costs per foot drilled. Completed well costs are now on the high side of the average costs in the Rocky Mountain area. Experience will, however, bring these costs down.

Although it can be stated correctly that the ultimate amount of gas to be discovered in any producing province is "fixed by nature", it might be added that the RATE of discovery depends upon the intensity of exploration activity. This, in turn, depends upon economic factors: a price for the product and an availability of market. These have now been provided in the Uinta Basin and its future is indeed promising.

CITED REFERENCES

- Abbott, Ward, 1957, Tertiary of the Uinta Basin: Intermountain Assoc. Petroleum Geologists Guidebook 8th Ann. Field Conf.
- Geology of East Central Utah, A symposium: Intermountain Assoc. Petroleum Geologists Guidebook 7th Ann. Field Conf.
- Hendel, C. W., 1960, Wasatch Gas in the Uinta Basin: Paper read at Rocky Mountain Section of A.A.P.G. meeting, Billings, Montana, February, 1960.
- LaRocque, Aurele, 1960, Molluscan Faunas of the Flagstaff Formation of Central Utah: Geol. Soc. America Mem. 78.
- Pruitt, Robert G., Jr., 1961, The Mineral Resources of Uintah County, Utah: Utah Geol. and Mineralog. Survey Bull. 71, p. 61.

Paper 21 GREEN RIVER OIL SHALE POTENTIAL IN UTAH

by M. Darwin Quigley¹ and Jack R. Price²

The Green River formation of Colorado, Utah, and Wyoming contains the greatest potential reserves of oil in the world. The problem has been that of finding an economical method of extraction.

The first economic study of the oil shale in Utah started in 1913 (Woodruff and Day, 1914). Since that time sporadic attempts have been made to establish oil shale as an economic source of liquid fuels. Much activity took place during the interval from 1914 to 1920. D. E. Winchester (1923) published a comprehensive account of the oil shale deposits and the efforts to exploit them. Immediately after Winchester's bulletin was published, the discovery of rich petroleum fields in Texas, Oklahoma, and Kansas flooded the market with abundant oil and dampened enthusiasm for further research on shale oil for a generation to come.

However, the oil shale reserves of the Uinta and Piceance Basins have been steadily increasing in potential economic importance, even though there is presently no large scale operation that converts the oil shale to crude oil. There are several reasons why the oil shale reserves are becoming more important. First of all, many oil companies have gone abroad to increase their reserves in crude oil. The profits from the sales of those reserves have to be shared with the foreign country wherein the reserves are developed. The growing nationalism of most foreign countries is such that they are demanding a greater and greater proportion of the profit. The increased percentage of profits strengthens their economic power until they are rapidly reaching the point where they are able to explore and develop their own petroleum resources. Then, they no longer welcome U.S. companies. As a result, the U.S. companies must look more carefully at the potentials of our domestic resources, the largest of which is oil shale.

Secondly, oil shale is becoming more important because of the ever-rising exploration costs. The cost of finding new oil is already above the value of the oil found in many domestic oil provinces. Many companies are continuing to exist only because they are still producing oil that was found ten or more years ago at much lower costs. As that low-cost oil is gradually exhausted, the economic squeeze becomes more and more intense. If these companies are to perpetuate themselves, they must turn to a resource where the odds are much more favorable, even though the maximum profit margin may be somewhat smaller. The answer is the solid petroleum resources, such as oil shale and tar sands.

The recent, mandatory import controls must have a stabilizing and an encouraging effect on the domestic oil industry. If the still-growing demand for more power from oil is to be satisfied, then we must increase the available supply of oil from domestic sources at lower-risk capital costs. Since there would be no dry holes in oil shale crude development, the risk capital is minimized, even though it is admitted that substantial amounts of risk capital must be expended in the near future in research and technological developments to more efficiently extract and refine the oil from the oil shale.

1. Chief Geologist, English Oil Company, Salt Lake City, Utah.

2. Formerly, Geologist, General Petroleum Corporation, assigned to special research on oil shale.

Finally, new developments in refining techniques (the possible application of nuclear energy to more economical mining and retorting "in situ", and the experiments and developments that are in progress in other countries) all tend to place the oil shale industry on the threshold of reality. The potential of the industry is so great that once it gets under way it could grow so rapidly as to be reminiscent of the growth of the search for liquid crude oil after the discovery of the first commercial well near Titusville, Pennsylvania, on August 27, 1859. Only those companies that are aware of the potential and are well acquainted with the latest techniques through experienced personnel of their own can expect to be economically successful in a phase of the industry that is so foreign and so mingled with problems unfamiliar to their past background. Consequently, it is quite timely to consider what is known of the oil shale reserves of Utah.

OIL SHALE ENVIRONMENT

"Oil shale" isn't really shale at all. The rock is more nearly a limestone or mudstone formed eons ago in quiet lakes where there was abundant plant and animal life in shallow water. In addition to the plant and animal remains, the calcium-carbonate ooze was intermixed with the sand and clay brought into the lakes by the streams and rivers draining into them. This mixture, over a period of millions of years, was compressed into rocks. These rocks, known as oil shales, are more correctly called limestones, mudstones, or dolomites, depending on the relative amounts of calcite, clay, or dolomite in them. The foregoing conditions of sedimentation existed during the deposition of the Green River (Eocene) formation in the Uinta Basin. The shallow, lacustrine environment, uninterrupted for such a long period of time, made possible the accumulation of vast quantities of decaying organic material, commingled with the argillaceous and calcareous deposits of the lake. These materials were compressed into oil shale, whose richness, thickness, and extent are unique when compared to similar deposits in any other part of the world.

The gradual subsidence of the Uinta Basin under the load of the accumulating organic and inorganic rock materials, without major diastrophism, made possible the preservation of the oil shale formed by compression and burial. The oil shale deposition was interrupted only by short periods of volcanism which spread thin tuff and ash blankets over the lake floor. Those blankets are preserved as analcitized tuff beds in the Green River section. They are remarkably continuous, even though they rarely exceed a few feet in thickness. The gradual burial of structures in the lower Green River section and in the Wasatch without unconformity or disconformity is indisputable evidence of the constant and continued accumulation of organic and inorganic material, together with gradual subsidence.

Following Eocene deposition of the oil shale, the accumulation of sediments in the Uinta Basin became mainly fluviatile in response to the greater uplift of the Uinta Mountains. In spite of the terrestrial origin of most of the sediments of the Uinta formation, lacustrine deposition continued to take place in the center of the lake, so that in the vicinity of Duchesne there are in excess of 10,000 feet of lacustrine beds. The widespread deposition of the Uinta formation and the overlying Duchesne River formation preserved the underlying rich oil shale deposits of the Green River from erosion over the northern two-thirds of the basin. The oil shales are either exposed, near exposure, or have been eroded away on the remaining one-third of the basin.

STRATIGRAPHY

A lengthy discussion of the stratigraphy of the Green River formation, wherein the bulk of the oil shale is deposited, is adequately covered in the literature by Picard (1955, 1957), Abbott (1957), Cashion and Brown (1956), Cashion (1957), Dane (1955), and by others. The bulk of the rich oil shale deposits occur in the Parachute Creek member of the Green River formation, with minor amounts occurring in the Evacuation Creek member, above. Near Soldier Summit, where Abbott (1957) reports $2,000 \pm$ feet of the lower black-shale facies of the Green River, the total thickness includes "some rich oil shale." To the west and northwest, the Parachute Creek member and the Evacuation Creek member change gradually by lithologic variation and become part of the saline facies of the central Uinta Basin. In general, the oil shales are thickest and richest near the depositional axis of the basin. Consequently, it would seem that they would be present in even greater amounts northwestward from the Sun Oil Company's Ouray well in sec. 22, T-9-S, R-20-E. The lithologic variation to a saline facies limits such a generalization to the west. It is probable that the oil shales give way to saline beds by gradual interfingering in the deeper parts of the basin. The lack of core analysis on oil and gas test wells to the west and northwest of the Sun Oil Company's Ouray well makes it difficult to do more than extrapolate the possible lithologic variations through detailed study of the electric logs.

The most notable bed of the Parachute Creek member is the Mahogany Ledge. Mapped by Cashion and Brown (1956) throughout the eastern part of the basin, it contains the thickest and richest oil shale zone in the Green River formation, and is a very persistent and an extremely useful marker bed. It thins to the south and thickens westward from the Colorado-Utah line. It can be traced to the Green River, but has not been recognized as a separate unit west of the river.

RECENT DEVELOPMENTS AND ECONOMICS

The lengthy research project on the refining of shale-oil crude at Rifle, Colorado, by the Bureau of Mines, and the construction of a production retort plant at Grand Valley, Colorado, by Union Oil Company of California, have paved the way for favorable economic competition between shale-oil crude and normal crude oil. Union Oil Company officials have stated that they were able to reduce the cost of refining to 75 cents per barrel of shale crude. Continued efforts and research are bound to reduce that cost even further. It is the opinion of the authors that the "heated ball" retorting method of the Aspeco process, developed by the Denver Research Institute, is a step in the right direction toward increased efficiency and lower refining costs. It would seem logical that, if the retorting takes place in an "air-free" environment without combustion, the volatiles emitted would have a B.T.U. value equal to, or nearly equal to, pipeline standards. The gases emitted by the combustion retort are diluted by air, carbon dioxide, water vapor, and other possible products of combustion. These gases must then be filtered and enriched to meet pipeline standards.

Mining

The cost of mining the oil shale and transporting it to the refinery are the other major factors contributing to the total cost of shale-oil crude, as compared to the cost of exploring for and developing new reserves of normal crude. It would appear that those areas where the oil shale is mineable by open-pit methods offer the most favorable economics. A complete mining-cost study undertaken recently by

one company indicated that the oil shale could be stripped and mined for a cost of slightly less than 50 cents a barrel, based on an average richness of 30 gallons per ton, as determined by laboratory analysis of cores.

Underground methods of mining materially increase the cost, and such methods will be required on those deposits which are too far removed from the outcrop to be economically stripped. The Bureau of Mines has been able to estimate a total cost of 75 cents per ton at the Rifle mine. The Union Oil Company's costs at the underground mine up Parachute Creek have been much higher because of unfavorable roof conditions. It is felt that underground mining conditions must be very carefully analyzed at each locale before mining is attempted. The initial development should be restricted to open-pit mining because of the reduced costs. Underground mining methods can be further studied after the initial problems of retorting, hydrogenation, and ash disposal have been worked out to yield the most "sweet" crude from the least amount of mined shale.

The possible application of nuclear energy to reduce over-all mining costs, as proposed by the Atomic Energy Commission, is a most important consideration. Such an experiment should have the support of all the oil companies. The possible success of the experiment would have a far-reaching significance. It could bring the oil shale industry into reality overnight.

"In Situ" Methods

There can be no doubt that the full potential of the oil shale reserves in Utah can be developed only when we have learned to retort and produce the oil from the shale in place. Otherwise, we are limited by the percentage of oil shale that can be removed from an underground mine and by the depth that we can economically mine and lift the oil shale. Then too, the disposal of the ash becomes an enormous and costly problem.

The major problem in preventing the early development of "in situ" retort methods is the complete lack of natural porosity and permeability of most oil shale deposits. The porosity and permeability must be created ahead of and prior to the distillation of the oil from the shale. If this porosity and permeability could be created by an underground nuclear explosion, then the distilled oil would be free to move to the production well. "In situ" retort methods would immediately become feasible because of the successful experiments already completed or under operation in permeable sand reservoirs. Field experiments based on the proper spacing and configuration of input and output wells insure complete "sweeping" of the reservoir and indicate that 90 per cent or more of the original oil in place could be recovered. It follows that the percentage of the total possible oil recovery from the oil shale is limited, principally, by the practical aspects of creating the proper permeability throughout the oil shale section.

The development and adoption of suitable "in situ" techniques would obviate the necessity of disposing of the enormous quantities of ash. "In situ" techniques would permit the recovery of the oil from the richest beds which lie far below practical mining depths. Moreover, no pillars would have to be left to support the roof, as is necessary in a mining operation.

To give an illustration of the tremendous potential of the "in situ" methods, it is necessary only to point out that oil shale which yields 30 gallons per ton is equivalent to 2,000 bbls. per acre foot. In comparison, a sandstone reservoir that has a porosity of 20% and a water saturation of 30% would have originally

about 1,000 bbls. of oil per acre foot in place. At best, one could not expect to recover more than 500 bbls. per acre foot by the usual methods of primary and secondary recovery. "In situ" methods might recover as much as 940 bbls. per acre foot from the sandstone reservoir and 1,880 bbls. per acre foot from the oil shale. It would seem that the oil shale has about twice the potential of a good sandstone reservoir.

For instance, let us assume that a 160-acre tract is underlain by an oil shale bed having a thickness of 50 feet and a yield of 30 gallons per ton. The quarter-section would contain 16,000,000 bbls. of oil in place. If a 500-foot, hexagonal well-spacing program was set up so as to obtain 100% sweep efficiency, it would require 55 wells to properly cover the quarter-section. If five of the 5-spot patterns were "fired" at once, then the entire section could be "swept" in five successive moves. On the basis of past experimentation, it appears that a practical rate of advance of the distillation front would be about 0.35 foot per day. The yearly rate of advance would be 125 feet per year. It would not be necessary to advance the front more than 80% of the 500-foot distance between the input and output wells before the move to the adjacent set of 5-spot patterns could take place, for there would be enough preheat left in the formation to insure that the sweeping agent would be able to complete the "sweep-cycle." Consequently, a move could be made every four years, and the entire 160 acres could be "swept" in 20 years. During that time 16,000,000 bbls. of oil would be produced at the rate of 800,000 bbls. per year, or more than 2,000 bbls. per day. On one section of oil shale property of moderate thickness and richness such an operation could be carried on for 80 years.

OIL SHALE RESERVES IN THE UINTA BASIN

The contour map, Figure 62 ^{1/}, attempts to illustrate the total oil in the shales of the Green River and lacustrine Uinta formations within the Uinta Basin of Duchesne and Uintah Counties, Utah. The data used in the construction of the map comes from the U.S. Bureau of Mines Report of Investigation No. 5081, "Oil Yields of Sections of Green River Oil Shale in Colorado, Utah, and Wyoming, 1945-1952."

"The total oil is represented in millions of barrels of oil per square mile, and the contour interval is 100 million barrels. The total oil content map is not restricted to minimum yields of 15 gallons per ton, such as are the oil shale maps that are already published. As a consequence, the total oil reserve of the oil shales in the Uinta Basin is crudely estimated at 1,300 billion barrels, instead of 26 billion barrels. Is such an approach practical? How can we deny the practicality of one billion barrels per square mile such as is present in Humble's Rosemary Lloyd No. 1 well in sec. 24, T-1-S, R-1-E, U.S.M.? This well penetrated an oil shale section in excess of 2,500 feet that was all oil bearing, yet only 60 feet of it yielded more than 15 gallons per ton. Whenever it becomes possible to distill the oil from the shale "in situ", then the entire 2,500 feet becomes important and not just the 60 feet.

"The two areas of greatest total oil reserve need some explanation. The Ute Trail area in T-9-S, R-21 and 22-E, shows a possible reserve of 1,000 million barrels per square mile, while the south Duchesne area in T-5-S, R-3 and 4-W, U.S.M., shows a possible reserve of 700 million barrels per square mile. The thickness of the Green River in the Ute Trail

1. Figure 62 and explanation are adapted from an article by the senior author and published in Petrogram, September, 1961.

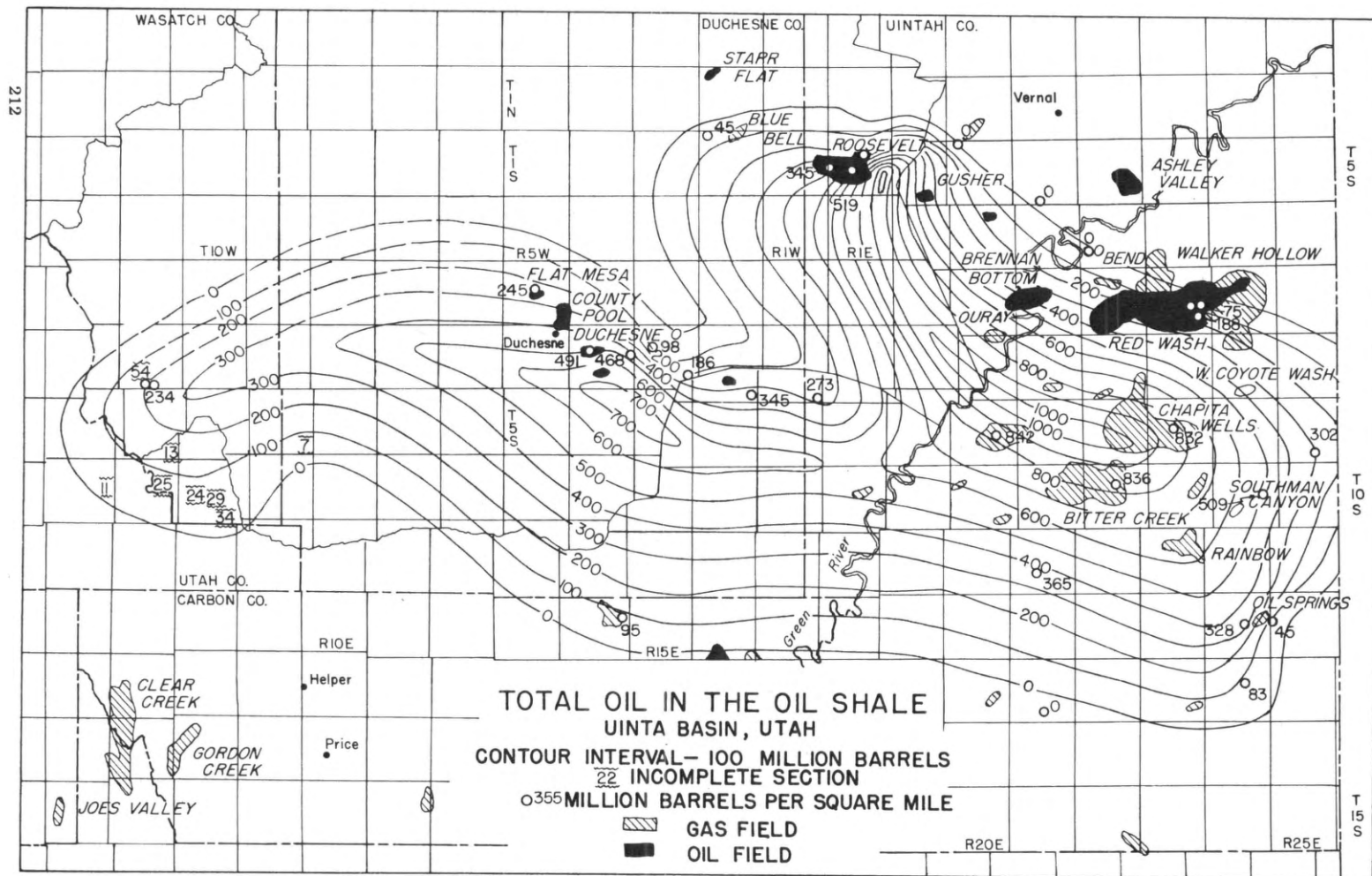


Figure 62.

area is approximately 3,500 feet while the thickness of the Green River and lacustrine Uinta in the south Duchesne area exceeds 7,000 feet. It follows then, that the richness in gallons per ton is several times greater in the Ute Trail area than it is in the south Duchesne area, even though the total oil is comparable.

"It must not be presumed that the map will remain unchanged when more information becomes available. In fact, it is probable that several of the oil companies have information on hand that would materially alter the map and particularly change its zero limits.

"The map was not constructed to show the possible total "shale oil" reserve alone, but rather to show the possible relationship between the occurrence of the Green River and Wasatch oil and gas fields, and the total oil in the oil shales. The relationship is rather striking. All the oil and gas fields are concentrated in or near areas of greatest "shale oil" reserve. Is not this concrete evidence of the indigenous nature of the oil and gas in Green River reservoirs? The Red Wash field, in T-7-S, R-22-23-24-E, extends beyond the limits of "shale oil" because of the delta sands in the Green River. Oil and gas migration has taken place from the rich source beds nearby into the reservoir sands deposited along the ancient river delta. Future exploration and development in the Uinta Basin is expected to give more support to the postulation that oil and gas will be found in paying quantities where the reservoir beds occur in the proximity of large "shale oil" reserves.

"In spite of the technical breakthroughs reported in the extraction of tar-sand oil, oil shale in the Uinta Basin must wait! One needs only to see the location of the present oil and gas fields in relation to the greatest shale oil reserves to know that no development of the oil shale can take place. Multiple use of the same area for the production of oil and gas by two entirely different extraction techniques would not be possible. The cost of immunizing one technique from harm by the other would be prohibitive. Still, it is most encouraging to know that the Uinta Basin, and its neighboring basins, the Piceance Basin and the Green River Basin, contain a natural resource that will provide adequate supplies of hydrocarbons for a continually growing market for many generations to come."

CITED REFERENCES

- Abbott, Ward, 1957, Tertiary of the Uinta Basin: Intermountain Assoc. Petroleum Geologists Guidebook 8th Ann. Field Conf., p. 102-109.
- Cashion, W. B., 1957, Stratigraphic relations and oil shale of the Green River formation in the eastern Uinta Basin: Intermountain Assoc. Petroleum Geologists Guidebook 8th Ann. Field Conf., p. 131-135.
- Cashion, W. B., and Brown, J. H., Jr., 1956, Geology of the Bonanza-Dragon oil-shale area, Uintah County, Utah: and Rio Blanco County, Colorado: U.S. Geol. Survey Oil and Gas Inv. Map OM 153.
- Dane, C. H., 1955, Stratigraphic and facies relationships of the upper part of the Green River formation in Duchesne, Uintah, and Wasatch Counties, Utah: U.S. Geol. Survey Oil and Gas Inv. Chart OC 52.
- Picard, M. D., 1955, Subsurface stratigraphy and lithology of Green River formation in Uinta Basin, Utah: Am. Assoc. Petroleum Geologists Bull., v. 39, no. 1.
- Winchester, D. E., 1923, Oil shale of the Rocky Mountain region: U.S. Geol. Survey Bull. 729, p. 137.

Paper 22 GILSONITE AND OTHER BITUMINOUS RESOURCES OF CENTRAL UINTAH COUNTY, UTAH

by Arthur L. Crawford¹ and Robert G. Pruitt²

INTRODUCTION

Central Uintah County, located in northeastern Utah, lies in the Uinta Basin and is underlain by relatively undisturbed Tertiary lacustrine and fluvial sediments. The area (shown in Figure 63) discussed in this chapter contains all of the known gilsonite veins in the western United States and is the site of large bituminous deposits including oil shale, tar sands, gas, and oil. Nearby portions of the same basin contain smaller deposits of other unusual bituminous substances, such as wurtzilite, tabbyite, ingramite, albertite, and ozocerite, the last of which is a native paraffin (Crawford, 1949; Hunt, 1954).

Because of the detailed treatment given the oil shale, bituminous sandstones (tar sands), gas and oil deposits of the area by authors elsewhere in this volume, the major emphasis of this paper will be directed toward the gilsonite deposits, with only such reference to the other deposits as are needed to understand the interrelationships which exist among them.

Much of the material which comprises this paper is taken from the unpublished (Crawford, 1959) and published (Crawford, 1949; Pruitt, 1961) works of the authors, brought up to date and in places expanded.

GILSONITE

The mineral gilsonite is a solid amorphous asphaltic bitumen which occurs in distinct veins and veinlets in the Tertiary nonmarine sediments of the gently downward warped Uinta Basin. These veins are considered classic, continuing unbroken for miles and maintaining a relatively constant width for great distances both horizontally and vertically. Most of the veins are vertical and filled with pure, massive gilsonite, showing clean contact with the massive sandstone walls of the veins and little or no impregnation or saturation of the vein walls.

Fresh gilsonite has a brilliant black luster, conchoidal fracture and a specific gravity of 1.07 (slightly denser than water). It is brittle and has a hardness of 2 on Moh's scale. Gilsonite oxidizes to a dull, soot-black appearance and takes on an uneven hackly fracture. Fresh gilsonite melts at temperatures as low as 230° F and dissolves in petroleum, giving it the valuable properties for which it is mined and used. Gilsonite has been used to saturate roofing and construction paper, as a base for paints and varnish, in mastics and asphalt tile, as a stiffener in petroleum products, as insulation and weatherproofing, and as a filler in rubber battery boxes and plastics. It is also used in mixtures for control of lost circulation in oil wells, in paving materials, light weight aggregates under special circumstances, and upon distillation gilsonite yields high octane gasoline, lubricating oils and leaves a residue of pure carbon "coke."

1. Assistant Director, Utah Geological and Mineralogical Survey.

2. Formerly Geologist, and Adjudicator, U.S. Land Office, Salt Lake City, Utah.

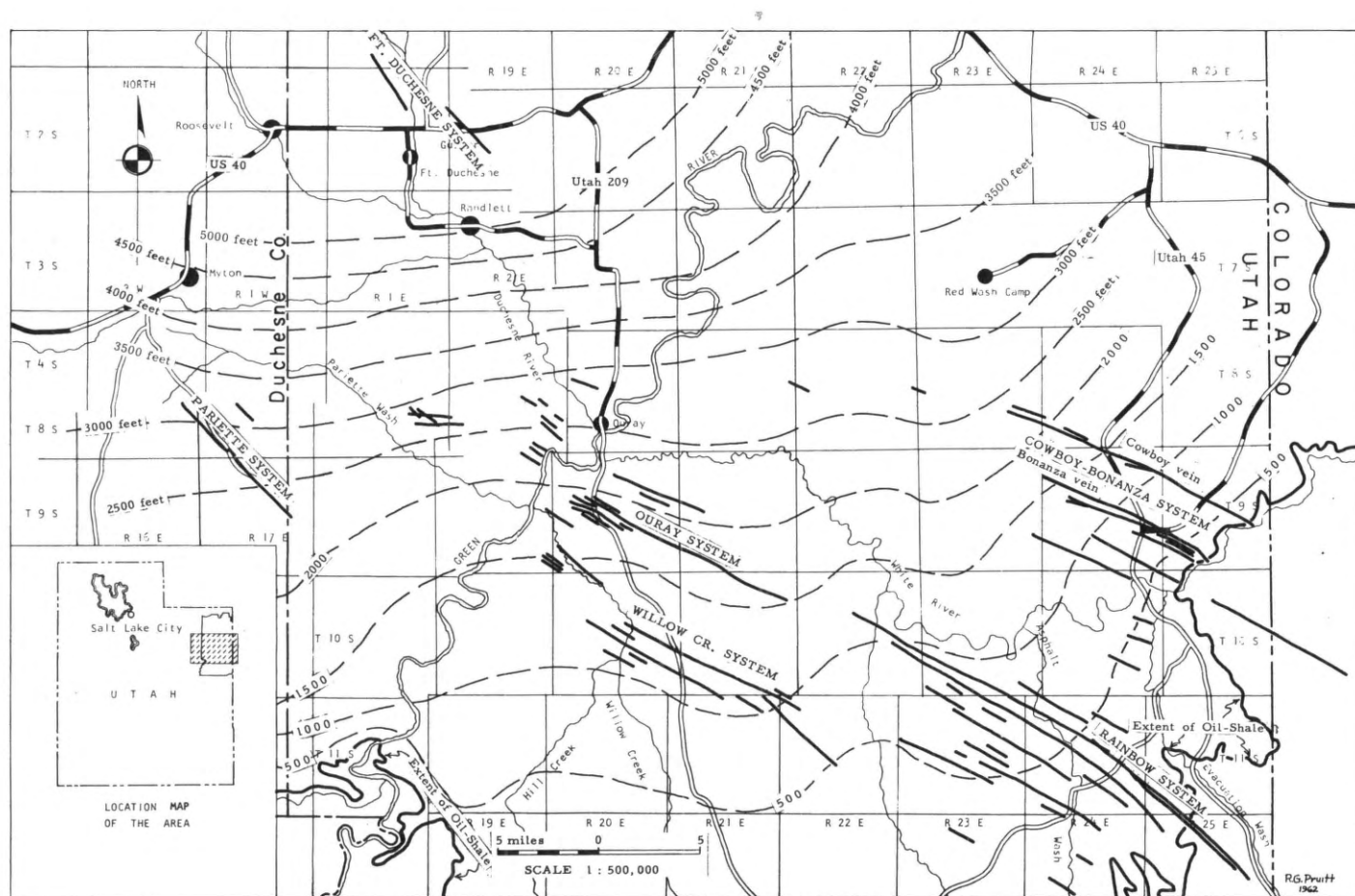


Figure 63. Map of the gilsonite vein systems in central Uintah County. Contours from an unpublished report by Kunkel, et. al., (1959) are plotted on the depth to the oil shale source beds to indicate the probable depth of veins in any given area. The veins are roughly parallel, but several of the veins branch or bend gently. The remarkable straightness of the strike of the veins across the rolling terrain and canyons is due to the vertical dip of the veins.

Gilsonite veins occur as a filling in vertical tensional cracks in the competent sedimentary beds. These veins trend northwestward for miles across the rolling terrain and extend vertically downward until they reach the incompetent mudstones of the Uinta and the oil shales of the Green River formations. In the latter the veins "break up" into smaller branching veins and ultimately veinlets. At least two large veins (the Weaver-Colorado vein and the Black Dragon vein, Pruitt, 1961) are known to extend beneath the oil shale horizon into the underlying members. Hunt (1954) shows that the gilsonite of the region is derived from the upper Green River formation oil shales, flowing upward into open tensional cracks. These veins frequently reach widths of 3 to 4 feet and the Cowboy vein is over 17 feet wide at one point. The depth of any given segment of a vein appears to be related to the depth to the oil shale source beds (Figures 63 and 64). In the eastern part of the area the veins are relatively shallow, 600 to 800 feet in depth. In the western part of the area the veins have been mined to depths of 1,500 feet and many extend downward to 3,000 feet or more. Figure 63 shows the depth to the oil shale beds throughout the area and gives a general idea of relationship between gilsonite veins and the oil shale beds.

Unfortunately much of the gilsonite region is still unexplored due to a federal withdrawal of the deposits in 1910 which was only lifted in 1960 ^{1/}. The sudden release of these deposits should do much to contribute to knowledge of the veins and the expansion of markets for gilsonite.

The known gilsonite veins occur in clusters or systems which are described briefly. A more detailed description is given by Pruitt (1961). It is likely that some of these systems will be found to interconnect and that veins will be discovered which do not reach the surface in areas where the oil shale source beds are deeply buried.

The Cowboy Bonanza system contains twelve named veins. Except for the Weaver-Colorado, the veins of this system are located north of the White River and west of the Colorado-Utah state line. This area is the location of the largest active gilsonite mines of the region, operated by the American Gilsonite Company and the G. S. Ziegler Company. The Cowboy vein is the largest of all known gilsonite veins, reaching a maximum width of 17.5 feet and a length of over 13 miles. The Bonanza vein is a branch of a larger vein complex whose total length is over 15 miles and whose maximum width is 13 feet. There are nine other named veins south of the Bonanza vein, several of which are currently being mined. The total length of gilsonite veins in this system having a width of 1 foot or more is 52 miles. Many of the veins on the eastern end of both systems are shallow since erosion near the White River has cut down to the oil shale source beds. Figure 64 shows a cut away view of the Cowboy-Bonanza vein system and their assumed relationship to the underlying beds.

Rainbow System

The large Rainbow system south of the White River and near the Colorado-Utah state line is presently idle, but once supported large scale mining operations.

1. Gilsonite and asphalt deposits were made available by the Act of September 2, 1960 (30 U.S.C. 181, 182, 184) and regulations published July 4, 1962 permit competitive leasing of deposits (43 C.F.R. 203).

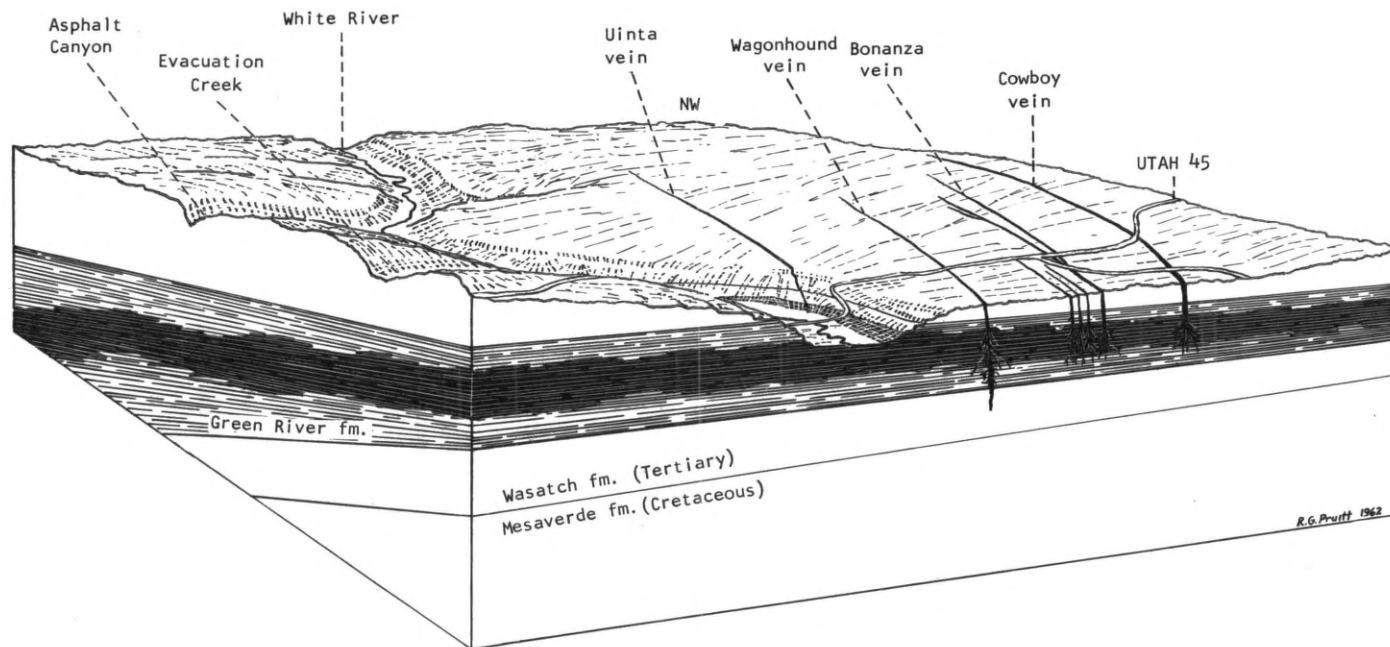


Figure 64. Block diagram of the gilsonite veins and oil shale beds in the Bonanza area, down White River to the north-west. The gilsonite veins bifurcate upon entering the oil shale source beds and are not minable in the oil shale zone. South (left) of the Cowboy vein is the Tabor vein, which branches to the west to form the Bonanza and Little Bonanza veins. Next (immediately to the left) are the Little Chapita vein, an unnamed vein, and the Chapita vein. Note that the Wagonhound vein is shown continuing below the oil shale into the upper Wasatch formation, based on the existence of the Weaver-Colorado vein along the strike of the Wagonhound vein, in the Wasatch formation farther to the east. It is possible that other gilsonite veins extend beneath the oil shale source beds.

The major vein of the system has three segments: from northwest to southeast the Pride-of-the-West, Rainbow, and Black Dragon. These segments together form the longest gilsonite vein known, totaling over 24 miles, with a maximum sustained width of 8 feet. The Black Dragon segment, the southeastern 4 1/2 miles, is beneath the oil shale zone and not known to be vertically connected to the rest of the vein, although it is precisely on the same strike and undoubtedly an extension of the same vein downward. This observation raises the possibility that other gilsonite veins may have a counterpart beneath the oil shales and if this is so it would multiply many fold the known gilsonite reserves.

There are at least 16 distinct veins in the Rainbow system and veins having a width of 1 foot or over total 72 miles in length. Depths of the veins vary from only 400 feet on the eastern end of the system to much deeper toward the west. The veins near the western end of the Rainbow system are largely unexplored and may extend westward to join with the relatively unexplored Ouray system of veins near the confluence of the Green and White Rivers.

Willow Creek and Ouray Systems

The area south of Ouray is relatively unexplored for gilsonite, but contains at least five moderate-sized gilsonite veins and a host of other veins whose dimensions are not yet fully known. Two systems may be involved (Figure 63), but it is difficult to recognize a distinct boundary between them. West of Ouray and northwest of the Green River, the old Florence Mining Company, before it promoted the old Ute land copper mill, patented under special act of Congress, a copper claim on which occur gilsonite veinlets. The adjacent Original Owner and O.K. patented claims, and isolated state-owned tracts southeast of the river, have been worked near the surface, intermittently; but information on the quantity and quality of gilsonite in this area is scarce. The largest three veins, the Pride-of-Utah, the Cottonwood, and the Willow Creek, about 10, 8, and 7 miles long, respectively, are southeast of the Green River. Their location and interrelationships are shown in Figure 63. It is very likely that some of the gilsonite veins on either side of the Green River in the vicinity of Ouray are interconnected. It is also possible that the veins immediately south of Ouray connect with the long veins of the Rainbow system to the southeast.

Pariette System

The Pariette and Castle Peak veins are the major features of this system, located south of Myton, Utah, in Duchesne County. The total length of these veins is 9 miles. Surface exposures of the veins are only 18 inches wide, but increase to over 40 inches at depths of 1,500 feet. The Pariette is the deepest gilsonite mine with the longest period of operation. It was closed from 1906 to 1932. This system represents the western extremity of the gilsonite deposits in Utah.

Fort Duchesne

Two prominent veins, the Carbon and the Raven, comprise this system, which is the northern extent of gilsonite deposits in the basin. One or the other of these veins have been in continuous operation from the late 1880's until about 1946. These veins measure up to 4 feet wide. Each vein is about 3 miles long. The Carbon vein crosses beneath U.S. highway 40 just east of the town of Gusher Utah.

Aside from the six named systems of gilsonite veins, other areas of small gilsonite veins are reported on Wild Horse Bench in T-10-S, R-19-E, near Red Wash in T-8-S, R-23-E, and near the head of Asphalt Canyon in T-12-S, R-24-E. Some

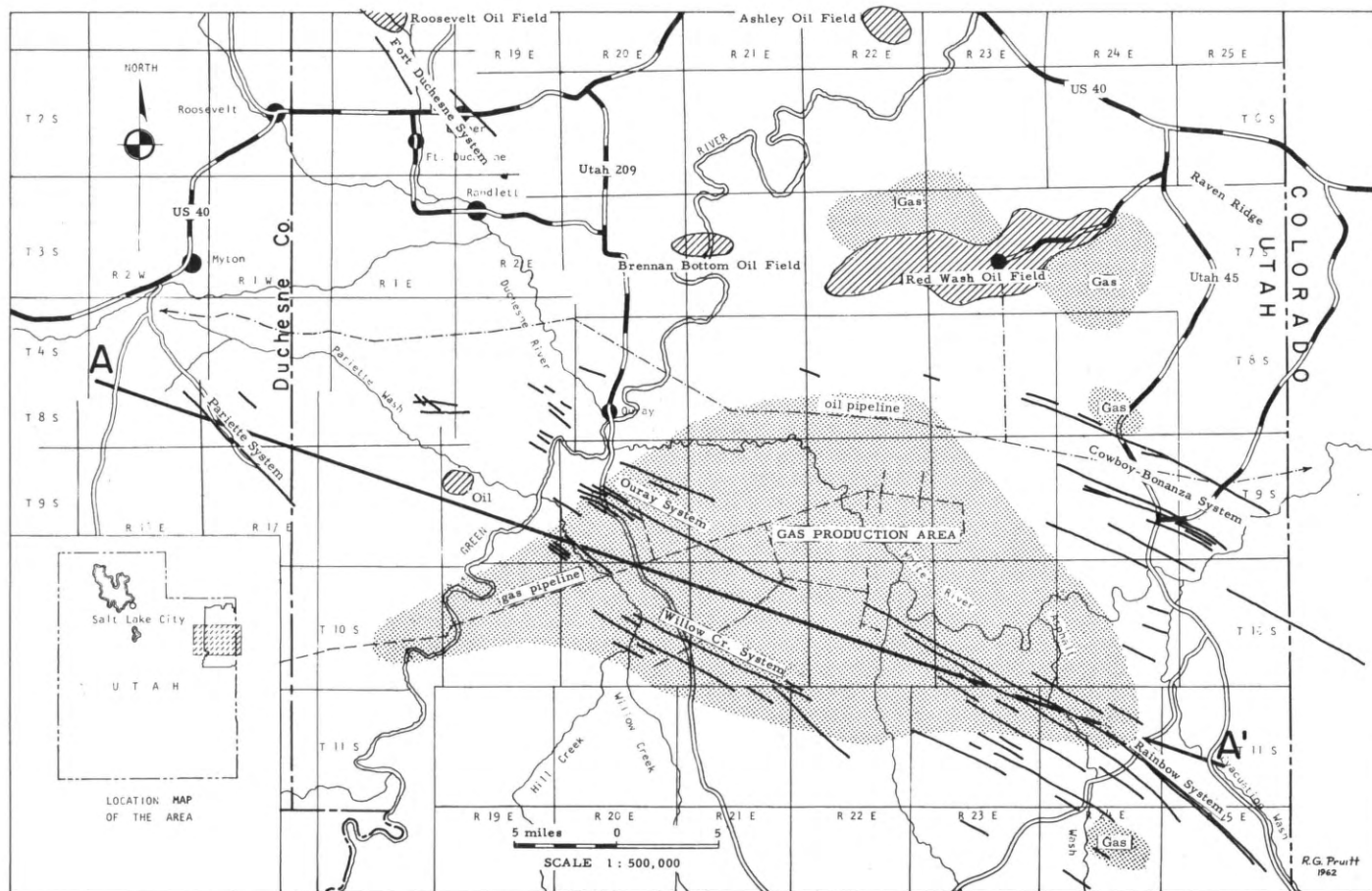


Figure 65. Map of the relationship of gilsonite to the gas- and oil-producing areas in the vicinity. Bearing in mind that oil shale underlies the whole area and that large bituminous sand deposits are found on the fringe of the area to the north and southwest, it is obvious that the Uinta Basin is an unusual locality of abundant bituminous resources. The shaded areas indicate gas (dots) and oil (lines) producing areas. Individual fields or wells cannot be shown accurately at this scale.

of these areas may become important as the region is opened to exploration and mining.

GILSONITE MINING AND MARKETS

Gilsonite is mined by various hand and mechanical methods, depending upon market specifications and characteristics of the individual veins. The fresh, unoxidized gilsonite is mined by hand or machine as lumps for use in insulation and coating products where its low melting point or high solubility in petroleum are important factors. Fresh gilsonite is massive and hard to break or cut mechanically, and so relatively high-cost hand methods are commonly employed to mine it. Most fresh gilsonite ore is sized and shipped in bags or in bulk directly to users with little additional preparation, bringing \$43-\$47 per ton, F.O.B. mine.

Oxidized gilsonite is more fractured and has a higher melt point. Its uses are different from those of the fresh, massive gilsonite, and it can be mined more easily by mechanical methods. The gilsonite ore of the Cowboy vein is of this class and is mined by hydraulic jet methods. This gilsonite ore breaks easily under the force of high pressure water jets and almost floats. It is conveyed to the surface, crushed, mixed in a slurry, and piped 72 miles to a refinery at Gilsonite, Colorado, and converted into gasoline, oil, and a high purity carbon char or coke. By far the largest quantity of gilsonite mined today is mined and treated in this manner by the American Gilsonite Company.

OTHER BITUMINOUS RESOURCES

Oil Shale

As discussed by Quigley and Price (Paper 21), the Uinta Basin is underlain by large deposits of rich oil shale in the Green River formation of Tertiary age. These oil shale beds crop out along the eastern edge of the area discussed in this chapter and dip gradually beneath central Uintah County, ultimately reaching depths in excess of 5,000 feet (Figures 63 and 65). The richest and thickest oil shales are found in what is assumed to have been the depositional trough of the Uinta Basin syncline which lies roughly along the course of the White River. Relatively rich deposits at or near the surface are located in T-9 and 10-S, R-25-E, near the old settlement of Watson, Utah, and in T-13-S, R-25-E on McCook Ridge. Some of these surface deposits are privately owned, whereas the deeper rich deposits are on federal or state-owned lands. All federal lands are closed to oil shale mining.

Oil shale is presumed to be the source of practically all of the abundant bituminous and petroleum deposits in Uintah County (Hunt, 1954, and Paper 24) and the recoverable shale oil reserves locked up in the deposits of eastern Uintah County are estimated to exceed 14.5 billion barrels (Cashion, 1956). Shales yielding over 45 gallons of oil per ton of rock are not uncommon in certain parts of the area. Some of the oil-shale zones are hundreds of feet thick near the center of the basin and undoubtedly will be exploited sometime in the future. The total estimated oil reserves for the oil shale deposits of Utah, Colorado, and Wyoming are truly staggering (Figure 67).

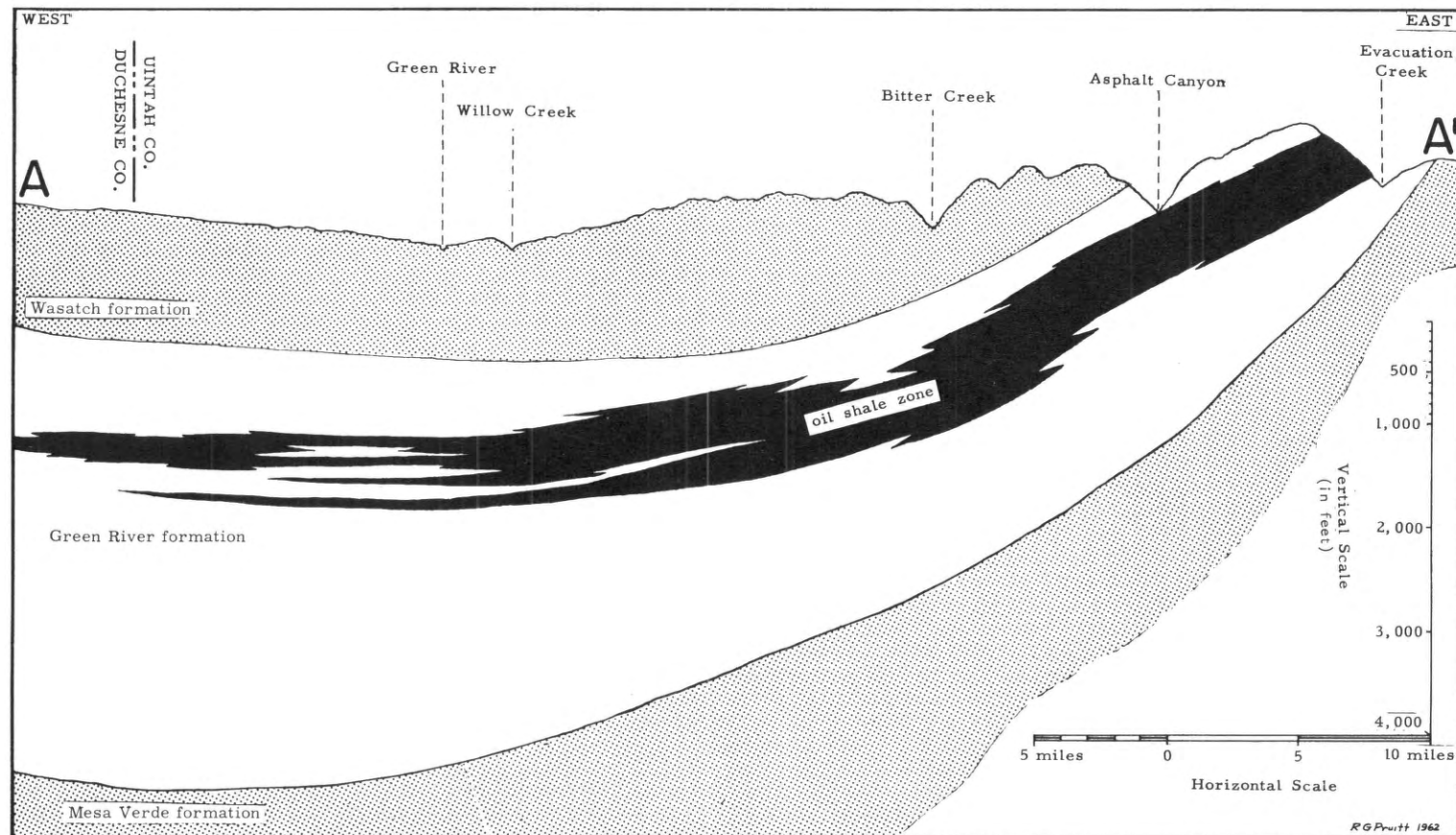


Figure 66. Sectional view of the oil shale zone in the Green River formation (Tertiary). The trace of this section (A-A') is shown on Figure 65 beginning in the region of the Pariette gilsonite system and extending east-south-east through the Willow Creek and Rainbow systems to the oil shale outcrops. The axis of deposition was north of the section, so that the abrupt thinning westward (left) is not representative of the best oil shale conditions. The depth of gilsonite veins is thought to be related to the depth of the oil shale source beds, indicating an increase in depth of the veins westward. If the number or width of gilsonite veins is related to the richness of the oil shales it would appear the best gilsonite localities are east (right) of the Green River.

Oil shales appear quite prominently in resistivity electrical logs of the numerous oil and gas wells in the basin. Individual beds appear to be quite discontinuous over any area, although the general oil shale can be plotted (Figure 66).

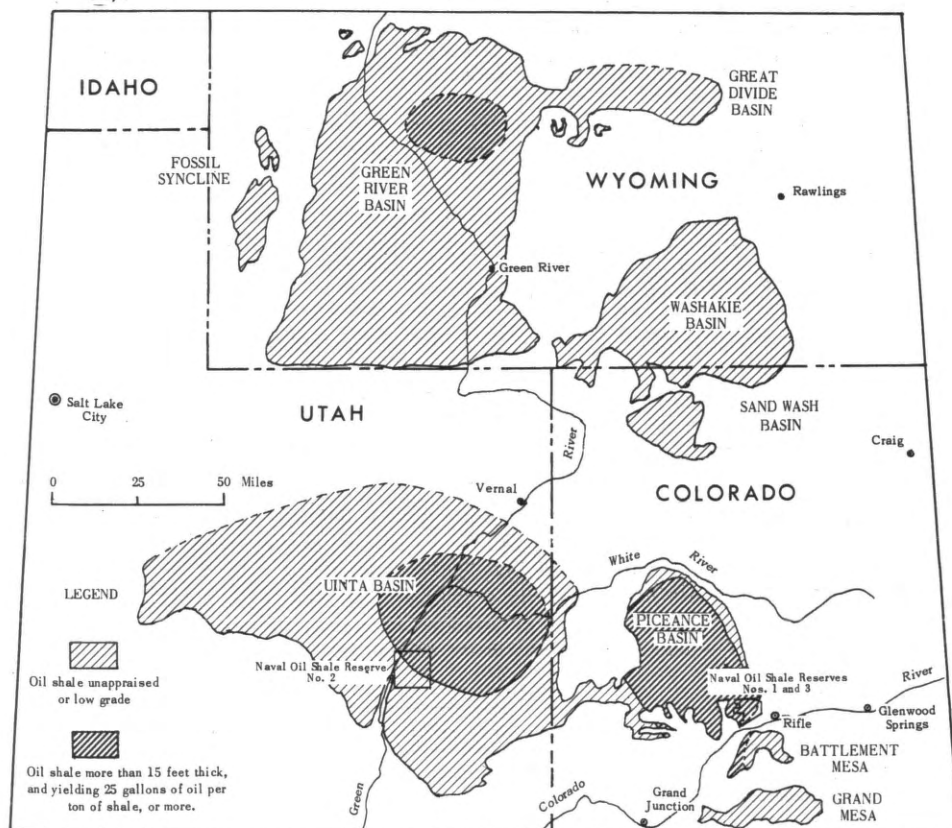


Figure 67.

Bituminous Sandstone

Rich deposits of asphalt-impregnated sandstone occur in and around the area known as central Uintah County. Asphalt Ridge is the richest nearby deposit and is located just west and southwest of Vernal. Covington (Paper 23) discusses this and another important deposit near Sunnyside, Carbon County, Utah, which are believed derived from the oil shale beds of the Green River formation. Smaller deposits are known on Raven Ridge and at Dragon, Utah, in Three Mile Canyon.

These asphalt deposits are possible sources of liquid petroleum providing pilot studies by the U.S. Bureau of Mines prove workable on a large scale (Shea, et al., 1952). Reserves in Asphalt Ridge alone exceed 2 billion barrels of crude asphaltic oil along an 11 1/2 mile front (Spieker, 1930). Near Vernal the rich asphalt beds are mined and used to pave city and county roads in the region. Wells drilled on the dip slope of the asphalt beds indicate a tarry liquid oil permeates the horizon to a considerable depth down dip.

Oil and Gas

High pour-point oils are produced from both the Green River (Tertiary) and the Mesaverde (Cretaceous) formations within the Uinta Basin. Low pour-point oil is produced from the Weber-Park City formation (Pennsylvanian-Permian) on the northern edge of the basin. The oil of Tertiary age is thought to be derived from the oil shale beds of the Green River formation.

The Red Wash oil field is the largest producer in northeastern Utah (Figure 65) and contains over 160 oil wells. The small Roosevelt oil field is another Tertiary deposit on the edge of the area under discussion.

The big recent development in Uintah County, and undoubtedly the most valuable resource from an immediate production standpoint, is the discovery of enormous deposits of gas in the Wasatch formation (Tertiary) near the center of the Uinta Basin (Figure 65 and Paper 20).

One puzzling feature of the relationship of the various bitumen and petroleum substances of the Uinta Basin is the high paraffin content of the Tertiary oil and the shale oil, contrasted to the asphaltic character of the bituminous sandstones and the gilsonite deposits. Crawford (1952, 1959) suggests that artificial ozocerite can be produced from the waxes contained in the crude Tertiary oils of the Uinta Basin.

Recent deep wells in the area near the White River indicate commercial gas and condensate in the Mesaverde and Dakota formations (Cretaceous). These deeper discoveries, coupled with the enormous proven gas reserves in the Wasatch formation (Tertiary), certainly make this area an important factor in the national mineral economy.

CITED REFERENCES

- Cashion, W. B., and Brown, J. H., 1956, Geology of the Bonanza-Dragon oil-shale area, Uintah County, Utah, and Rio Blanco County, Colorado: U.S. Geol. Survey Oil and Gas Inv. Map OM-153 (1:62,500 with text).
- Crawford, A. L., 1949, Gilsonite and related hydrocarbons of the Uinta Basin: Oil and Gas Possibilities of Utah, Utah Geological and Mineralog. Survey, publisher, p. 235-260.
- _____, 1952, Ozokerite--a possible new source--a challenge for research: Utah Acad. Sciences, Arts, and Letters Proc., v. XXX, p. 74-83.
- _____, 1959, Mineral Potentials on approximately 30 townships for which Utah State Land Board selections are recommended (in Uintah County): Unpublished report for the Committee on Oil Shale and Solid Hydrocarbons of the Utah State Land Boards, p. 22.
- Hunt, J. M., Stewart, F., and Dickey, P. A., 1954, Origin of hydrocarbons of the Uinta Basin, Utah: Am. Assoc. Petroleum Geologists Bulletin, v. 38, no. 8, p. 1671-1698.
- Pruitt, R. G., Jr., 1961, Mineral Resources of Uintah County: Utah Geol. and Mineralog. Survey Bull. 71.
- Shea, G. B., and Higgins, R. V., 1952, Separation and utilization studies of bitumens from bituminous sandstones of the Vernal and Sunnyside, Utah deposits: U.S. Bur. Mines Report Inv. 4871, p. 1, 28 p.
- Spieker, E. M., 1930, Bituminous sandstone near Vernal, Utah, U.S. Geol. Survey Bull. 822, p. 77-98.

Paper 23 BITUMINOUS SANDSTONE AND LIMESTONE DEPOSITS OF UTAH

by Robert E. Covington¹

INTRODUCTION

The significant bituminous sandstone and bituminous limestone deposits of Utah are located within, or on the edges of, the Uinta Basin. They are all located within the boundaries of Carbon, Duchesne, and Uintah Counties. The Sunnyside deposits in Carbon County contain the greatest reserves of bituminous sandstone in the United States. The sandstone averages 8 to 10% bitumen by weight, (Holmes, 1956), totaling more than 1,600,000,000 cubic yards of bitumen. The second largest deposit in Utah is the Asphalt Ridge bituminous sandstone area in Uintah County, Utah. Reserves for this area have been estimated at more than 1 billion barrels, although this figure is probably high. The asphaltic sandstones of the Peor Springs area and the Whiterocks Canyon area are described. The Asphalt Ridge, Sunnyside, Peor Springs, and Whiterocks Canyon area deposits contain more than 90% of the asphalt reserves in the State of Utah.

There are many other small, relatively insignificant deposits of no commercial value, but of geologic interest: Among those discussed are the asphaltic sandstones in the Deep Creek area, the Chapita Wells area, the Raven Ridge deposits, the John Starr Flat accumulation, the Lake Fork-Yellowstone River area, the North Tabiona area, the South Myton area, the "argulite" deposits in Argyle Creek, the asphaltic limestone deposits in Indian Canyon-Lake Canyon, and the asphaltic sandstones in the Dragon-Asphalt Wash area.

ASPHALT RIDGE AREA

The Asphalt Ridge bituminous sandstones lie in the northeastern district, a topographic district 3 to 4 miles south and west of Vernal, Utah, on the northeast flank of the Uinta Basin. The area derives its name from the northwest-southeast trending topographic ridge which borders Ashley Valley (Figure 69). The lower 700 feet of the Mesaverde formation is exposed at the base of the ridge, dipping south to southwest from 8 to 12 degrees. The Oligocene Duchesne River formation overlaps and truncates the middle and upper Mesaverde sections. The Wasatch, Green River, and Uinta formations wedge out and are truncated in the Asphalt Ridge area (Figure 70).

The north end of Asphalt Ridge is cut by a normal fault which trends slightly east of north, repeating the saturated Rim Rock sandstone. The regional structure of the ridge area is monoclinical, with several small "bowings" or noses which interrupt the regional dip. Several strike faults, pre-upper Duchesne River in age, are present along the monocline. Only the fault at the County Pit is important as a structural control in the accumulation of bitumen. The County Pit fault strikes northwest-southeast and sharply delimits the saturation on the northeast, for the bituminous Rim Rock sandstone is downthrown on the southwest against lignitic shale which overlies the non-saturated Asphalt Ridge sandstone member of the Mesaverde on the upthrown (northeast) side. Tar seeps or "brea" occur along the fault plane.

1. Petroleum Consultant, Caldwell and Covington, Vernal, Utah.

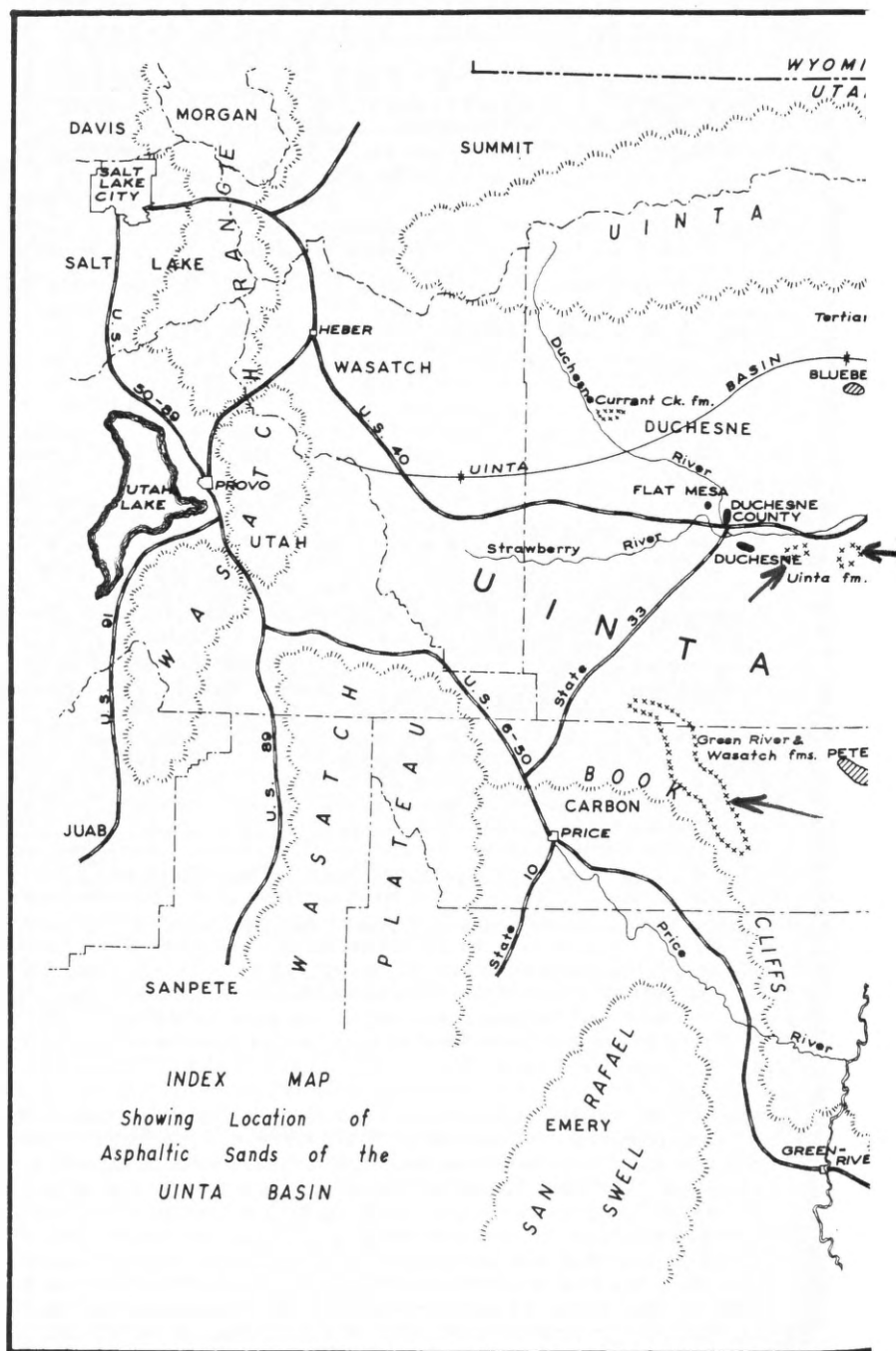


Figure 68.

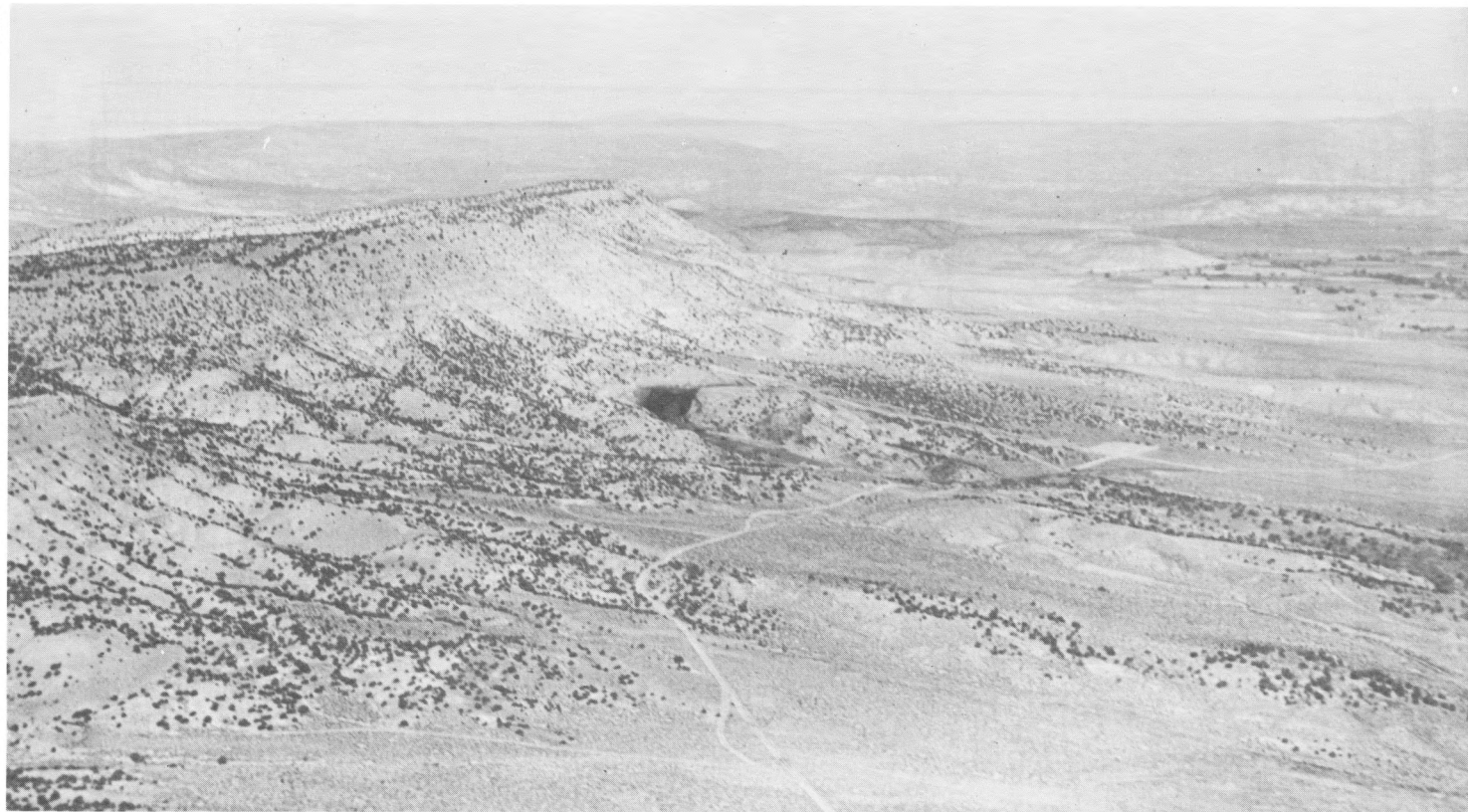


Figure 69. Aerial photograph of Asphalt Ridge, looking northwest. The County Pit is prominent at the base of the ridge.

The asphaltic sands occur in the Rim Rock sandstone member of the Mesaverde formation and in the unconformably-overlying Duchesne River beds in the ridge area south of the Lapoint-Vernal highway. North of the highway, saturation occurs in both the Rim Rock and the Asphalt Ridge sandstone members of the Mesaverde and also in the Duchesne River formation.

Rim Rock Member of the Mesaverde

The Rim Rock sandstone member of the Mesaverde is approximately 250 feet thick at the north end of Asphalt Ridge and is highly charged with inspissated, tarry bitumen along the length of the outcrop and in the subsurface. The Union Oil Company's Cottonwood Springs well in section 21, T-4-S, R-20-E, penetrated bituminous Mesaverde sandstones. More than one-half of the asphalt reserves of the ridge area are in the Rim Rock sandstone. This member was recently described in detail (Pruitt, 1961).

Asphalt Ridge Member of the Mesaverde

The lowest sandstone member of the Mesaverde formation in the Asphalt Ridge area is the Asphalt Ridge member. This sandstone is separated from the Rim Rock sandstone by a shale interval which is approximately 100 feet thick in the central part of the ridge (Figure 73). The shale interval contains thin lignite beds and gray, bentonitic shales. There is no asphaltic material in the Asphalt Ridge sandstone member, except on the tract of land north of the Lapoint-Vernal road; this tract is on the downthrown side of a northeast-southwest trending fault (Figure 70). The relationship of this fault to the accumulation on this tract is uncertain.

Duchesne River Formation

A discussion of the stratigraphy of the Duchesne River formation is not pertinent to this paper. There are several intraformational unconformities within the Duchesne River series of fluvatile red beds, conglomerates, and variegated shales and sandstones. The formation unconformably overlies and truncates the more steeply-dipping beds of the Mesaverde formation. The unconformities and dip are probably a reflection of the uplifting of the Split Mountain and Blue Mountain anticlinal nosings. Regional monoclinal dip in the Duchesne River beds is interrupted by several small "bowings" or archings which are mappable on the surface. Several north-south trending faults cut the monoclinal dip between the outcrop and the Carter Oil Company Ruth Nelson No. 1 well in Sec. 33, T-5-S, R-21-E. The asphalt saturation in this formation is very definitely related to the unconformities present in the area (Figure 71). The richest saturation occurs along the planes of the unconformities, although it is controlled, in part, by the porosity and permeability of the subjacent and the superjacent beds. Nearly one-half of the total reserves of asphalt in the Asphalt Ridge area are in the Duchesne River formation.

Recent Development of the Asphalt Ridge Area

Development of the Asphalt Ridge was begun in 1954 by the Barnes Engineering Company of Los Angeles, California, and by the Ridge Development Corporation of New York City. The author (Covington, 1957) was in charge of the core-drilling and mapping program for the above firms and made the first preliminary estimates of reserves and "over burden" on certain properties. The mining properties were then turned over to the Sohio Oil Company. This company has been engaged in an active program of core drilling, mapping, and evaluation since 1956.

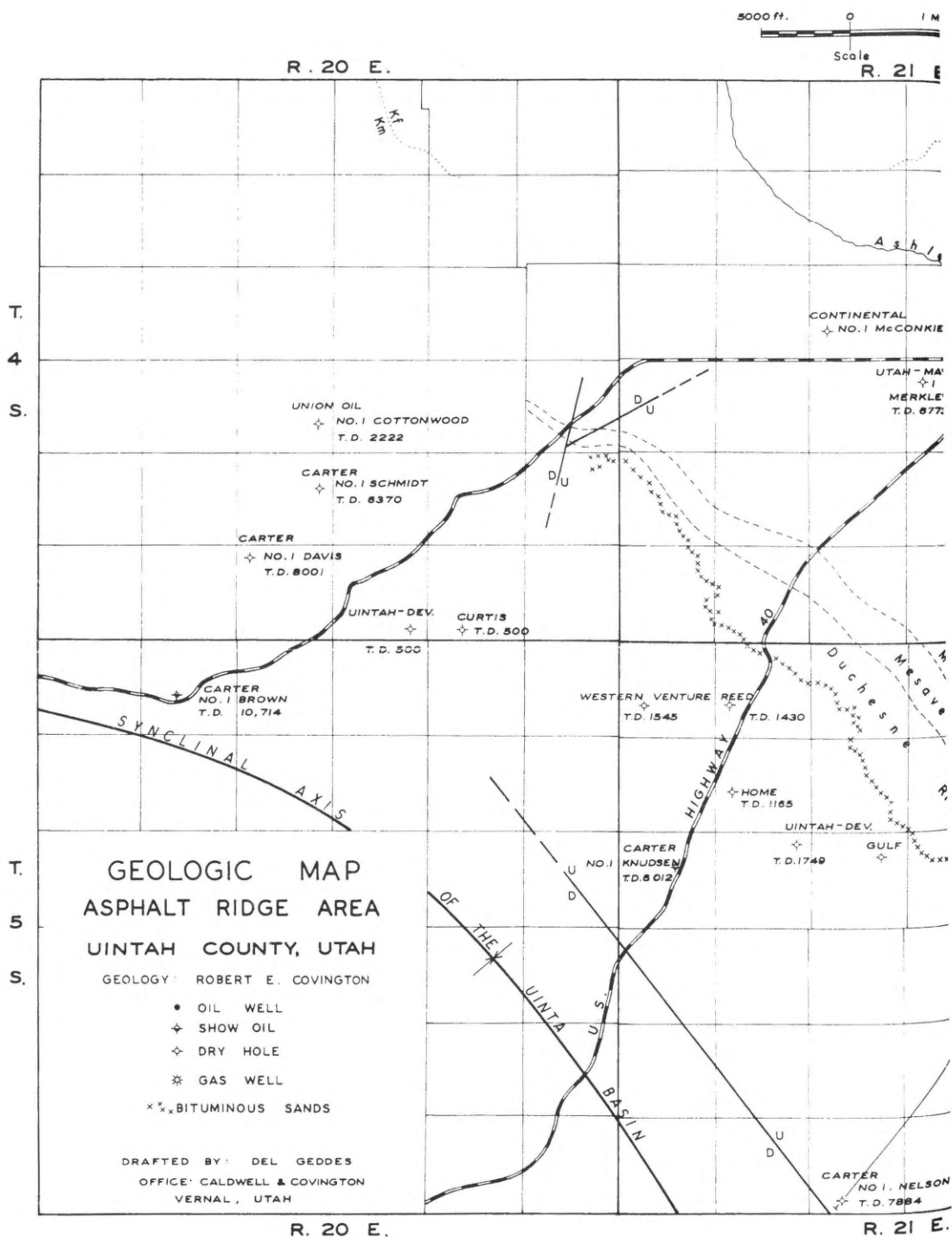
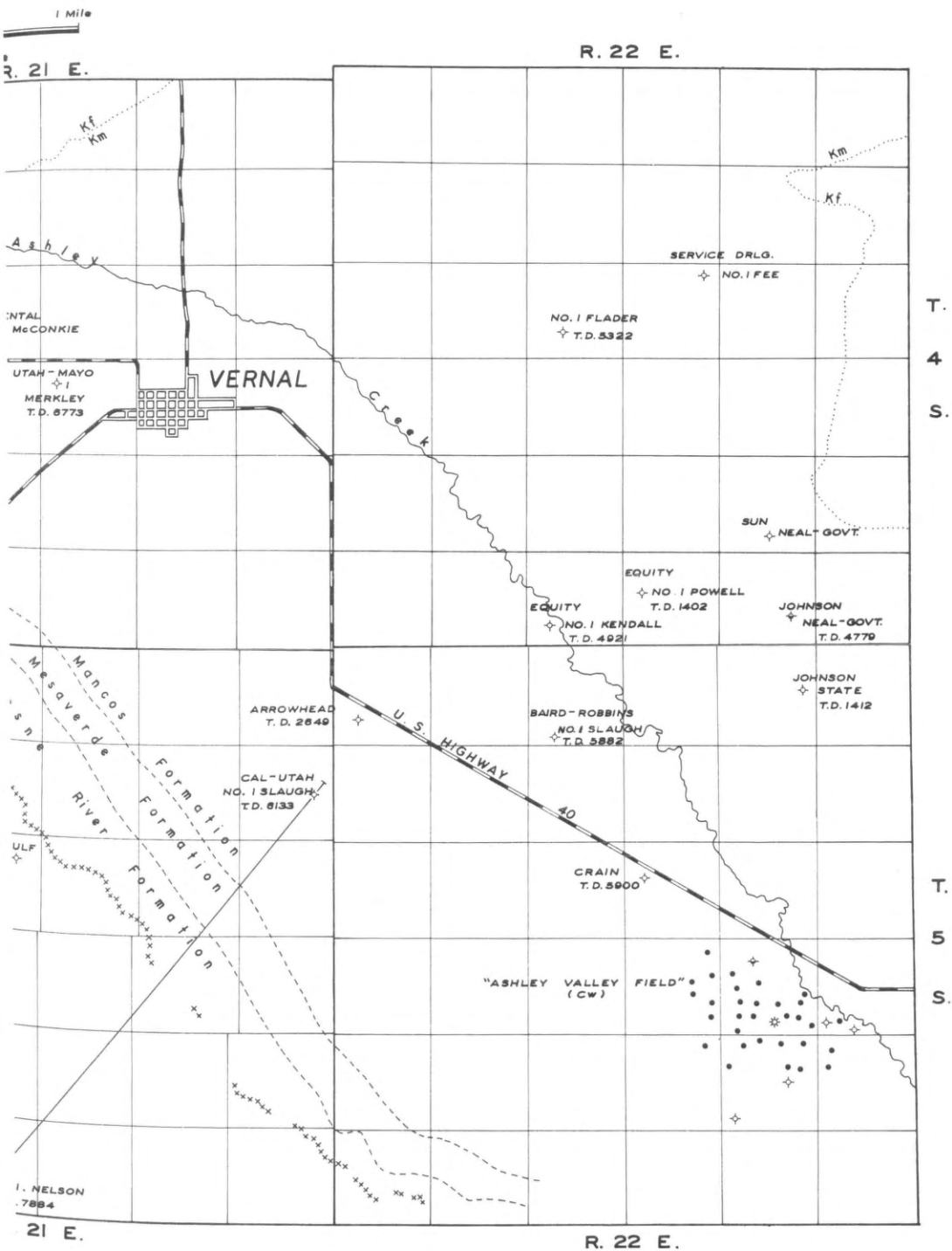


Figure 70.



GEOLOGIC CROSS PROFILE

ASPHALT RIDGE AREA

NORTHEAST

T. 5 S., R. 21 E.
UINTAH COUNTY, UTAH

GEOLOGY: ROBERT E. COVINGTON

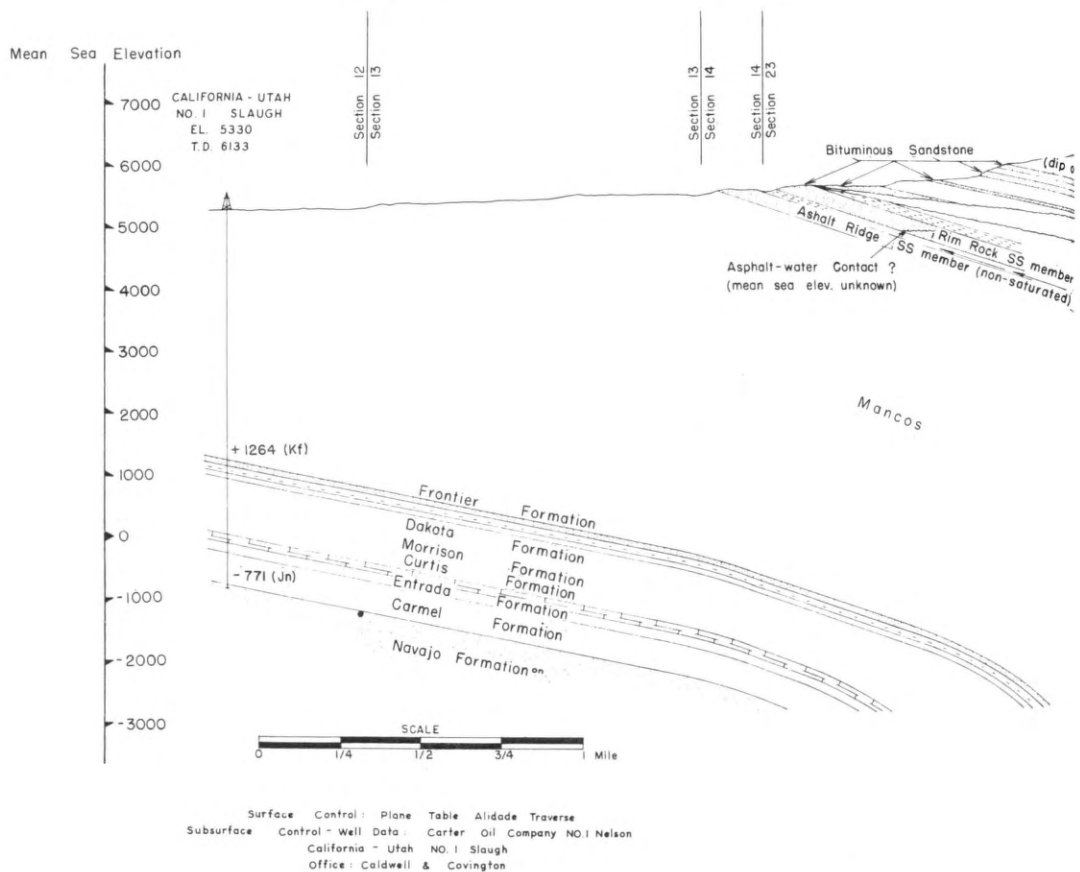


Figure 71.

SOUTHWEST

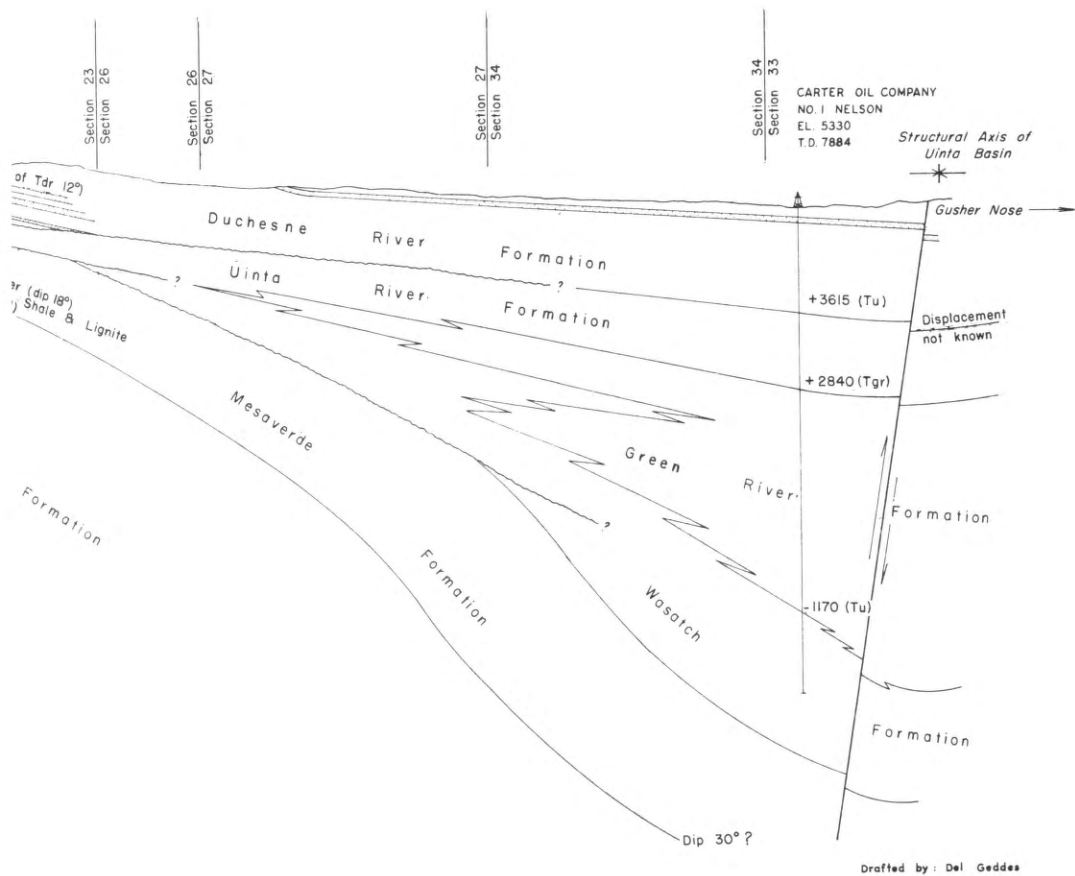




Figure 72. Photograph of the County Pit, Asphalt Ridge area, Uintah County, Utah.

Nature of Bituminous Sandstone

The Rim Rock sandstone bleeds tarry, viscous oil on a freshly broken surface. This may be observed in the County Pit area (Figure 72). On fresh surface the sandstone has a decidedly cool feel, a property which Barb and Ball (1944) ascribe to the fact that the individual sand grains are water-wet. The fresh sample also has a "tacky" feel; this tenacious quality makes the bitumen an excellent material for road paving. The degree of saturation within the sandstone and conglomerate beds of the Mesaverde and the Duchesne River formations is dependent upon three criteria: (1) the porosity and permeability of the member; (2) the proximity of the member to an unconformity; and (3) the structural position of the member (greater enrichment is found associated with the small nosings or folds than with the sandstones off-flank or down the dip). The asphalt sandstones in the Mesaverde have a definite asphalt-water contact.

The saturation can be classified as follows: (1) tar, with sand grains interspersed throughout; (2) sandstone, semi-consolidated, with tar as the primary cementing agent, and with clay and silica as secondary binding material; (3) sandstone, lean, with some interstitial tar; (4) sandstone, barren, with trace of staining, water-wet. Saturation is often found in the conglomerates and in the shales along bedding planes or fractures in the Duchesne River beds.

The asphaltic sandstones weather a blue-white; however, the weathered surface is thin. The Mesaverde sandstones have clay pellets and lenses which are unsaturated, appearing as splotches against the fresh, black, tarry surface. The sandstones also have a distinctive speckled appearance, due to the small white clay inclusions.

A Brief Discussion of the Economics of Asphalt Property Development

The feasibility of mining an asphaltic sandstone deposit is dependent upon many factors. Some of these factors are the ratio of overburden to material, the degree of consolidation of material and overburden, the amount of interbedded "waste", local topography, and the degree of asphaltic enrichment. Also important is the mining method used, whether "open pit" or thermal recovery ("in situ"). Finally, one of the most important factors is the price obtainable per barrel of liquid bitumen. Other considerations are the local and state tax structure, interest rates, availability and cost of building material and equipment, local labor rates, cost of water and fuel, and the cost of transportation.

An overburden to material ratio of 0.5 to 1.0 would probably be a favorable ratio to make strip-mining economically feasible. The author feels that a part of the Asphalt Ridge property could be worked by strip-mining operations. Where the material is at too great a depth and where the overburden-to-material ratio is not favorable, perhaps an "in situ" or fireflood process could be successfully used. The Gulf Oil Corporation and the Sohio Oil Company have already conducted some tests to determine the efficiency and costs of a fireflood project on asphaltic sandstones.

Since the nearest railhead to the Asphalt Ridge properties is 120 miles to the east at Craig, Colorado, or 120 miles to the west at Heber, Utah, any plan for the development of the bituminous sandstones, whether for mining or extraction, must include the erection of a plant to extract the bitumen from the sandstones, or, possibly, even the building of a refinery near the quarry. The cost of the separation process will be a direct function of such factors as ease of separation of bitumen from the sandstone, cost of crushing material, cost of fuel for heating,

cost of flotation chemicals, the quality and cost of an adequate water supply, costs of electricity, and costs of erection of the plant, including equipment for crushing, grinding, and retorting and flotation.



Figure 73. Photograph of outcrop of asphaltic sand and tar seep in the Rim Rock member of the Mesaverde formation, Asphalt Ridge area, Uintah County, Utah.

The bitumen, thus separated, is a heavy, viscous liquid with a gravity of about 10 A.P.I., which is not suitable for pipeline transportation. This tar can be "upgraded"; one of the most economically feasible methods of doing this would be to employ what is known as a "delayed coking process." A part of the coke from this process could be used to generate steam and power for the operation and part could be sold for metallurgical-grade coke. The other product is coker distillate, which can be readily utilized by the refineries as it produces a high yield of gasoline, kerosene, and fuel oils. It is highly possible that a fluid-

coking process could be used successfully, or an oven type of coking unit might be employed, in which the hot oil is sprayed on the floor of a refractory-lined oven. This latter process is not adaptable to an operation involving over 1,000 barrels of bitumen per day. The coke produced by the former method of fluid coking can be used for fuel, and not for metallurgical-grade coke.

Origin of the Asphalt

Over 95% of the saturation on Asphalt Ridge occurs in the Mesaverde and Duchesne River beds. Of this amount, nearly half of the reserves are in the Mesaverde sandstones. Spieker (1930) has estimated the reserves in the Asphalt Ridge area as being in excess of 1 billion barrels. The author considers this figure to be excessive, although the reserves are believed to be of sufficient size to warrant commercial exploitation.

The author believes the source of the bitumen to be the down-dip (basinward) Green River shales and marlstones which grade into sandstones in a shoreward (eastward) direction (Figure 71). The interfingering of the lacustrine, highly organic Green River shales with the fluvatile to deltaic "Uinta-Wasatch type" sediments could have formed the original reservoir. Subsequent uplift in the Blue Mountain-Split Mountain area during Duchesne River time tilted the overlying Duchesne River beds, with the movements taking place through many local pulsating uplifts. The oil then migrated updip along the unconformities, losing its more volatile constituents during the movement. There is a preferential saturation which is evident in the field. Any slight increase or decrease in either porosity or permeability results in greater enrichment or in "barren" patches, respectively. This tends to augment the idea that the fluid was rather viscous at the time of the up-dip migration.

WHITEROCKS AREA BITUMINOUS SANDSTONES

The bituminous sandstones of the Whiterocks area are located in T-2-N, R-1 and 2-W, U.S.M., Uintah County, Utah, a distance of 20 miles north of Roosevelt, Utah, along the south flank of the Uinta Mountains (Figure 68). The asphalt saturation occurs in the Jurassic Navajo sandstone, which has a total thickness of over 1,000 feet in the area. Saturation is essentially complete, although it is not completely uniform. Degree of bitumen saturation is dependent upon the porosity and permeability of the sandstone. One local, thin zone which is extremely hard and tight was barren.

A surface cross section, north to south, and a subsurface cross section, north to south (Figures 76 and 77), are included in this report. A surface geologic map is shown in Figure 74. The Mesozoic beds dip 62 degrees to the southeast. A bowing in the Paleozoic beds has given the name of Whiterocks nose to the area (Kinney, 1955).

Occurrence of the Bituminous Saturation

An analysis of the bitumen has shown that the oil has about a 12° gravity. The asphaltic sandstone averages about 10% bitumen by weight. A well drilled by Caldwell and Covington in 1958, the No. 1 Merimon Ranch-Fee (Figures 74 and 77), cored 560 feet of asphaltic Navajo sandstone before reaching "barren" sandstone. Based upon available well data and surface plane-table mapping, the reserves of the area have been estimated to be approximately 50,000,000

barrels of liquid bitumen. Core analysis of the saturated Navajo sandstone has shown porosities which range from 14 to 19% and permeabilities which range from 110 to over 550 millidarcies.

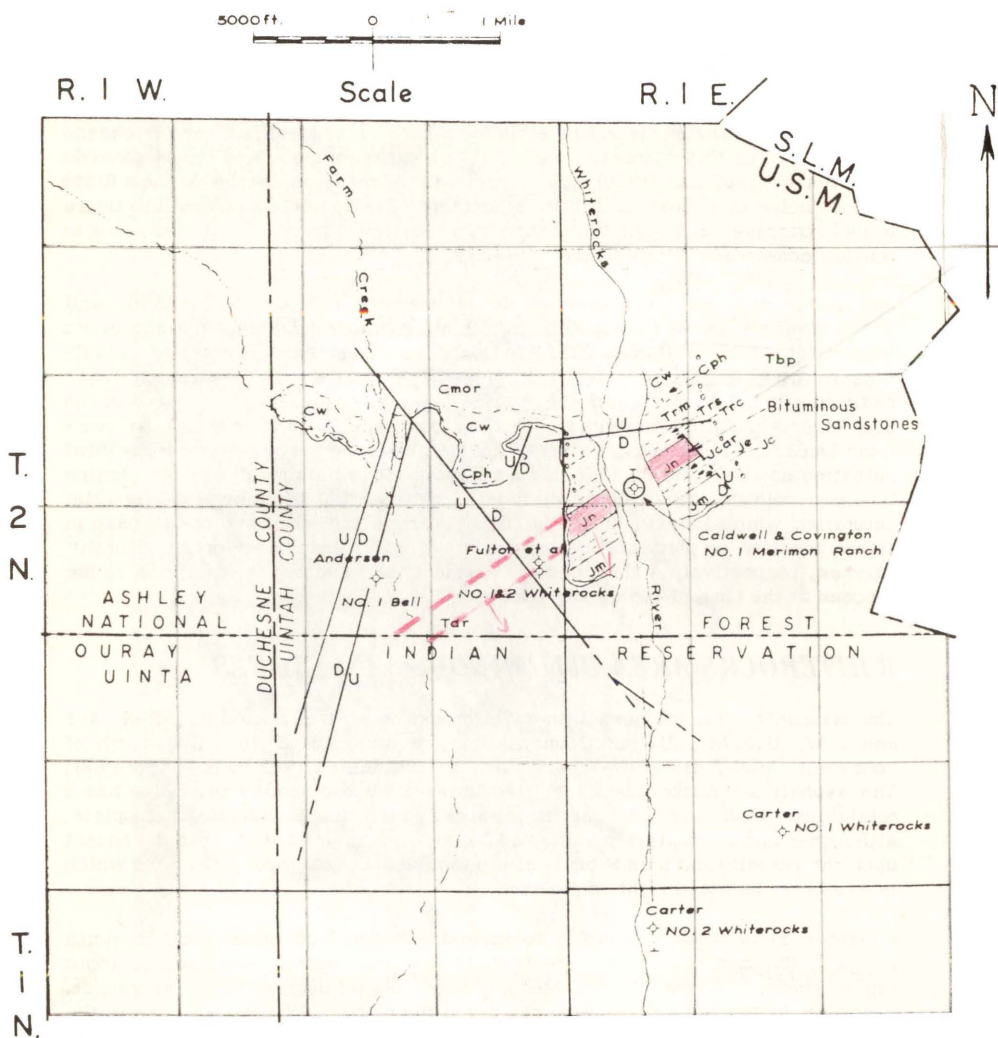


Figure 74. Geologic Map, Whiterocks Area.

GEOLOGY : ROBERT E. COVINGTON

- ✦ DRY HOLE
- ⊕ CORE TEST

Origin of the Oil

The Tertiary Green River formation has been proposed as a source for the oil in the Navajo formation. It is not thought that the oil is indigenous to the Navajo, as the formation is considered to be an eolian type deposit. The author is of the opinion that the oil is of Pennsylvanian age and migrated from the Weber

sandstone at a point where the Navajo sandstone is faulted against the Weber (Figures 77 and 78). The movement of oil into very fine-grained, low porosity and permeability lenses of the Navajo sandstone would seem to indicate that the oil which migrated into the sandstone was of very high gravity. Uplift and erosion beveled the edges of the outcrop, and downcutting through the formation by the Whiterocks River exposed the oil sandstone, so that the lighter and more volatile ends escaped through weathering and oxidation.

The following criteria were used in arriving at this conclusion:

1. There is no evidence of asphalt or tar across the beveled Mesozoic-Paleozoic Duchesne River unconformity, other than the saturation in the Navajo sandstone.
2. There is no increase in the degree of asphalt saturation in an upward direction near the beveled top of the Navajo, along the unconformity. If the oil had moved updip along the unconformity, one should expect to find a decrease in saturation at lower elevations from the beveled surface.
3. The highly fossiliferous Curtis formation has been proposed as a source of the Navajo oil; on the outcrop of the Curtis there is only slight evidence of staining or asphalt saturation. The author does not feel that this formation was the source of the oil in the Navajo of the Whiterocks area.

The eastward wedging of the Thaynes limestone tongue in the Whiterocks area may have been a source for the oil in the Navajo sandstone. Entrapment would be due to the wedging or shaling out of the Thaynes eastward and updip on the southwest flank of the Whiterocks structural nose.

SUNNYSIDE AREA BITUMINOUS SANDSTONES

The geology and asphalt reserves of the Sunnyside area on the south flank of the Uinta Basin have been evaluated in an excellent paper by Holmes and Page (1956). Therefore, the author will only briefly review the salient features of the accumulation. The deposits lie on the south-facing escarpment of the Book Cliffs in Carbon County, Utah, a few miles north of the coal-mining town of Sunnyside. The asphaltic material occurs in beds of late Wasatch and early Green River age. Only the deposits in the Wasatch formation are considered to be of economic value. The calculation of the Wasatch reserves is difficult, due to the highly lenticular nature of the beds and due to their limited exposure. A conservative estimate places the reserves at more than 1,600,000,000 cubic yards of material which averages 9% bitumen by weight.

For a detailed discussion of the stratigraphy of the area, the reader is referred to the paper by Holmes and Page (1956). The beds of Wasatch lithology are more than 3,700 feet thick in the Sunnyside area. The upper one-third of the Wasatch contains the only beds which are bituminous. Only the lower 450 feet of the Green River formation is present in the area, as the upper beds have been stripped by erosion. The individual sandstone beds containing the asphalt vary in thickness from 10 feet to over 300 feet. The saturation is variable, with the degree of saturation being a function of the porosity and permeability of the sandstone. The lateral extent of the beds is more than 9 miles in a northwest to southeast direction. Minor strike faulting is present, but seems to have no relationship to the accumulation of asphalt.

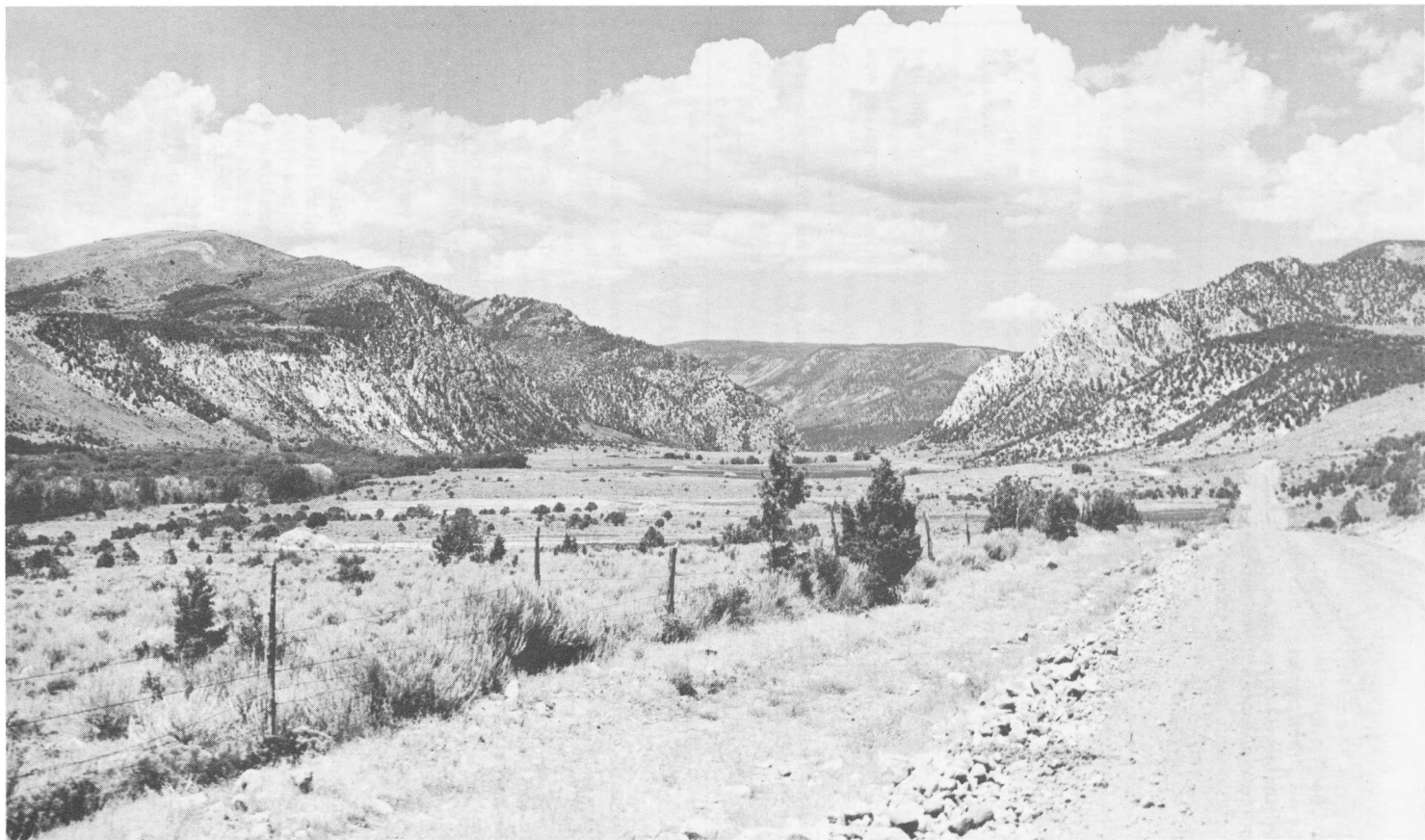


Figure 75. Photograph of Whiterocks Canyon area, looking north; white sandstone on low hill to right is the Jurassic Nugget sandstone.

The asphaltic sandstones weather a blue-gray and are similar in appearance to the weathered beds of the bituminous sandstones of the Asphalt Ridge and White-rocks area. On a freshly broken surface, however, the Wasatch sandstones do not have the typical speckled appearance. Porosities vary greatly, ranging from 14% to more than 30% by volume, with the permeabilities varying from 100 to 600 millidarcies. The Wasatch sandstones are quite well indurated and require blasting to permit removal by dozers with rippers. The ore is carried down an aerial tramway from the quarry and is then trucked to the railroad at Sunnyside. Several of the Sunnyside properties appear to offer excellent possibilities for strip-mining operations. Other parts of the deposits may be well adapted to "in situ" or fireflooding recovery of the oil.

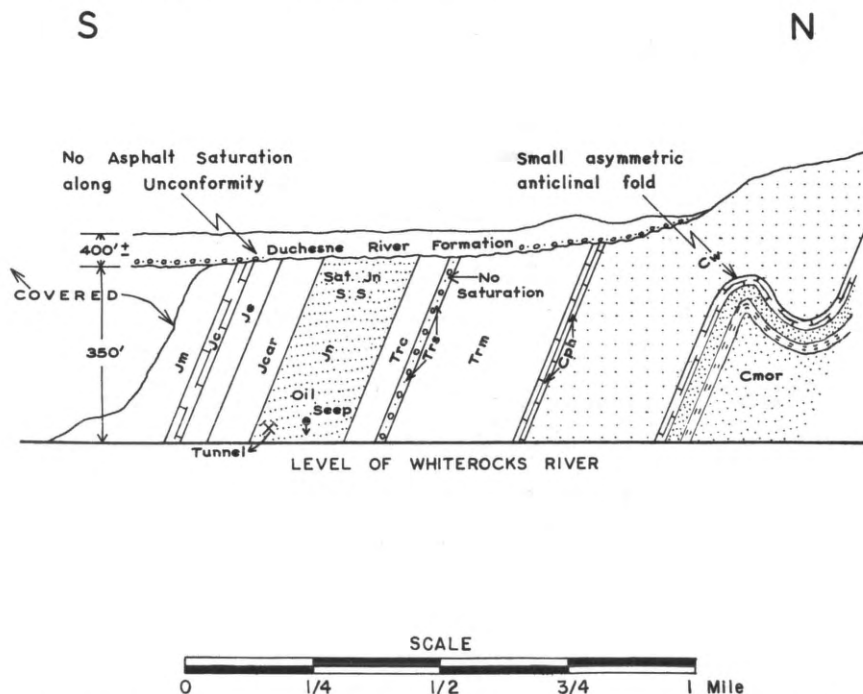
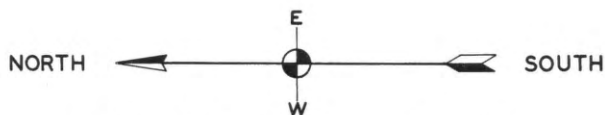


Figure 76. Surface Cross Section, west side Whiterocks River, Sec. 18, T-1-N, R-1-W, U.S.M. Uintah County, Utah.

MISCELLANEOUS LOCALITIES

A glance at the Index Map (Figure 68) will show the location of all of the properties herein described. The author checked reports of an asphaltic sandstone northwest of John Starr flat in the NE 1/4 of Sec. 24, T-2-N, R-3-W, U.S.M., Duchesne County, but was unable to locate the seep. The asphalt occurrence would have been in beds of Eocene-Oligocene age. Another tar seep was reported east of the Whiterocks river in the SW 1/4 of Sec. 16, T-2-N, R-1-E, U.S.M., in Uintah County, but the author failed to locate this also. This seep would have been in beds of Duchesne River formation at a point where the Duchesne River beds overlies beds of the Curtis formation.



GEOLOGIC CROSS PROFILE

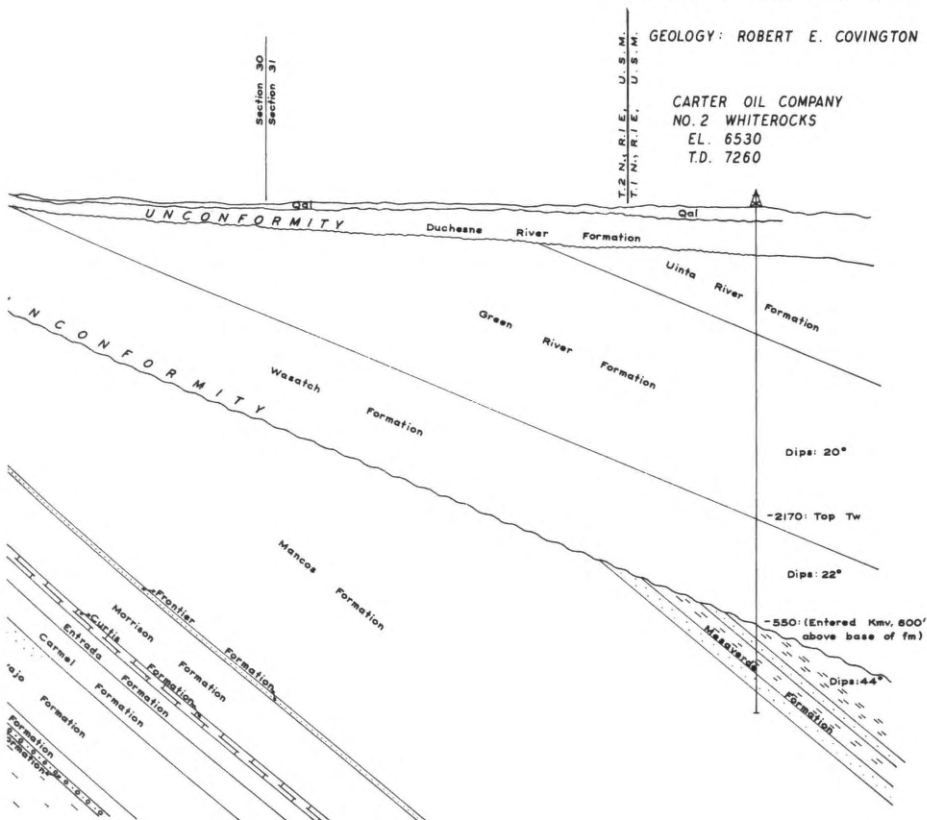
WHITEROCKS AREA

UINTAH COUNTY, UTAH

GEOLOGY: ROBERT E. COVINGTON

CARTER OIL COMPANY
NO. 2 WHITEROCKS
EL. 6530
T.D. 7260

Mean Sea Elevation



Surface Control: Plane Table Alidade Traverse
Subsurface Control-Well Data: Fulton et al. NO. 1 & 2
Carter Oil Company NO. 1 & 2
Caldwell & Covington NO. 1 Merimon Ranch
J. R. Gilbergh NO. 1 Bell

Drafted by: Del Geddes
Office: CALDWELL & COVINGTON
VERNAL, UTAH

Peor Springs Bituminous Sandstones

The Peor Springs bituminous sandstone deposit lies on the southeast flank of the Uinta Basin in T-15 and 16-S, R-23 and 24-E, S.L.M., Uintah County, Utah. The bituminous sandstones are in beds of late Wasatch age and the geologic occurrence is very similar to the geologic occurrence of those in the Sunnyside area. The best saturation is in beds which structurally lie on small nosings or "bowings" and where the porosity and permeability are high. The source of the oil is undoubtedly the down-dip, highly organic, Green River shales and marlstones, with which the fluvatile beds of the Wasatch formation interfinger. The extent of the reserves is not known, although the author has observed saturation in beds which covered an interval in excess of 250 feet.

Chapita Wells Bituminous Sandstones

The bituminous sandstone deposits of the Chapita Wells area lie on the eastern flank of the Uinta Basin in the northwest part of T-9-S, R-23-E, and in the northeast part of T-9-S, R-22-E, in the southwest part of T-8-S, R-23-E, and the southeast part of T-8-S, R-22-E, S.L.M., Uintah County, Utah. The bitumen occurs in the fluvatile sandstones of the Eocene Uinta formation. Although many of the sands are extremely "dry," there are several beds of asphaltic sand which are quite highly impregnated with a thick, tarry bitumen. The reserves are not known, although it is believed that they are not great. The origin is uncertain, but may be related to faulting or to the impregnation of the sandstones by a gilsonitic-type liquid hydrocarbon which moved upward along faults or fractures from a Green River formation source.

Dragon-Asphalt Wash Bituminous Sandstones

The Dragon-Asphalt Wash asphaltic sandstones are located on the southeast flank of the Uinta Basin, near the gilsonite camp at the Black Virgin mine in Uintah County, Utah, in the east half of T-12-S, R-24-E, and the west half of T-12-S, R-25-E. The size of the deposit is not known, although it is extremely doubtful that the deposits have any commercial value. Many of the sandstones are dry, tarry beds with light saturation. About one mile up the canyon from the Black Virgin gilsonite mine is a sandstone, about 25 feet in thickness, which is heavily saturated with a tarry oil. The deposit is adjacent to and updip from a northwest-trending gilsonite vein. Field evidence clearly shows that the gilsonite vein has acted as the feeder to the porous Green River sandstone and has completely charged it with tarry bitumen.

The Deep Creek Nose Asphaltic Sandstones and Conglomerates

In the SW 1/4 of T-3-S, R-19-E, S.L.M., Uintah County, Utah, on the north flank of the Uinta Basin, is a small, south-plunging anticline which is locally known as the Deep Creek nose. The feature is developed in the Tertiary Duchesne River beds. At the point of overlap and along the unconformity between the underlying Mancos shale and the Duchesne River beds of Oligocene (?) age are a series of sandstones and conglomerates which are charged with a viscous, tarry oil. The deposit is only of academic interest. The origin of the crude was the down-dip Green River organic shales. The oil probably moved updip into deltaic-type sandstones north of the organic shales and marlstones. When further uplift occurred to the north, the oil moved updip along the unconformities into the overlying Duchesne River beds.

South Whiterocks Tertiary Bituminous Sandstones

In the SE 1/4 of Sec. 19 in T-2-N, R-1-E, U.S.M., on the south flank of the Uinta Mountains and on the north flank of the Basin, there is a small isolated patch of fairly "dry" bituminous sandstone. The areal extent of the outcrop is small, and the saturation is related to a small northeast-trending fault. The thickness of the beds probably does not exceed fifteen feet.

John Starr Flat Area

About 12 miles west of the Whiterocks area, there is a small inlier of basal Duchesne River beds, a part of which is well saturated with an asphaltic material. This area is the NW 1/4 of the NE 1/4 of Sec. 24 in T-1-N, R-3-W, U.S.M., Duchesne County, Utah. The saturation is sharply delimited on the northwest by a small northeast-striking fault. The asphaltic sandstones are approximately 70 feet in thickness, although the areal extent is extremely small. The deposits are not commercial, but are of academic interest in that the saturation is controlled by faulting.

North Tabiona Bituminous Sandstones

A few miles north and east of Tabiona, Duchesne County, Utah, on the north flank of the Uinta Basin, in the south half of Sec. 17, T-1-S, R-7-W, U.S.M., on Ute Indian Reservation lands, are several small areas where the basal Currant Creek formation has been impregnated with asphalt. The saturation seems to be related to the unconformity between the Currant Creek beds and the underlying Mesaverde formation. The thickest sandstone observed was not over 25 feet in thickness and was extremely limited in areal extent. The Currant Creek formation dips approximately 23 degrees to the south in this area. No saturation was observed in beds above the basal Currant Creek or in the underlying Mesaverde beds.

The Lake Fork-Yellowstone River Bituminous Sandstones

In the summer of 1958 the author checked an asphaltic sandstone deposit on Ute Indian Reservation land, in Sections 5 and 6, T-1-N, R-4-W, U.S.M. The saturation is in the Uinta formation and is located on the north flank of the Uinta Basin, on the divide between Lake Fork and the Yellowstone River. There are three to four tar sandstones which range from 15 to 20 feet in thickness, although the degree of saturation is poor. One of the basal asphaltic sandstones is quite porous and permeable, and a small "brea", or tar spring, flows out of a fractured area and onto the ground. This deposit was cored by the Duchesne County Road Commission in 1958, but the cores were not evaluated. It is understood that the material is not sufficiently rich nor the beds of sufficient thickness to be used as a source of paving material for the county. The origin of the oil is not known. Another deposit is located in Sec. 33, T-2-N, R-4-W, U.S.M., just north of the Uintah and Ouray Indian Reservation line.

South Myton Bench Area Bituminous Sandstones

There are three bituminous sandstone deposits in an area which lies south of the town of Myton, Duchesne County, Utah, and on the Pariette Bench. The deposits are in the central part of the Uinta Basin and occur in beds of the Uinta formation of Eocene age. Due to the highly lenticular nature of the sandstone beds, it is believed that these deposits do not have any great commercial value, for many of the sandstones contain "dry" tar. The origin of the oil is not known,

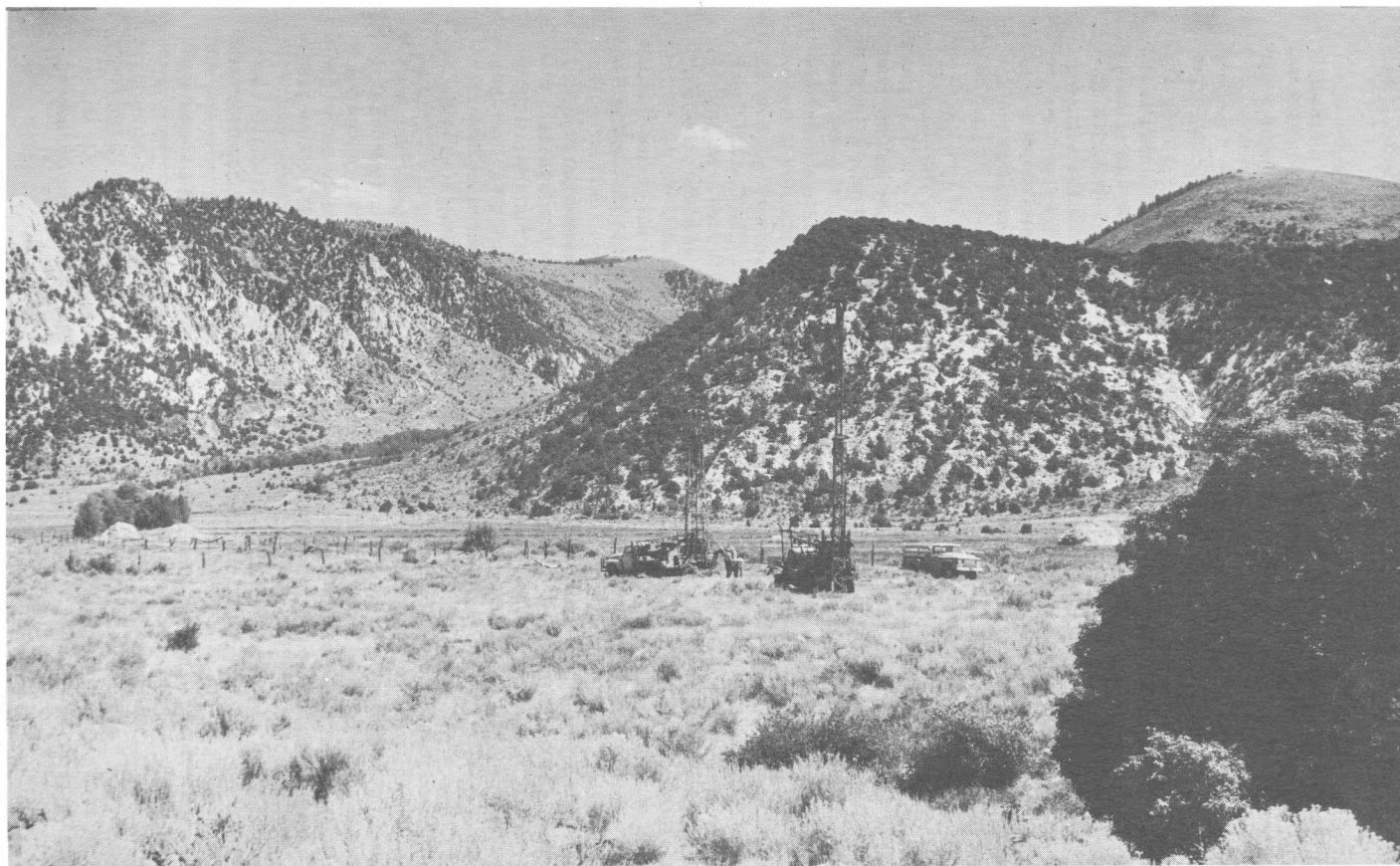


Figure 78. Photograph in Whiterocks Canyon, looking east at the outcrop of asphaltic Navajo sandstone.

although the author believes that the accumulation may have been related to the east-west trending Duchesne fault zone, for the saturated beds are south of and updip from the fault zone. North of the faults, there is no saturation or impregnation of asphalt. The oil could have migrated up the fault plane from the underlying Green River formation. It is also possible that the origin of the oil could be related to the interfingering of the lacustrine Green River sediments with the fluvatile Uinta-type sediments.

Indian Canyon-Lake Canyon Bituminous Limestone Deposit

In the Argyle Canyon area on the southwest flank of the Uinta Basin, there is an asphaltic sandstone which has been marketed under the trade name of "argulite" and which contains from 8 to 10% bitumen by weight. The deposits are in beds of the basal Green River (?) and lie south of the divide which separates the drainage of the Minnie Maude Creek from the north-draining streams on the dip slope of the Green River Formation. This deposit was mentioned by Abraham (1918).

The Raven Ridge Asphaltic Sandstone

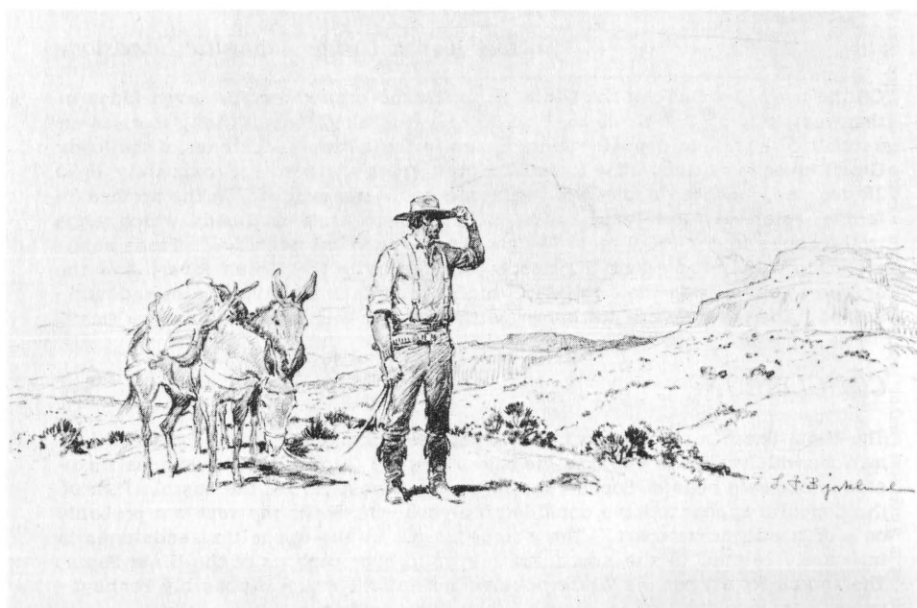
On the northeast flank of the Uinta Basin in the area known as Raven Ridge in the west half of T-7-S, R-25-E, S.L.M., Uintah County, Utah, there is an asphaltic sandstone deposit which occurs in the deltaic sandstones of the lower Green River formation. The formation dips southwestward approximately 16 to 18 degrees, and the asphaltic sandstone beds are exposed on the northeast-facing, relatively low-lying escarpments. There are 6 to 8 beds which range in thickness from 2 to 10 feet. Much of the sandstone is "dry." These sandstones probably represent the near-shore facies of the Green River, and the source of the oil was the down-dip, highly organic Green River shales and marlstones. The reserves are not known, although it is believed that they are small.

CONCLUSION

The Uinta Basin in northeastern Utah is replete with asphaltic sandstones in formations which range in age from the Jurassic to the Oligocene. Bituminous limestones occur in beds of Eocene age in the southwest part of the Basin. Four of the deposits appear to have considerable economic merit; the rest are probably only of academic interest. The source of oil in the asphaltic sandstones is intimately related to the source of the solid hydrocarbons of the Uinta Basin. The source for all but the Whiterocks accumulation, which is possibly Pennsylvanian, is undoubtedly the Eocene Green River sediments.

CITED REFERENCES

- Abraham, H., 1945, *Asphalts and allied substances*: New York, D. Van Nostrand Co., Publisher.
- Barb, C. F., and Ball, J. O., 1944, *Hydrocarbons of the Uinta Basin*: Colo. School of Mines Quart., v. 39.
- Covington, R. E., 1957, *The bituminous sandstones of the Asphalt Ridge area, northeastern Utah*: Intermountain Assoc. Petroleum Geologists Guidebook 8th Ann. Field Conf.
- Holmes, C. F., and Page, B. M., 1956, *Geology of the bituminous sandstone deposits near Sunnyside, Utah*: Intermountain Assoc. Petroleum Geologists Guidebook 7th Ann. Field Conf.
- Kinney, D., 1955, *Geology of the Uinta River-Brush Creek area, Duchesne and Uintah Counties, Utah*: U.S. Geol. Survey Bull. 100, p. 73-77, 150-159.
- Pruitt, R. G., 1961, *Mineral Resources of Uintah County, Utah*: Utah Geol. and Mineralog. Survey Bull. 71, p. 11-22.
- Spieker, E. M., 1930, *Bituminous sandstones near Vernal, Utah*: U.S. Geol. Survey Bull. 822-C.



Paper 24 COMPOSITION AND ORIGIN OF THE UINTA BASIN BITUMENS

by John M. Hunt¹

INTRODUCTION

The names of the three formations of interest, from oldest to youngest, the Wasatch, Green River, and Uinta, have been used largely as facies terms to differentiate sediments which were believed to be of different age but actually were deposited simultaneously. The Wasatch is predominantly fluvial and continental, consisting of redbeds and thick sands. Much of what has been called Wasatch in the cliffs along the south side of the basin was deposited at the same time as what has been called Green River in the center of the basin. The Green River includes those beds of lacustrine lithologic type, of which the most distinctive are the oil shales. The Uinta formation, red and green shales and channel sands, is well developed in the northeastern part of the basin and grades into lacustrine beds which have been called Green River toward the center. In this paper the terms Wasatch, Green River, and Uinta are used to designate time-stratigraphic units, unless it is expressly stated that they are used as facies terms by some phrase like "Green River lithology."

OCCURRENCE OF THE BITUMENS

The bituminous substances of the Uinta Basin include oil shales, vein deposits, and bituminous sandstones (Fig. 79). Each type of material occurs only in a particular sedimentary facies: oil shales in the lacustrine facies, veins of bitumens in fractures associated with minor structures in the portion of the lacustrine facies containing oil shale, and deposits of bituminous sandstone in the shore facies where reservoir sandstones interfinger with lacustrine facies containing oil shales. The subaerial facies are essentially barren of bitumens. This association between bituminous substances and facies is shown schematically in Figure 81. Some of the vein deposits extend into subaerial deposits, but all originate in the lacustrine facies. In addition, the individual bitumens, ozocerite, albertite, gilsonite, and wurtzilite, appear to be associated with definite time intervals as illustrated in Figure 80. Each formation or time stratigraphic unit contains its own peculiar bitumens.

Wasatch Formation — Ozocerite

The Wasatch is primarily a redbed, non-lacustrine formation, and is exposed all around the southern margins of the basin. In the Soldier Summit area the upper Wasatch consists principally of variegated shales and channel sandstones with some lacustrine sediments, consisting of fossil shales and dense limestones. Some shales contain ostracods, but the limestones are almost barren of fossils, which differentiates them from the limestones in the units above and below. Locally this lacustrine facies contains highly bituminous calcitic oil shales. Ozocerite is a native wax which occurs as filling in fracture breccia associated with north-south trending faults in the southwest margin of the basin near Soldier

1. Geochemist, Jersey Production Research Company, Tulsa, Oklahoma.

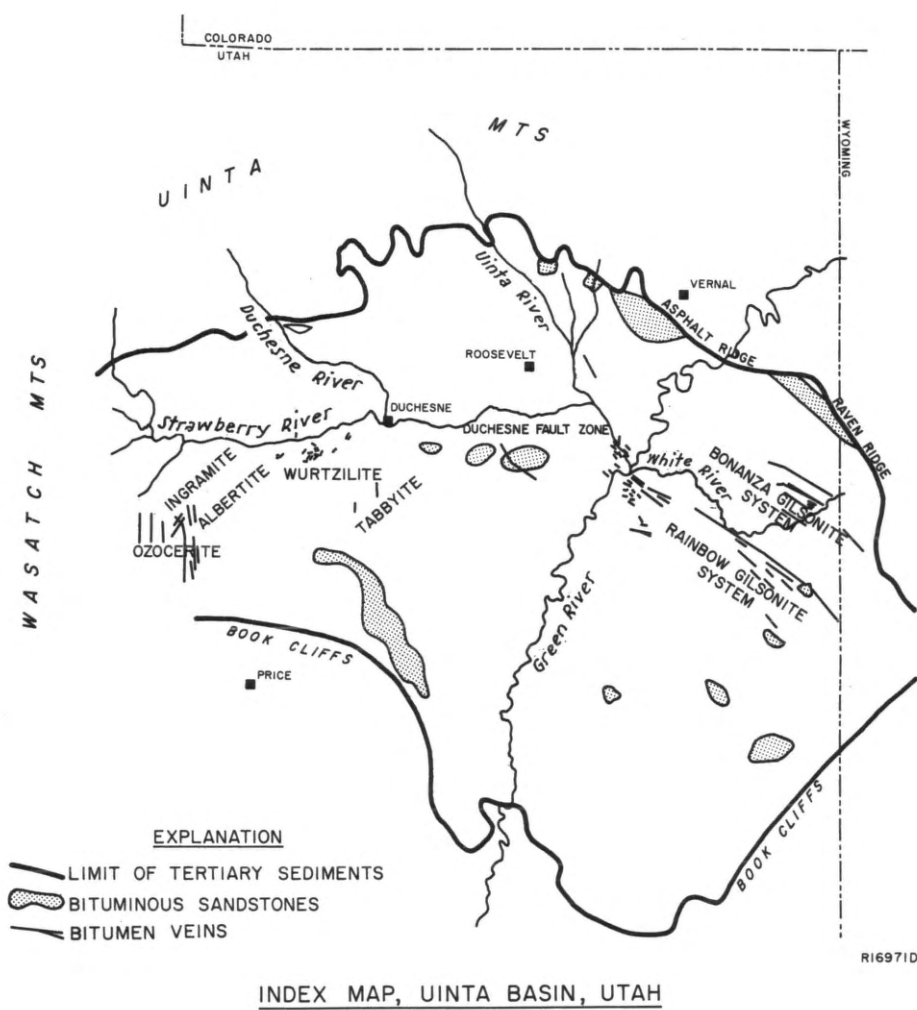


Figure 79.

Summit. The faults cut the non-marine upper Wasatch, and the origin of the ozocerite is apparently the bituminous lacustrine oil shales farther northeast toward the center of the basin. The most important deposit is the Soldier Summit mine (Sec. 30, T-10-S, R-8-E) in a bed of oil shale. This vein extends over 2,000 feet in a belt of breccia that varies from five to 50 feet in width. It has been mined as deep as 600 feet. Liquid ozocerite drips from the deeper mine levels. The Humble Oil Company's Ruth Nelson No. 1 had a show of oil containing wax similar to ozocerite on the northern margin of the basin in beds of shoreline facies close to typical Wasatch redbeds. In the latter area it appears that the bitumen was generated in oil-shale facies and migrated a short distance laterally into sandstones in a redbed facies. A similar condition appears to exist at Soldier Summit where the upper Wasatch red shales change facies to oil shales a short distance downdip (northward). In the Roosevelt and Duchesne field, oil is produced directly from fractured bituminous shales in the basal Green River. The heavy ends of this oil are remarkably similar to ozocerite.

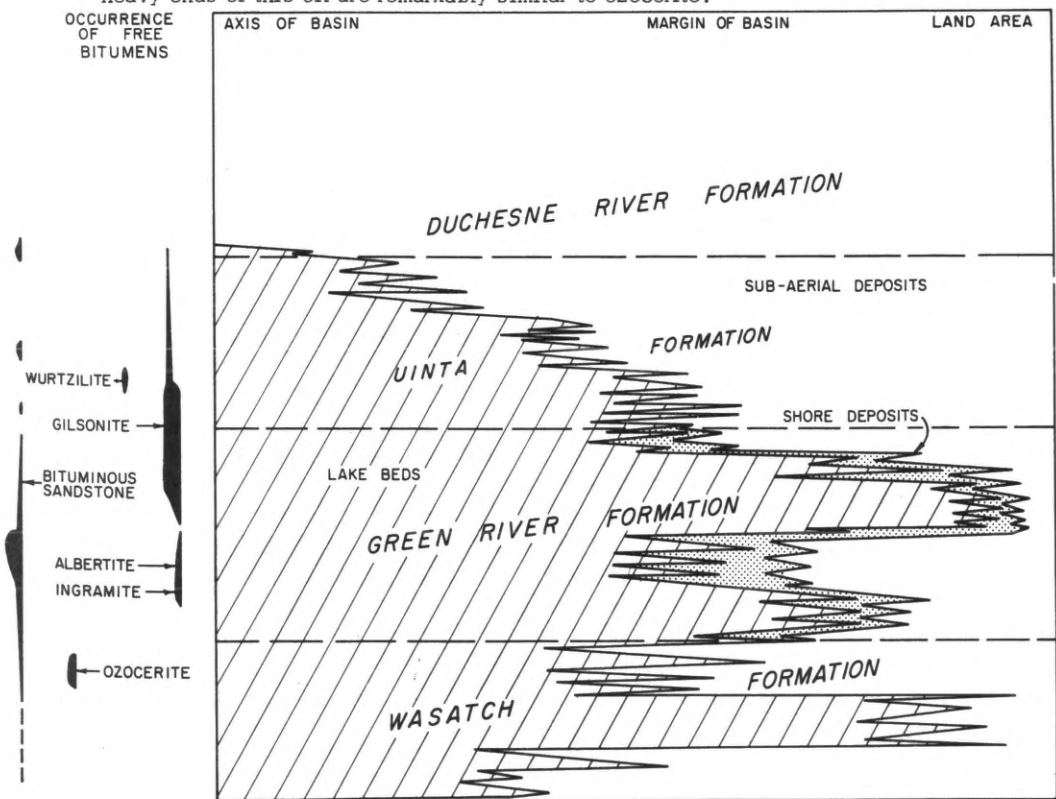


Figure 80.

RI6967D

SUBDIVISION OF THE TERTIARY IN THE UINTA BASIN

Green River Formation — Albertite, Ingramite, Gilsonite

The Green River formation reaches a maximum thickness of nearly 7,000 feet near the center of the basin. It includes three major facies: lacustrine, shore, and subaerial. The lacustrine facies are of two major types. The first type consists of

siliceous carbonates called "oil shales." They contain dolomite, calcite, and finely crystalline quartz with a widerange in amounts of organic matter. Less than one-fourth of the samples contain clay minerals. They weather white and are exposed as high cliffs in many places. The other lacustrine type consists of gray-green shales interbedded with minor amounts of thin white limestone or dolomite. These beds occur abundantly in the western and southwestern part of the basin. The shore facies is composed of interbedded sandstones and calcareous shales and muds, which locally contain oolites, clastic calcareous mudstones, and algal reefs. These grade laterally into the subaerial facies which is predominantly brown sandstone and siltstone, interbedded with minor amounts of red and green shale. The latter have generally been called Wasatch, even though they are of Green River age.

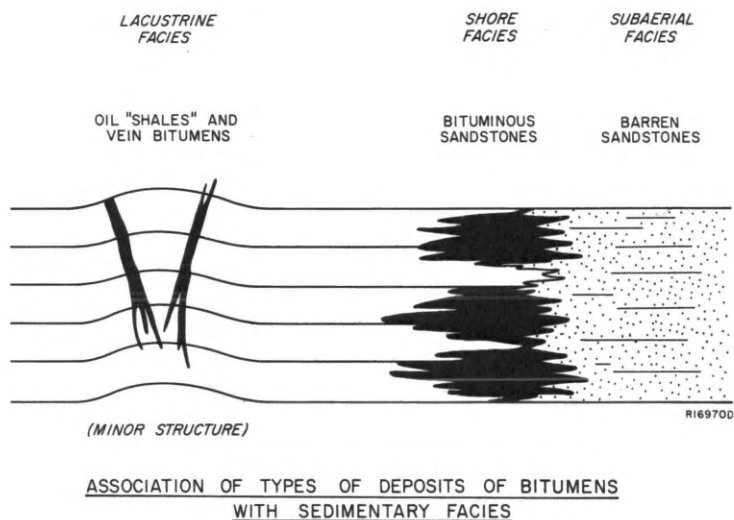


Figure 81.

The lower part of the Green River consists of oil shale, red and green shale, sandstone, marlstone, oolite and algal reefs. The unit contains many fossils at the base, predominantly gastropods and pelecypods that are believed to be either fresh or brackish-water types. Similar fossils are not found in any of the overlying beds.

In the lower Green River formation about 500 feet stratigraphically higher than the ozocerite deposits are found small deposits of a pyrobitumen: albertite. This material occurs in fissures within the lake beds. The largest albertite vein is 4-8 inches wide and can be traced for several hundred feet. Other bitumens that appear to be less weathered forms of albertite, such as ingramite, occur in the same general area, and all of them fill fractures and joints in a mahogany-type shale which contains an abundance of fossil scales and fish skeletons. Small amounts of liquid ingramite exude from bedding planes of the shale where exposed

to the heat of the sun. Some veins have such a small lateral and vertical extent that they can be tied directly to their source--the mahogany-type oil shales.

The middle part of the Green River contains a large number of sandstones, which are more common on the margins of the basin than in the center. Along the south rim of the basin there are thick bituminous sands. The saturated sandstones belong in the near-shore facies and are interbedded with and grade laterally into dolomitic oil shale. The more massive sands farther from the oil shales are not saturated, even though they are laterally updip from them.

Many small joints occur in the lacustrine facies in the center of the basin. These are filled with gilsonite that apparently was derived from the adjacent shales. In the eastern part of the basin, the large Dragon and Weaver gilsonite veins terminate downward in oil-shale beds. The sediments in Evacuation Wash are near-shore, and characterized by oolites and algal reefs which have been described by Bradley (1929). No fossils except ostracods and insects are found.

The lake reached its maximum areal extent during late Green River time. Shore-line facies occur around the margins of the basin, but most of the subaerial beds have been removed by erosion. The top of the unit contains a highly saline facies, characterized by cavities formerly occupied by crystals of various carbonate salts. In the western part of the basin the lithologic character is still lacustrine, and the unit consists of green shales with little bituminous or carbonate content, and no bitumen veins. In the eastern part of the basin the section is predominantly oil shale which ranges widely in richness. The richest member of the oil shales, known as the "mahogany ledge," consists of bedded oil shales of various lithologic types, mainly very dark brown and black, hard, cherty dolomite and papery, laminated shale, and averages, when retorted, 30 gallons per ton of shale-oil. It is stratigraphically the same member that is being mined by the U.S. Bureau of Mines in the Piceance basin at Rifle, Colorado. It is exposed on the east margin, but is not present on the west or south sides of the basin.

In the Bonanza-Rainbow area there is a restricted zone containing crystal cavities which are empty, filled with calcite, or filled with gilsonite. These cavities apparently were formed by the solution of nahcolite, or other complex carbonate salts.

A shoreline facies of upper Green River is present along Raven Ridge on the northeast margin of the basin, and many of the sandstones are saturated with asphalt. The source of this asphalt is apparently the rich shales into which the sandstones interfinger basinward. Heavy sandstones of Green River age which also interfinger with oil shales basinward are found saturated with asphalt around the southern margin of the basin.

All the veins within middle and upper Green River are gilsonites, most of which branch into a series of veinlets in the rich oil shales. The gilsonite apparently moved into the veins as a fluid. A liquid form of gilsonite is found at depths in the Bonanza mine. The largest gilsonite veins cut about 1,500 feet of section and reach a thickness of approximately 18 feet. At their base in the general zone of the Mahogany ledge, veins as thin as 1/4 inch have been observed, although the average is nearer 1 inch. The gilsonite veins appear to be derived from the upper Green River formation, since most of the veins terminate in this section. There is no evidence that any of the gilsonite veins originate in the overlying Uinta formation. Although many of the veins are widest in the subaerial deposits

of the Uinta formation, in all places they terminate downward in the Green River. A more detailed description of the gilsonite mines is given by Abraham (1960).

Uinta Formation — Wurtzilite, Tabbyite

The Uinta formation overlies the Green River formation. The red and green shales and channel sandstones which are characteristic of the Uinta formation in the Bonanza area, grade westward into lacustrine oil shales. Some of these lacustrine beds are lithologically peculiar, consisting of very cherty bituminous dolomites with abundant cavities once occupied by crystals of soluble salts.

West and south of Duchesne in these Uinta beds of lacustrine facies are found veins of the pyrobitumen wurtzilite. Most of the veins are less than 2 feet wide and 20-30 feet in height. Few veins can be traced more than a mile or two, and occur at about the same stratigraphic horizon. All are completely enclosed by bituminous marlstones which appear to be their source beds (Abraham, 1960).

The asphalt tabbyite is found in Tabby Canyon several miles to the southeast of the wurtzilite mines at approximately the same stratigraphic horizon. It extends as a series of disconnected veins for about 3 miles with a maximum width of about a foot. It breaks into a number of veinlets or stringers with depth.

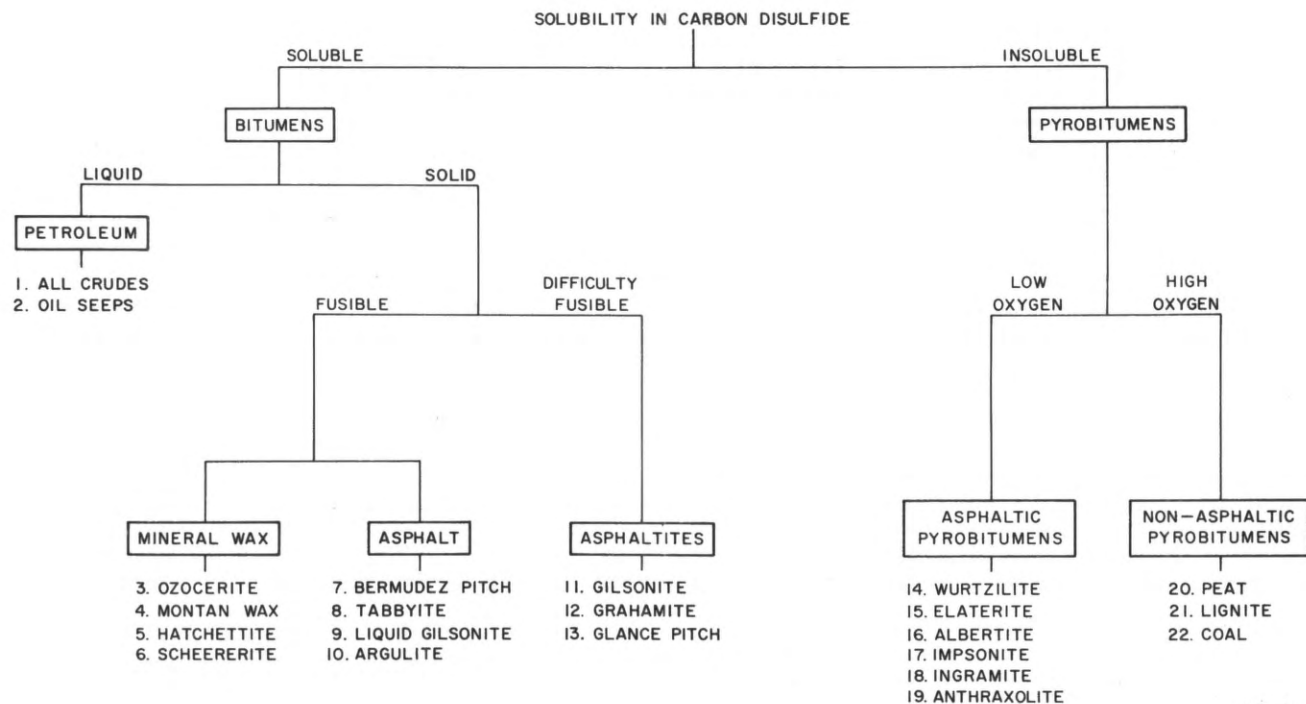
COMPOSITION OF THE BITUMENS

Types and Classification of Bitumens

Bituminous substances are generally divided into two major classes, those soluble, and those insoluble, in carbon disulfide (Abraham, 1960). Subdivisions of these major classes are made on the basis of the fusibility of the substance. Figure 82 presents a classification of most of the known types of naturally occurring bitumens. The crude oils and oil seeps are relatively low molecular-weight, distillable bitumens, whereas all the rest of the substances are higher molecular-weight, non-distillable bitumens. Going across the chart from left to right there is a decrease in the solubility and an increase in the fusion point and the carbon to hydrogen ratio of the bitumen.

Ozocerite is a mineral wax composed principally of straight chain paraffin hydrocarbons with a few naphthenes. Hatchettite and scheererite are local names for varieties of ozocerite found in Scotland and Switzerland. Montan wax is a mixture of high molecular weight acids and esters in the range from about C₂₉ to C₃₅. It is not found in a free state, but is extracted from lignite or pyropissite by solvents. Ozocerite is the only mineral wax found in the Uinta Basin. It is called Utah wax in the literature to distinguish it from Galician ozocerite.

Viscous liquids or solid low-melting bitumens are classified by Abraham as asphalts. The asphalts that are readily extracted from asphaltic sandstones and limestones also come under this classification. Among the asphalts found in the Uinta Basin are: tabbyite, a solid found in veins in Tabby Canyon; a semi-solid bitumen oozing from a creek bed west of Duchesne and called "liverite" in this paper; liquid gilsonite found at depths in the Bonanza gilsonite mine; and argulite, an asphalt saturating sandstone in the canyon of Argyle Creek south of Ouray. There are also asphaltic limestones north of Colton and asphaltic sandstones at many other places in the basin. Some of these contain up to 50% asphalt by volume.



R 16897 D

Adapted From H. Abraham (1)

TERMINOLOGY AND CLASSIFICATION OF NATURALLY OCCURRING BITUMINOUS SUBSTANCES

Figure 82.

An asphalt with a fusing point higher than 230°F is classified as an asphaltite. Gilsonite is the only asphaltite found in the Uinta Basin.

Bituminous substances that decompose before they melt are called pyrobitumens. The asphaltic pyrobitumens are differentiated from the non-asphalts or coals, in that the former generally contain less than 5% oxygen. Wurtzilite, "ingramite," and albertite (also called nigrite) are the principal asphaltic pyrobitumens found in the Uinta Basin.

The bitumens listed in Figure 82 can be separated into fractions on the basis of their solubility in organic solvents. When the bitumen is mixed with petroleum ether, it separates into a soluble portion (malthenes) and an insoluble portion (asphaltenes). The malthenes can be further subdivided by mixing them with adsorbent clay and extracting with carbon tetrachloride. The extracts are the oily constituents, and the residues are the asphaltic resins. The resins are removed from the clay with carbon disulfide. When the asphaltenes are mixed with carbon disulfide, they separate into a soluble portion (carbenes) and an insoluble portion (carboids).

Physical and Chemical Properties

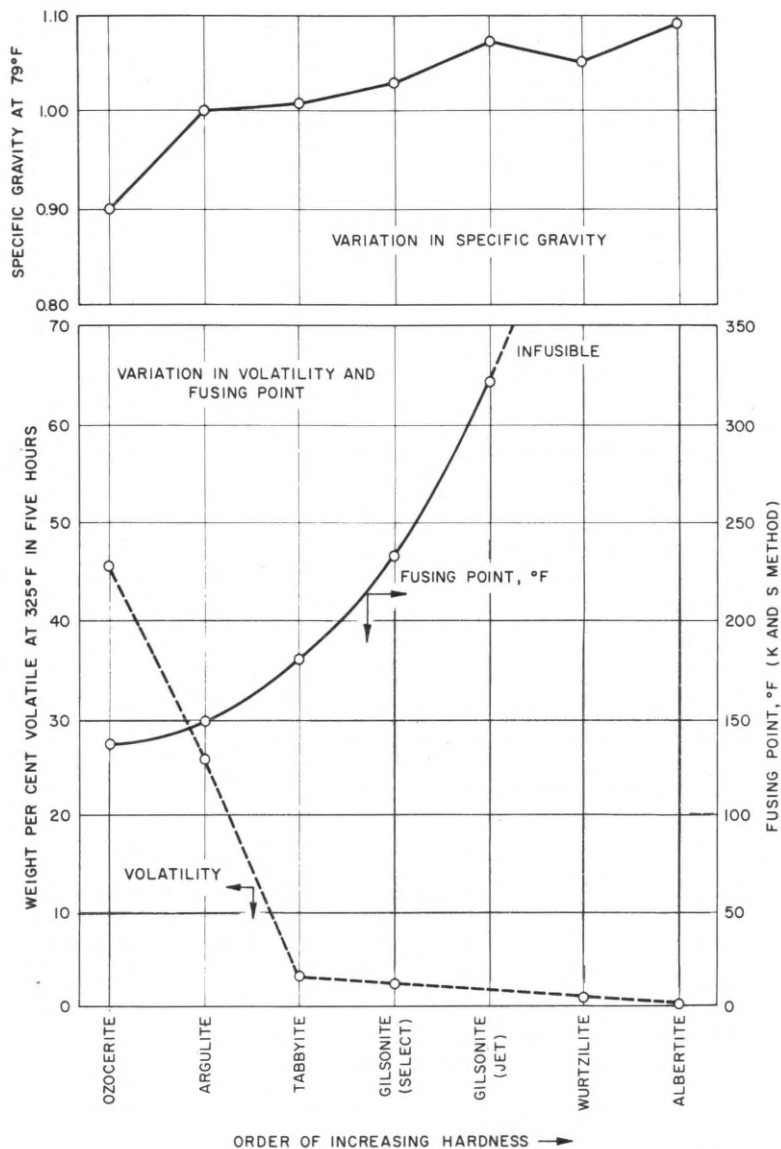
General Properties: The different bitumens of the Uinta Basin vary considerably in their physical and chemical properties which provide a means for characterizing and identifying them. Figures 83 and 84 show the variation in fusing point, specific gravity, and solubility. The bitumens are arranged in order of increasing fusing point: waxes, asphalts, asphaltites, and pyrobitumens. The fusing points increase rapidly for the denser bitumens. Different grades of gilsonite range in fusing point from 230 to 350°F. Solubilities in carbon disulfide show a sharp break between the soluble asphaltite, gilsonite, and the insoluble pyrobitumen, wurtzilite.

The fixed carbon content, useful in making a preliminary classification of the bitumen, is defined as the carbon residue left after heating the bitumen at 950°C for 7 minutes in the absence of air. In general, it stays within definite limits for the different types of bitumens. Some of the fixed carbon analyses made on Uinta Basin samples are listed in Table XIII. These values are on an ash-free basis.

TABLE XIII
FIXED CARBON ANALYSES OF UINTA BASIN BITUMENS

Bitumen	Source	Wt. % Carbon Residue *
Ozocerite	Soldier Summit	4.1
Wurtzilite	Country Gentlemen	5.9
Wurtzilite	Powtin vein	6.2
Wurtzilite	Canyon Junction	7.6
Ingramite	Soldier Summit	8.1
Ingramite	Soldier Summit	8.4
Gilsonite	Black Dragon	13.8
Gilsonite (pencilated)	Bonanza	16.3
Gilsonite	Bonanza	16.6
Gilsonite	Weaver	18.6
Albertite	Soldier Summit	38.0
Albertite	Soldier Summit	37.7

*ash free basis



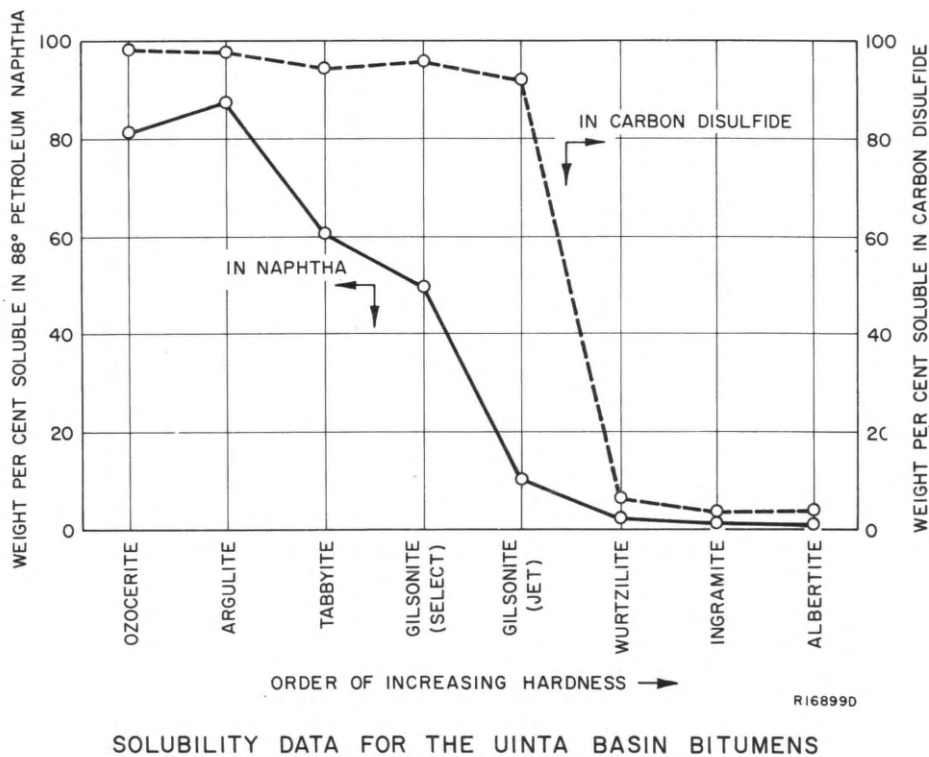
R 16898D

Adapted From H. Abraham (1)

PHYSICAL AND CHEMICAL PROPERTIES OF THE UINTA BASIN BITUMENS

Figure 83.

Albertites are readily distinguished from the other bitumens by their high carbon residues. Different types of gilsonites differ only by a few per cent in their carbon residues. Wurtzilites and ingramites have unusually low residues considering the fact that both are pyrobitumens.

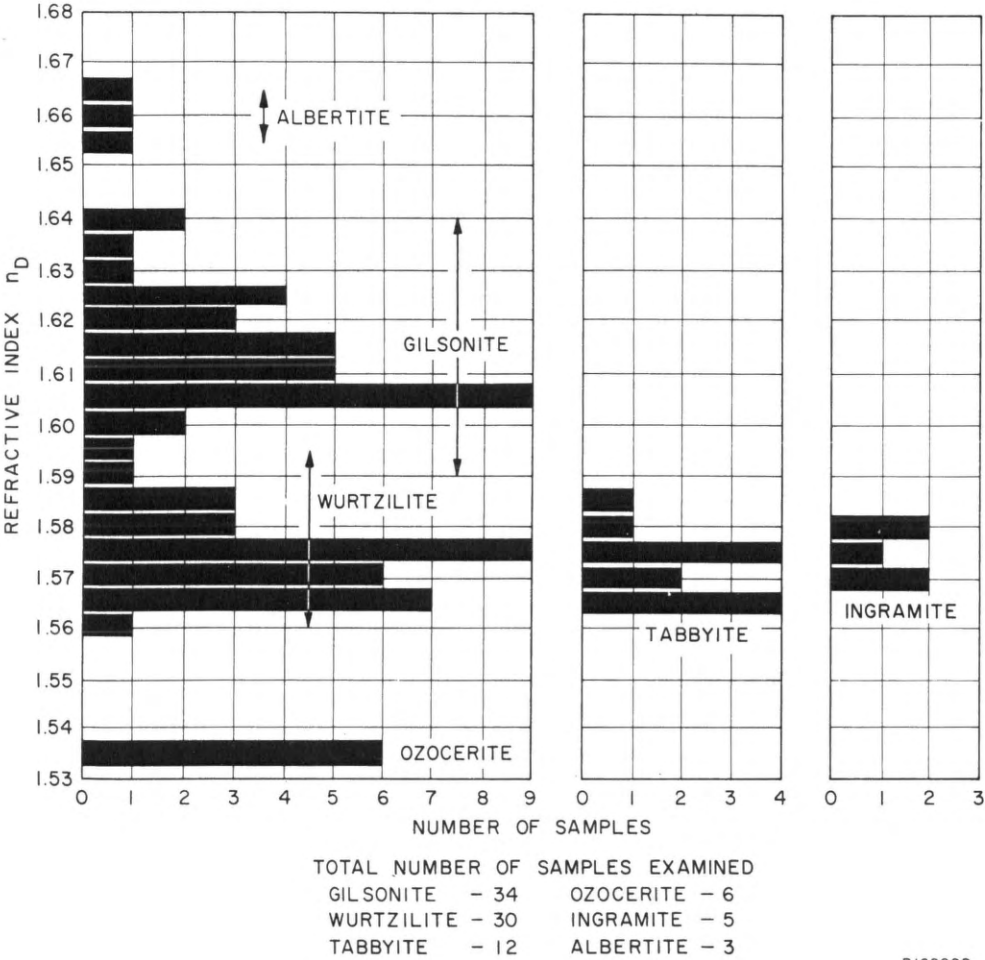


SOLUBILITY DATA FOR THE UINTA BASIN BITUMENS

Figure 84.

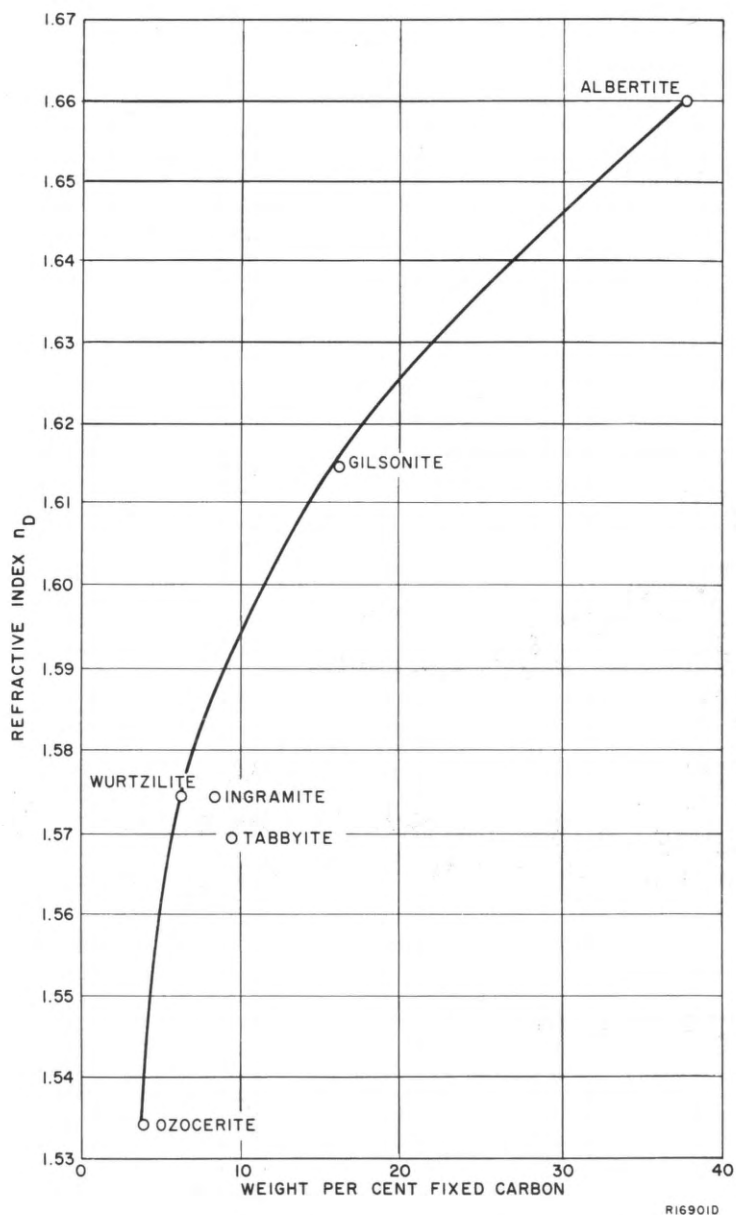
The refractive index of a bitumen is useful as a correlation index and as an indication of molecular structure. Within any one molecular weight range, the order of increasing refractive indices is paraffins, naphthenes, aromatics. In the high molecular weight ranges there is some overlap, but the rule still applies generally. Figure 85 is a frequency distribution chart of the refractive indices of ninety bitumen samples. These samples were chosen from as many different localities as possible so as to obtain a completely random distribution. The length of each bar in Figure 85 indicates the number of samples having that particular refractive index. It is apparent that with refractive indices alone it is possible to distinguish between albertite, gilsonite, wurtzilite, and ozocerite, except for indices between 1.585 and 1.595 where gilsonite and wurtzilite overlap. It is not possible to distinguish between ingramite, wurtzilite and tabbyite by refractive index since all three overlap each other.

When the median refractive index of the bitumens is plotted against fixed carbon content, the points fall in a smooth curve as shown in Figure 86. Ozocerite, with a high paraffin content, has a low refractive index and carbon residue. At points higher on the curve, where the indices and carbon contents are high, there is a decrease in the paraffin content and an increase in the aromatic and condensed ring structures. The position of the two pyrobitumens, wurtzilite and ingramite, at the low end of the curve strongly suggests that they either have fewer aromatics in their structure, or smaller molecular units than either gilsonite or albertite. There is also other evidence to support this, such as the carbon to hydrogen ratios.



FREQUENCY DISTRIBUTION OF THE REFRACTIVE INDICES OF
 UINTA BASIN BITUMENS

Figure 85.



REFRACTIVE INDEX AND FIXED CARBON CONTENT OF
THE UINTA BASIN BITUMENS

Figure 86.

Structure Correlations from Infrared Absorption Spectra: Additional information on organic structures of asphalts can be obtained from a study of their infrared spectra. Specific atomic configurations, such as an -OH , >C=O and phenyl groups, have absorption bands in specific narrow regions of the spectrum. For example, the -OH group of alcohols absorbs at a wave length of 3.0μ , the >C=O of ketones, aldehydes, and acids at about 5.9μ , oxygenated structures in the region of $8\text{--}10\mu$, aromatic structures from 11 to 13.5μ , and long chain-aliphatic paraffins around 13.9μ . The ratios of aromatic and paraffinic structures can be compared among bitumens from the intensity of absorption bands in the $11\text{--}13.5\mu$ aromatic region and in the 13.9μ paraffin region. A considerable amount of data on the correlation of atomic groups and infrared absorption frequencies has been reported in the literature (Faraday Society, 1945; Barnes, et al., 1948; Randall, et al., 1949). In general, the order of compounds having increasing intensities of absorption bands is naphthenes, paraffins, olefins, aromatics, oxygen, sulfur, and nitrogen compounds. The non-hydrocarbons have absorption bands approximately twenty times more intense than paraffin hydrocarbons.

Structures in the carbon disulfide soluble portions of the Uinta Basin bitumens can be determined by examination of the curves in Figure 87. The absorption peaks at 13.9μ in the spectra of ozocerite, wurtzilite, albertite, and ingramite indicate the presence of chains of five or more carbon atoms in these compounds. The sharp peaks at about 13.4μ in the ingramite and albertite spectra are attributed to polycyclic aromatics. The two broad humps at 11.5 and 12.3μ in gilsonite are due to aromatics, the latter peak being attributed to para-substituted aromatics. The peaks around 8.6μ in the spectrum of gilsonite, and at 8.9μ in the spectrum of wurtzilite, are probably due to oxygenated compounds which absorb strongly in the $8\text{--}10\mu$ region. The sharp peaks at about 5.9μ in the spectra of ingramite and albertite are due to the >C=O group.

The liquid bitumens of the Uinta Basin have essentially the same basic structures as the soluble portion of the solids. Evidence for their similarity in basic structures is provided by the similarity of their infrared spectra. In Figure 88 the spectra of liquid, semi-solid, and the soluble portion of solid forms of gilsonite and wurtzilite type bitumens are shown. The gilsonites are all from the Bonanza vein system. No. 1 is a liquid ooze from a gilsonite mine, and No's. 2, 3, and 4 are harder forms of gilsonite with increasing asphaltene content. It will be noted that all of the first four spectra are characteristic of gilsonite (Figure 87). Their chief differences are in the $8\text{--}10\mu$ range where the increasingly harder forms show increasing absorption due to the presence of oxygenated compounds. They are distinctly different from the bottom spectra of wurtzilite-type bitumens. No. 5 is a semi-solid material that is completely soluble in CS_2 , and No. 6 is a true wurtzilite that is only partially soluble. Both show the characteristic wurtzilite curve with strong absorption at 8.9 , 9.65 , and 13.9μ .

Elemental Analyses: Some information about the molecular structures of bitumens from the Uinta Basin can be obtained from an analysis for the elements carbon, hydrogen, sulfur, and nitrogen. The ratio of hydrogen to carbon atoms varies in different molecular structures. Naphthene and paraffin hydrocarbons have high H/C ratios whereas condensed aromatics have low H/C ratios. Consequently, bituminous substances rich in the former materials have high H/C ratios, whereas carbonaceous substances rich in the latter materials have low H/C ratios. Ozocerite, a paraffin wax, has the highest H/C atomic ratio of the Uinta Basin bitumens, whereas albertite, the pyrobitumen has the lowest ratio next to the coals. The ratios of these and other natural bitumens are listed in Table XIV.

The order in which the substances are listed in Table XIV represents an order of decreasing paraffinicity and increasing aromaticity.

TABLE XIV
HYDROGEN AND CARBON ATOMIC RATIOS FOR NATURAL BITUMENS

Bitumen	Source	Atomic H/C Ratio
1. Ozocerite	Soldier Summit	1.96
2. Ozocerite	Miller Mine	1.89
3. Tabbyite	Tabby Canyon	1.62
4. Ingramite	Soldier Summit	1.62
5. Wurtzilite	Indian Canyon	1.60
6. Wurtzilite	Red Creek	1.59
7. Gilsonite	Black Dragon	1.47
8. Gilsonite	Bonanza	1.45
9. Gilsonite	Rainbow	1.42
10. Albertite	Soldier Summit	1.32
11. Albertite	Albert Co., New Brunswick, Canada	1.24
12. Coal	Uinta Basin	0.99
13. Bituminous Coal		0.80
14. Anthracite Coal		0.56

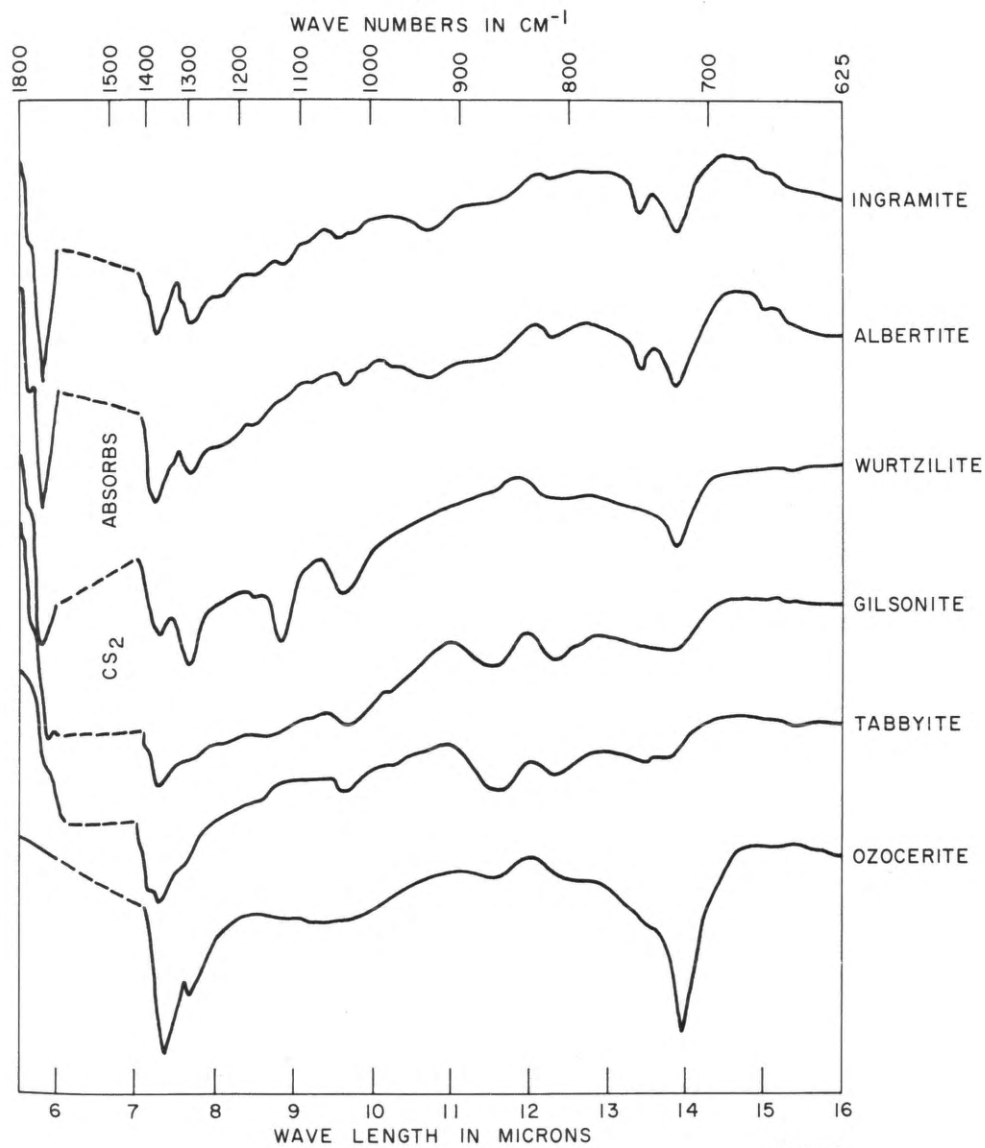
Structural interpretations based on H/C ratios are valid only if the total quantity of nitrogen, sulfur, and oxygen in the substances being compared does not differ appreciably. Since these elements replace hydrogen, a pure hydrocarbon structure would have a higher H/C ratio than a corresponding structure containing nitrogen, sulfur, or oxygen. Maximum differences in the nitrogen, sulfur, oxygen content of the Uinta Basin bitumens are about 6%, which is too low to influence the order in Table XIV. The Uinta Basin coal and bituminous coal with a high (10-15%) nitrogen, sulfur, oxygen content would have H/C ratios closer to 1.28 and 1.05, respectively, on a nitrogen, sulfur, oxygen free basis.

The bitumens with low H/C ratios are generally more insoluble and infusible than those with high H/C ratios. Wurtzilite is a notable exception to this rule, having a higher H/C ratio than gilsonite, but being more insoluble. Solubility and fusibility are influenced by other factors, such as the sulfur, nitrogen, and oxygen content of the bitumens.

The sulfur and nitrogen content of the Uinta Basin bitumens are shown in Figure 89. Wurtzilite has the highest sulfur content, by far, of the entire group, averaging about ten times as much sulfur as gilsonite. The presence of sulfur linkages in the wurtzilite structure is believed to lead to its insolubility and infusibility. Sulfur is known to cross link large hydrocarbon molecules, as in natural or synthetic rubber, imparting rigidity and insolubility to the material.

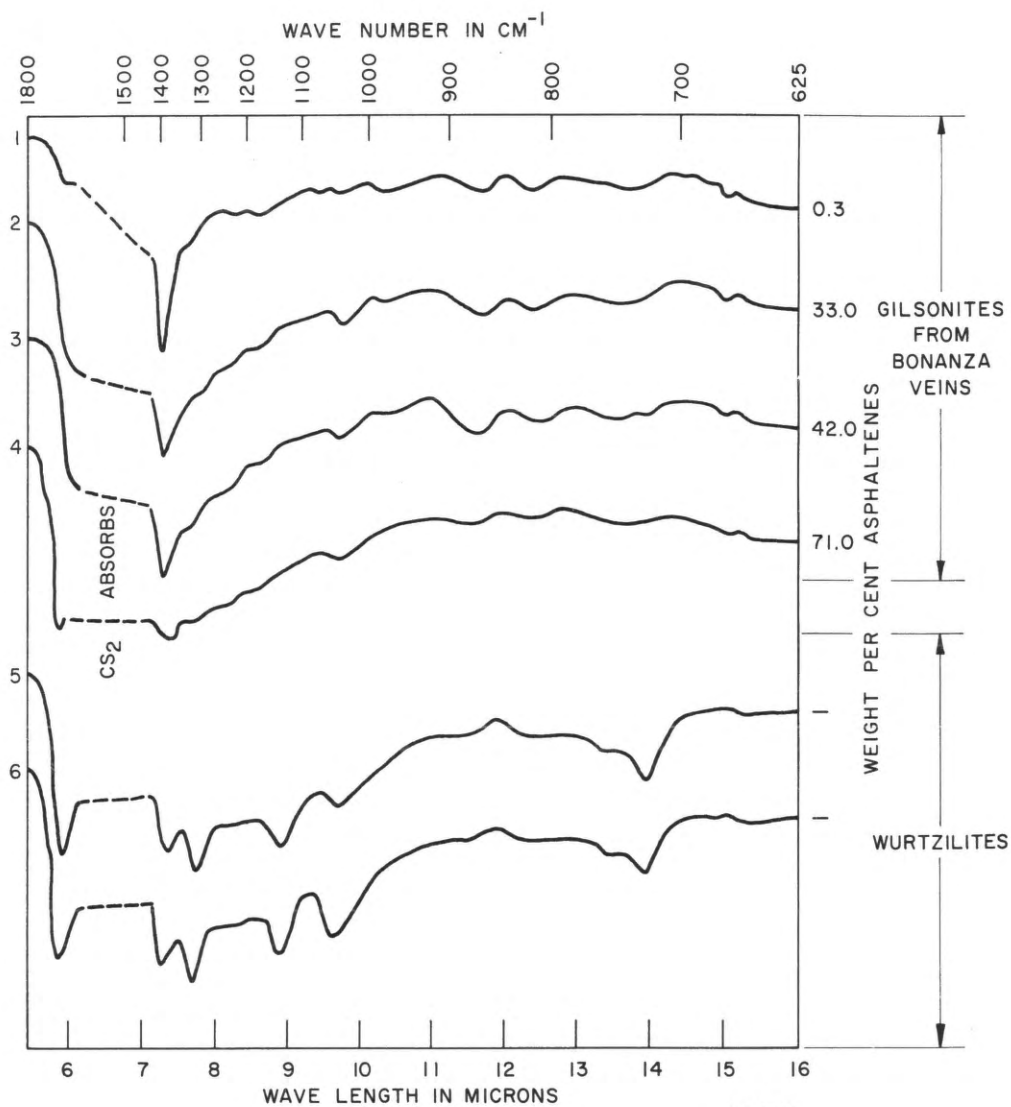
Only one analysis each was available for tabbyite, ingramite, and albertite, but they seem to fall in between gilsonite and wurtzilite in sulfur content. Gilsonite samples from several different localities are remarkably uniform in elemental composition, all being high in nitrogen (2.25-3.29%), and low in sulfur (0.22-0.53%). The high nitrogen content indicates that proteinaceous material played an important part in the origin of gilsonite. Ozocerites are low in both nitrogen and sulfur.

The mechanism of the oxidation of asphaltic materials can proceed along two paths: (1) the addition of oxygen to form unstable compounds from which water, carbon dioxide, or other unstable oxygen-containing substances are eliminated leaving unsaturated compounds which then polymerize, and (2) the addition of



INFRARED SPECTROGRAMS OF BITUMENS OF
THE UINTA BASIN (IN CS_2 SOLUTION)

Figure 87.



INFRARED SPECTROGRAMS OF LIQUID AND
SOLID BITUMENS UINTA BASIN

Figure 88.

oxygen to form stable oxygenated compounds. Some deductions as to the possible oxidation mechanism for a bitumen such as gilsonite can be made from elemental analyses of the material in various stages of weathering.

Data of this type have been obtained for a group of gilsonites and are shown in Figure 90. The percentages of elemental constituents for 10 gilsonites are plotted against the per cent asphaltenes which is a rough measure of the extent of polymerization. Inasmuch as asphaltenes are of high molecular weight, an increase in the average molecular weight of the substances occurs with an increase in asphaltenes. Liquid asphalts are low in asphaltenes and the hard solid asphalts are high in asphaltenes; consequently, asphaltenes can be used to measure the change from liquid to semi-solid, to solid which represents various stages of weathering.

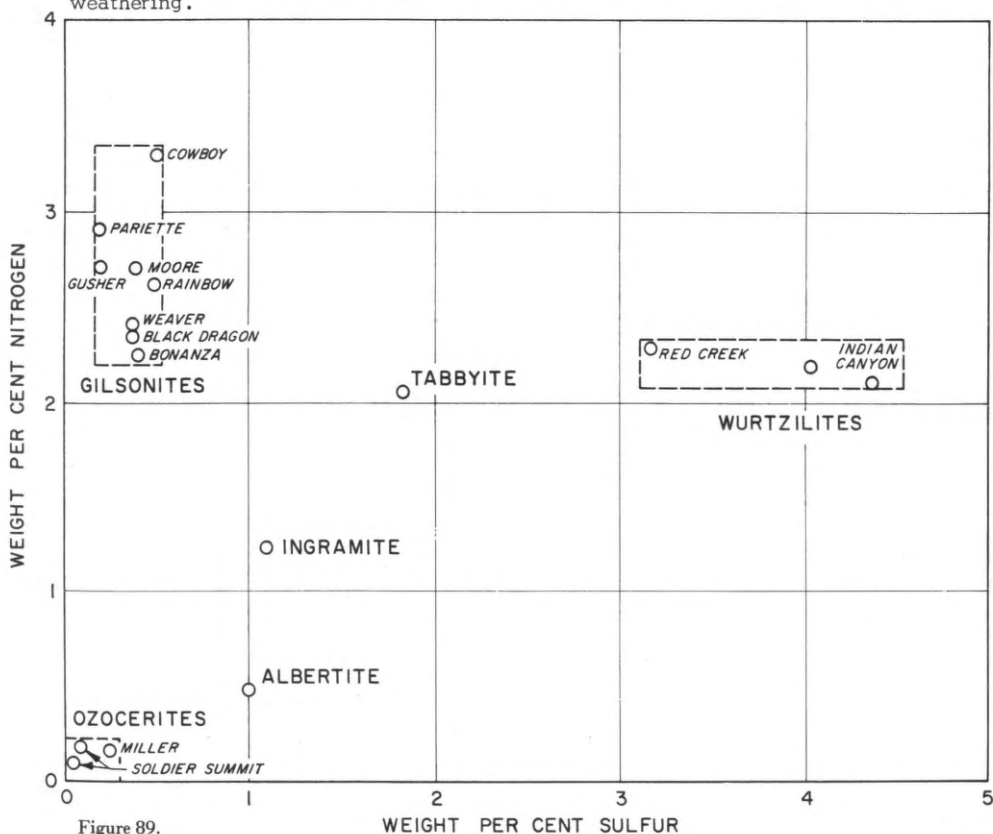


Figure 89.

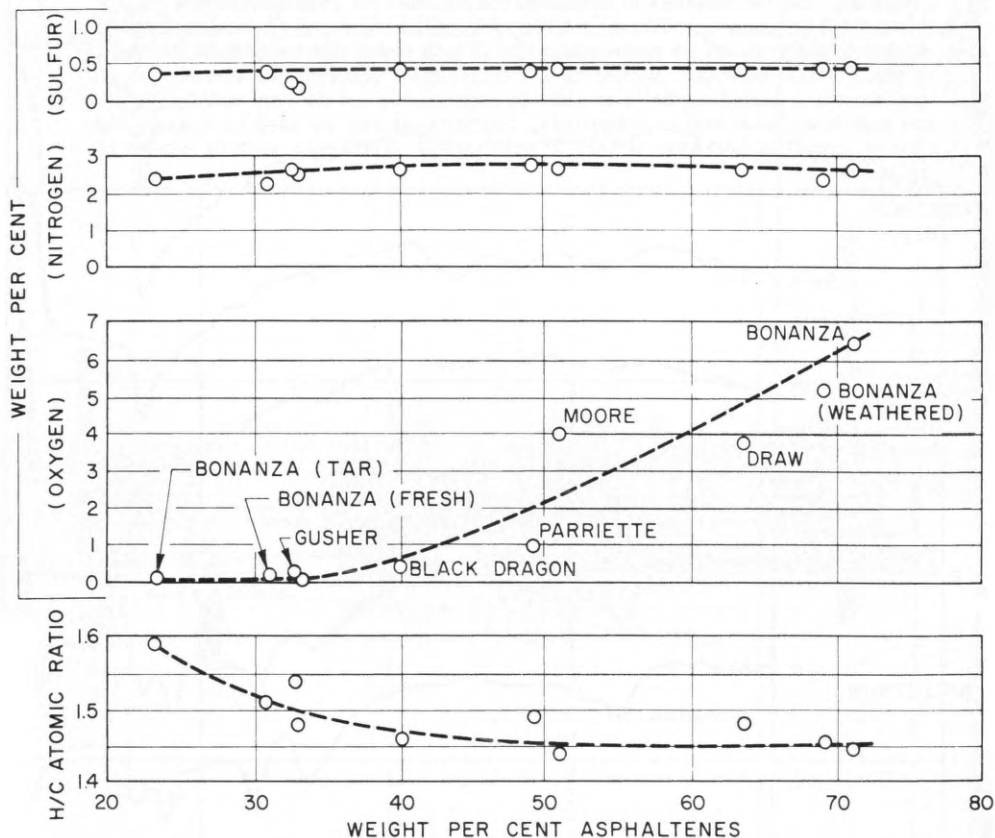
WEIGHT PER CENT SULFUR

RI6903D

SULFUR AND NITROGEN CONTENT OF THE UINTA BASIN BITUMENS

The data in Figure 90 show a very interesting relationship. In going from Bonanza tar with 23% asphaltenes to some of the fresh samples of solid gilsonite with 30 to 40 per cent asphaltenes there is no appreciable increase in the oxygen content, but there is a definite lowering of the hydrogen to carbon ratio. This signifies that the change from liquid to solid forms of gilsonite is chiefly a polymerization reaction with loss of hydrogen (probably as water). However, in going from the fresh solid to the more weathered solid forms of gilsonite having from 40-70% asphaltenes, there is little change in the hydrocarbon to carbon ratio, but a definite increase in the oxygen content. This indicates that the alteration of the

more weathered forms of gilsonite is a result of the formation of stable oxygenated compounds rather than of increased polymerization. It is also interesting to note that neither the sulfur nor the nitrogen content varies appreciably. Apparently neither of these elements is lost or concentrated in going from the tar to the solid weathered gilsonite.



RI6904D

RELATION BETWEEN ELEMENTAL CONSTITUENTS AND ASPHALTENES IN 10 GILSONITE SAMPLES

Figure 90.

Separation of Hydrocarbons from Bitumens by Chromatography: The chromatographic procedure involves dissolving the bitumen in some light hydrocarbon, such as normal heptane, and passing it through a column of activated alumina. This is followed by benzene and methanol, ether, or pyridine. The heptane removes the paraffin and naphthene hydrocarbons; the benzene, the aromatic hydrocarbons; and the pyridine, the nitrogen, oxygen, and sulfur compounds (non-hydrocarbons). The separations are not quantitative and it usually is necessary to repeat the procedure to obtain an accurate analysis. The approximate distribution of hydrocarbon types in ozocerite, liquid gilsonite, and two crude oil residues by this method is shown in Table XV. The high paraaffinity of ozocerite (81%) and the

aromaticity of gilsonite (48%) are evident from these data. Also, it is evident that the heavy end of the Duchesne oil from 7,596 feet is very similar to ozocerite, whereas an oil show obtained at 3,000 feet in a nearby well is more similar to liquid gilsonite.

TABLE XV
CHROMATOGRAPHIC SEPARATION OF OZOCERITE, LIQUID GILSONITE,
AND TWO CRUDE OIL RESIDUES

Compound Type	Ozocerite	Duchesne Ute Tribal #1* 7596'	Liquid Gilsonite (Bonanza Mine)	Duchesne Ute Tribal #2* 3000'
Paraffin and Naphthene				
Hydrocarbons	81	82	18	30
Aromatic Hydrocarbons	10	11	48	36
Nitrogen, sulfur, and oxygen compounds plus insoluble mat- erial	9	7	34	34

*Residuum boiling above 428°C.

Composition Studies by Mass Spectrometry: In recent years mass spectrometers have been used in making detailed composition studies of the fractions of oils and bitumens containing up to about 40 carbon atoms. These analyses were made for the soluble fraction of a gilsonite, wurtzilite, ozocerite, and the bitumen extracted from lacustrine shales associated with ozocerite veins. The results are shown in Table XVI.

TABLE XVI
MASS SPECTROMETRY ANALYSES OF UINTA BASIN BITUMENS

	<u>Gilsonite</u> (Cowboy vein)	<u>Wurtzilite</u> (Rat Hole Canyon)	<u>Ozocerite</u> (Soldier Summit)	<u>Shale Extract</u> (Soldier Summit)
Per Cent Soluble	25	6	88	93
<u>Compound Type</u>	<u>Weight Per Cent in Soluble Fraction</u>			
Paraffins	0	7	68	51
Non-Condensed ring				
Naphthenes	12	21	6	11
2-ring Naphthenes*	10	9	6	3
3-ring Naphthenes*	10	17	4	3
4, 5, 6-ring Naphthenes*	7	24	4	5
Aromatics	61	22	12	27

*Fused rings

The gilsonite contains no paraffins which is most unusual for a natural bitumen. The wurtzilite is predominately naphthene rings as was suspected from previous analyses. The extract of shale near ozocerite veins has a very high paraffin content comparable to the vein material. The mass spectra data also show that the paraffin fraction of ozocerite is about 60% isoparaffins and 40% normal paraffins. The aromatic fraction of gilsonite is about 23% alkylbenzenes, 17% naphthalenes, 16% acenaphthenes, 16% indanes and tetralins, and the rest indenenes, acenaphthylenes and tricyclic aromatics.

Summary of Composition Data

The Uinta Basin bitumens are complex mixtures of high molecular weight hydrocarbons and non-hydrocarbons which can be separated into fractions consisting of an oily medium, asphaltic resins, asphaltenes, and carboids. These groups merge into one another and their atomic H/C ratios decrease with each succeeding member, except for the carboids which differ mainly in having more oxygen than the asphaltenes. The asphaltenes are usually aromatic, the asphaltic resins are aromatic or naphthenic, and the oily medium may be naphthenic or paraffinic in structure. The molecular weights of these groups vary from about 500 for the oily medium and resins to 10,000 for the asphaltenes, and probably higher for the carboids.

The distinct differences in the Uinta Basin bitumens are due to the differences in the structural units forming the constituent groups. Although asphaltenes are usually aromatic, they may have naphthenes in them. Likewise, the oily medium may be more aromatic than naphthenic or paraffinic, and sulfur or nitrogen linkages may be introduced in the units. Sulfur, particularly, may act as a cross-linking agent to impart rigidity and insolubility to the bitumen. A description of the probable structures of the individual Uinta Basin bitumens based on all available data is presented below.

Ozocerite is composed principally of straight and branched chain saturated hydrocarbons with minor amounts of naphthene and aromatic rings. The sum of oxygen, nitrogen, and sulfur averages less than 0.5%. The H/C ratio of 1.96 is approximately that of the $-\text{CH}_2-$ group. The low refractive index, low carbon residue, and absence of aromatic peaks and presence of a strong paraffinic peak in the infrared spectra identify a predominantly paraffinic material. High mass spectral data show the paraffin fraction is about 50% isoparaffins, 30% normal paraffins, and 20% cycloparaffins (naphthenes). The chain length deduced from melting point and X-ray data is in the C_{25} - C_{35} range.

Gilsonite is predominantly aromatic, containing condensed ring aromatic structures in the high molecular weight asphaltene fraction and simpler dinaphthyl structures with a few paraffins in the oily constituents and resins. The soluble material is about 60% aromatic rings and 40% naphthene rings with no paraffins. Both nitrogen and oxygen linkages are present, particularly in the higher molecular weight fractions, but the sulfur content is low. Some carbonyl and other oxygenated compounds are present in the oily constituents and resins. Over 50% of the solid gilsonite probably consists of non-hydrocarbons.

The high carbon residue, refractive index and mass spectrometer data show that condensed rings are present. The low atomic H/C ratio of 1.42 establishes the aromatic character of gilsonite. Infrared spectra show the presence of para and meta substituted aromatics and oxygenated compounds, and the absence of long paraffin chain structures. Mass spectrometer data show a variety of condensed aromatic structures. The elemental analysis shows that gilsonite is high in oxygen and has the highest nitrogen content of the Uinta Basin bitumens.

Wurtzilite is naphthenic in character with fused naphthene rings rather than aromatic rings predominating in the higher molecular weight fractions. Chains of five or more $-\text{CH}_2-$ groups are attached to the condensed ring units in both the oily constituents and the asphaltenes. Wurtzilite contains some oxygen, probably in the form of carbonyl side chains and oxygen bridges. It also has a high sulfur content (4%). The low carbon residue and refractive index, and the high atomic H/C ratio of 1.60 definitely establish that wurtzilite has fewer condensed ring aromatics than naphthenes in its structure. The absence of strong infrared peaks

in the aromatic region at 11.5 and 12.3 microns further substantiates this conclusion. Its infusibility and insolubility probably arise from the joining of multiple units of naphthene rings with sulfur and oxygen acting as crosslinking units. The presence of strong infrared absorption peaks due to paraffin chains, $>C=O$, and other oxygen linkages establishes that these groups are present in wurtzilite.

Albertite is composed predominantly of condensed aromatic ring structures with the oily constituents containing polycyclic aromatics, carbonyl groups, and some paraffin chains. It has less sulfur and nitrogen than any other Uinta Basin bitumen except ozocerite.

The very high carbon residue, high refractive index, and low atomic H/C ratio establish the presence of the condensed aromatic rings. The insolubility and infusibility of albertite indicate the condensed rings to be of several more units than in gilsonite. The infrared spectra of the oily constituents and asphaltenes establish the presence of carbonyl groups, polycyclic aromatics, and some paraffin chains.

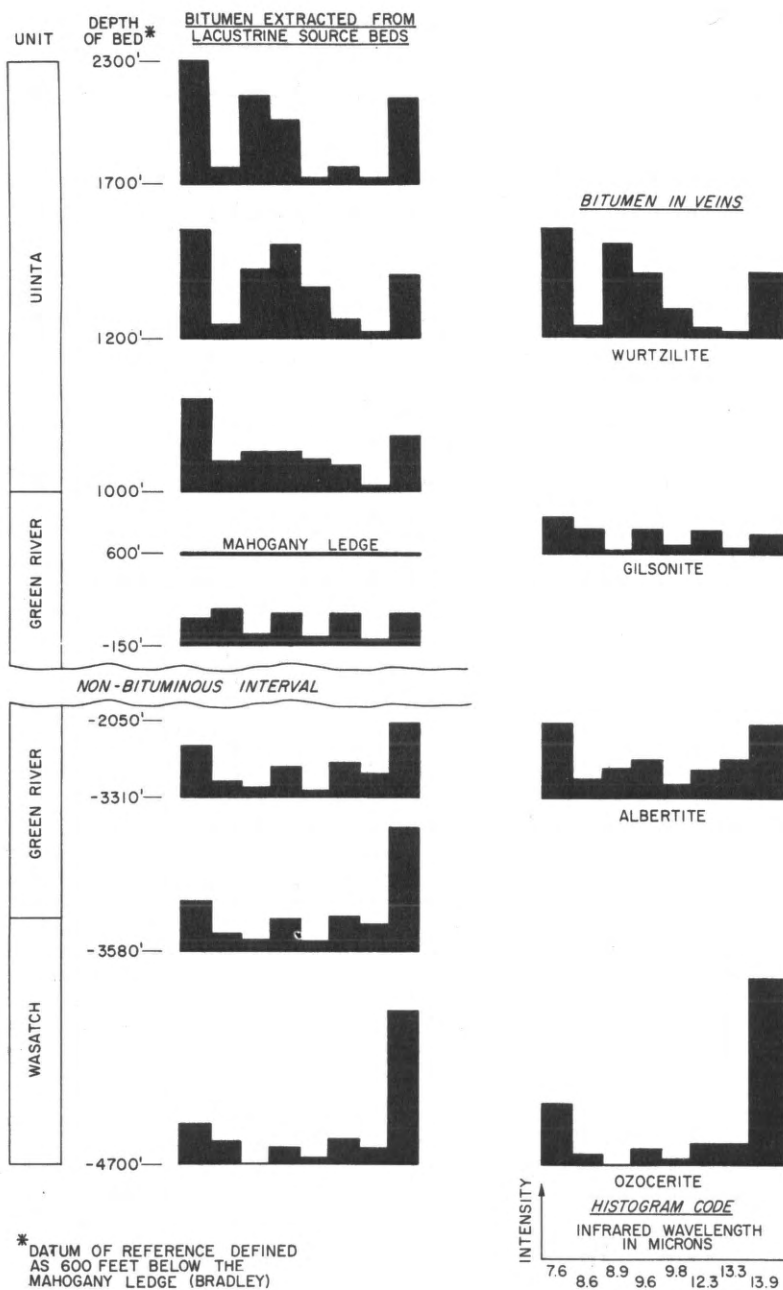
Ingramite appears to be a less polymerized form of albertite. The oily constituents and asphaltenes of ingramite have the same infrared spectra as those of the soluble fraction of albertite, but ingramite has a higher atomic H/C ratio and lower carbon residue than albertite. These properties would be characteristic of a less polymerized form.

Tabbyite has an infrared spectrum similar to gilsonite except that weaker infrared peaks in the carbon-oxygen regions indicate that fewer oxygenated compounds are present in tabbyite. In all other properties, such as refractive index, sulfur content, and atomic H/C ratio, it resembles wurtzilite. It is probably some intermediate type of bitumen.

IDENTIFICATION OF SOURCE BEDS

The author has previously published a paper showing both chemical and geological evidence to identify the source rocks of the Uinta Basin bitumens (Hunt, et al., 1954). The identification was made by comparing the physical and chemical properties of the bitumens in the veins to minute quantities which still exist disseminated in the original source beds. Subsequent studies have not altered the original conclusions. The results clearly show that the calcareous oil shales of the lacustrine facies are the source beds of the hydrocarbons. In addition the bitumens disseminated in these lacustrine source beds differ with depth. There is a definite and clear transition in the composition of the rock bitumen that parallels the change in composition of the vein deposits in going up the entire Eocene section.

Figure 91 illustrates this clearly. This figure contains histograms representing infrared spectra of bituminous materials from the basin (Hunt, et al., 1954). Each histogram represents a "fingerprint" of the particular bitumen examined. When two histograms are similar it means that the two bitumens that were analyzed are the same. The histograms on the left side of the diagram represent the minute amounts of bitumen still finely disseminated in the original shale source beds. Each histogram actually represents an average of several analyses of bitumen existing in the shale at the depth intervals as listed to the left. For example, the histogram next to -150 feet is the average of 41 samples analyzed between -150 feet and 1,000 feet. In going from the bottom to the top of this series of histograms, there is a definite change in the pattern signifying a definite change in the chemical composition of the bitumen existing in the source rocks.



HISTOGRAMS OF INFRARED PATTERNS OF BITUMENS
IN SOURCE BEDS COMPARED TO VEINS

R16968D

Figure 91.

The histograms to the right represent actual vein bitumens. The four main types are shown; ozocerite, albertite, gilsonite, and wurtzilite. It is apparent that the ozocerite is chemically similar to the bitumen in the Wasatch and basal Green River oil shales, however, it differs from the shale bitumens at higher stratigraphic intervals. The albertite resembles shale bitumen in the interval from -3,310 feet to 2,050 feet. The gilsonite is quite similar to the bitumen disseminated in the upper Green River oil shale and differs from those both below and above it. This interval from -150 feet to 1,000 feet contains the Mahogany Ledge and is generally more bituminous than other sections in the basin. The wurtzilite is similar only to the bitumens in the Uinta shales. This comparison establishes that the composition of the bitumen extracted from the lacustrine shales in any one section is very similar to the composition of the associated vein deposits. It also limits the source of the various vein materials to the stratigraphic units in which they are found.

CHANGE OF BITUMEN TYPE WITH DEPOSITIONAL ENVIRONMENT

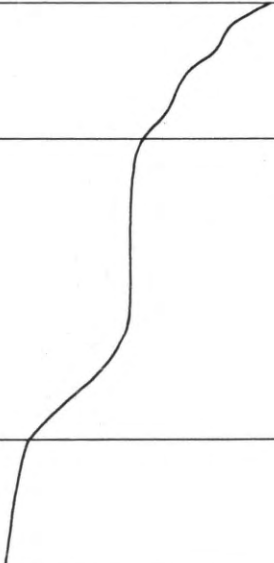
Circumstantial evidence suggests very strongly that the most important single factor controlling the composition of the bitumens in the Uinta Basin was the salinity of the lake, which in general increased with time. The increasing salinity resulted from continued evaporation accompanying continuous input of stream water into the lake. The increase in salinity with time is shown by the occurrence of minerals such as calcite, requiring relatively low concentrations for precipitation, in the basal sediments, and complex iron, magnesium, and sodium carbonates of high solubility in the younger sediments. Also, the increasing number of crystal cavities in the youngest sediments are a reflection of highly saline conditions. Accompanying this change in mineralogy is a decrease in the number of macroscopic fossils of benthonic organisms. The major changes in the composition of the bitumens correlate stratigraphically with the changes in mineralogy and fossil type. In general, the dominant molecular structure of the bitumens changes from paraffin chains to aromatic rings, and to chain and ring compounds high in sulfur and nitrogen, the most important representatives being ozocerite, albertite, gilsonite, and wurtzilite, respectively. The nature of the controlling environment and the resultant mineralogic components and bitumen types for the various time units of the Uinta Basin sediments are summarized in Figure 92.

FORMATION OF THE VEIN DEPOSITS

It is important to clearly visualize the quantities of bitumen involved in trying to understand how the bitumen which is disseminated in the dense oil shales moved into the veins. The author estimated from data in the I.A.P.G. Guidebook (1957) that there are approximately 1,970 cubic miles of lacustrine sediments in the Uinta Basin. At an average shale density of 2.3 this is equivalent to 21×10^{12} tons of sediment. Data on the extraction of the shales (Hunt, et al., 1954) indicates that about 0.1 per cent of this weight, or 21 billion tons, is free, disseminated bitumen.

Abraham (1960) estimates that the original gilsonite deposits were about 25 million tons. Consequently total vein deposits of all bitumens probably do not exceed 50 million tons. Yet this is only two-tenths of one per cent of the bitumen still remaining in the shales. Obviously nature was very inefficient in moving this material from source to vein.

There may be several reasons why so little moved, such as (1) there are very few permeable sections within the lacustrine facies, (2) the bitumen is too heavy to migrate very far from its source, and (3) the carbonate mineral surfaces and high organic content may have held onto the bitumen more tenaciously than in more typical marine sediments.

AGE	CONTROLLING ENVIRONMENT	RESULTS OF ENVIRONMENT	
GROUP	INCREASING RELATIVE SALINITY AND H ₂ S CONC.	DOMINANT COMPONENTS OF SEDIMENTS	
		MINERALS	BITUMENS
UINTA		SILICEOUS DOLOMITES PYRITE	<u>WURTZILITE</u> NAPHTHENES, SULPHUR AND NITROGEN COM- POUNDS
GREEN RIVER		CALCAREOUS DOLOMITES PYRITE	<u>GILSONITE</u> AROMATICS AND NITROGEN COM- POUNDS
		DOLOMITE	<u>ALBERTITE</u> CONDENSED AROMATIC RINGS
WASATCH		CALCITE	<u>OZOCERITE</u> PARAFFIN CHAINS

R16969D

CHANGE IN COMPOSITION OF BITUMENS AND MINERALS WITH ENVIRONMENT

Figure 92.

The author believes that the veins themselves represent tensional cracks which developed when the area was uplifted. At one time these shales were buried under a pressure equivalent to a depth varying from possibly 6,000 feet for albertite to 2,000 feet for wurtzilite. As the area was uplifted, tensional cracks developed tending to create reduced pressure voids into which the bitumens moved as viscous fluids. The cracks probably opened slowly and were filled simultaneously by the bitumens. None of these veins contain the rock debris that would be expected if they were open for any length of time. The viscous bitumens in the veins subsequently became solids through polymerization, oxidation, the formation of gel structures and related processes. Nearly all of the solid hydrocarbons of the basin have their liquid counterparts at depth.

In summary, the Uinta Basin represents a unique environment--non-marine yet varying from brackish water to highly saline. Although the original waters were oxidizing, they later became strongly reducing, and the toxic hydrogen sulfide in the bottom layers resulted in a tremendous accumulation of organic matter. This resulted in the deposition of several thousand feet of bituminous sediments. As the area later became uplifted tension cracks slowly opened at depths and forms of ozocerite moved into the veins. In successively younger sediments viscous forms of albertite, gilsonite, and wurtzilite filled the openings as they formed. As time went on and the uplifting continued these materials polymerized and hardened to become the solids we now see. The changes in the types of bitumens originating in successively younger beds coincide with changes in the minerals and the fossils. Apparently they all are a reflection of changes in depositional environment.

CITED REFERENCES

- Abraham, H., 1960, *Asphalts and Allied Substances*: D. Van Nostrand Co., Publisher.
- Barnes, R. B., Gore, R. C., Stafford, R. W., and Williams, V. Z., 1948, Qualitative Infrared Organic Analyses and Infrared Spectrophotometry: *Anal. Chem.*, v. 20, p. 402-410.
- Bradley, W. H., 1929, *Algae Reefs and Oolites of the Green River Formation*: U.S. Geol. Survey Prof. Paper 154-C.
- Faraday Society, 1945, *The Application of Infrared Spectra to Chemical Problems*: *Trans. Faraday Soc.*, v. 41, p. 171-295.
- Hunt, J. M., Stewart, F., and Dickey, P. A., 1954, Origin of Hydrocarbons of Uinta Basin, Utah: *Am. Assoc. Petroleum Geologists Bull.*, v. 38, p. 1671-1698.
- Randall, H. M., Fowler, R. G., Fuson, N., and Dangle, R., 1949, *Infrared Determination of Organic Structures*: Van Nostrand, Publisher, p. 237.

Paper 25 THE BEARING OF SULFUR ISOTOPES ON COLORADO PLATEAU URANIUM AND PETROLEUM DEPOSITS

by Mead LeRoy Jensen²

INTRODUCTION

Isotope geology has provided an abundance of significant information to the subject of geology, and has developed into many sub-specialties, two of the broad divisions being radiogenic isotopic age studies and non-radiogenic isotopic abundance studies. Many geologists are aware and appreciative of the age determinations obtained by the study of uranium and lead isotopes collected from uranium and lead isotopes collected from uranium deposits of the Colorado Plateau, but probably few are cognizant of the bearing that stable sulfur isotopic studies have on the origin of sandstone-type uranium deposits and some of the petroleum occurrences of the Colorado Plateau. Some of the recent results, suppositions, and suggestions obtained through sulfur isotopic abundance studies are herein presented.

BASIC CONCEPTS

At the present time, 102 elements have been identified. Each element is represented by one or more isotopes or nuclides; more than 1,380 nuclides are now known. The number has increased by leaps and bounds during the past few decades, primarily through the ability of nuclear scientists to produce new radioactive species, but also through the discovery of new stable isotopes. There are now recognized about 272 stable isotopes in nature, and more than 1,000 radioactive species of which only 58 occur in nature.

A specific nuclide of an element is represented by the unique chemical symbol with the addition of a subscript at the lower left and a superscript at the upper right of the symbol. The subscript is the atomic number (Z) of the specific isotope, determined by its number of protons, and the superscript represents the mass number (A), or the total number of nucleons, i.e. protons plus neutrons. Thus: the stable isotopes of sulfur, for example, are represented as follows: $^{32}_{16}\text{S}$, $^{33}_{16}\text{S}$, $^{34}_{16}\text{S}$, and $^{36}_{16}\text{S}$. The subscript is usually omitted, as the unique chemical symbol identifies the atomic number.

The chemical properties of an element depend essentially upon the number and configuration of the orbital electrons, especially the electronic configuration of the outer shell. As the nuclides of a given element all have the same number of electrons, the stable nuclides of a given element behave alike chemically, and as their cosmic abundances were determined during or soon after the origin of the solar system, one might expect the stable nuclides to be found together in a relatively constant isotopic abundance, regardless of the geologic occurrence or age of the specimen.

1. Portions of this study have been supported by the National Science Foundation Grant 3001 and Atomic Energy Commission Contract AT (30-1)-2261.
2. Associate Professor of Geology, Yale University, New Haven, Connecticut.

On the other hand, however, it is known that the isotopes of any one element differ slightly in their rate of chemical behavior because of the slight differences in the thermodynamic properties of these isotopes, properties which are determined for the most part by their mass and atomic structure. In fact, because of these slight thermodynamic differences, the specific rates of reaction of the different species of one element do differ slightly, even though all do behave chemically alike.

In the case of sulfur, numerous mass spectrometric analyses indicate that meteoritic troilite contains almost precisely 22.22 times as much S^{32} as it does S^{34} ; i.e., all troilites exhibit a ratio of S^{32}/S^{34} equal to 22.22 $\pm$ 0.01. In contrast, mass spectrometric analyses of sulfur-bearing minerals collected from heterogeneous sources from the earth exhibit variations from this ratio ranging from a low value of 20.82 to a high of 23.62, a variation of more than 10 percent, while the precision of the mass spectrometric measurement is at least 0.02 percent. The meteoritic value is assumed to be very near to the S^{32}/S^{34} ratio of primordial earth sulfur; variations from this ratio indicate geologic processes that have resulted in isotopic fractionation of sulfur, resulting in either a loss or gain of, for example, the heavy (S^{34}) species.

Instead of indicating the isotopic composition of sulfur-bearing substances as a ratio of S^{32}/S^{34} , the variation of any given ratio from the composition of meteoritic troilite is expressed as a permil variation according to the relationship $\delta S^{34} = \frac{S^{32}/S^{34}(\text{standard}) - S^{32}/S^{34}(\text{sample})}{S^{32}/S^{34}(\text{sample})} \times 1000$. δS^{34} , therefore,

is the permil variation of a given sample from the troilite ratio of 22.22. For meteorites, therefore, $\delta S^{34} = 0\text{‰}$. Positive values indicate enrichment in the heavier (S^{34}) isotope.

All mechanisms and processes that can cause fractionation of isotopes in nature are of great interest because isotopic ratio variations may not only suggest that specific processes have occurred, but they may also provide us with a fuller understanding of the relative importance of the different natural physical and chemical processes.

FRACTIONATION OF SULFUR ISOTOPES

The most significant method by which sulfur isotopes are fractionated is by isotopic exchange reactions that take place during oxidation or reduction of sulfur. Sulfur occurs in several valence forms, viz., S^{-2} , S^0 , S^{+2} , and S^{+4} , and, therefore, occurs in many different ions and compounds. Hydrogen sulfide (H_2S) and sulfate ions ($SO_4^{=}$) are two common, almost ubiquitous, examples. An isotopic exchange reaction indicating oxidation and reduction of these substances is shown as follows:



Based upon the application of the Mass Action Law and the computation of partition function ratios of the two substances indicated, it is possible to compute the equilibrium constants, K , of this reaction for given temperatures. The results, as compiled by Ault (1957), may be summarized in the following table:

Equilibrium Constant Versus Temperature for the $\text{SO}_4^{=}/\text{H}_2\text{S}$ Exchange Reaction*

	Temperature °C					
	0	25	50	100	500	1000
K	1.0911	1.0733	1.0641	1.0500	1.0126	1.0047

*from Ault (1957)

The equilibrium constant at 25°C for the reaction in which, for example, $\text{SO}_4^{=}$ is reduced to H_2S is 1.0733. This means that under equilibrium conditions the H_2S formed will be enriched in S^{32} to the extent of 7.33 per cent. In other words, H_2S having an $\text{S}^{32}/\text{S}^{34}$ ratio of 22.22 ($\text{S}^{34} = 0$) that undergoes initial oxidation to form a small quantity of $\text{SO}_4^{=}$ at 25°C under equilibrium conditions will result in an enrichment of 7.33 per cent S^{34} , or 73.3 permil, in the $\text{SO}_4^{=}$ ($\delta \text{S}^{34} = +73.3$ permil). On the other hand, initial reduction of $\text{SO}_4^{=}$ to H_2S at 25°C under equilibrium conditions will result in a depletion of S^{34} in the H_2S produced in the amount of 73.3 permil ($\delta \text{S}^{34} = -73.3$).

It is extremely significant, however, that the sole process by which this reduction takes place in nature is through the action of anaerobic bacteria that acquire their oxygen from $\text{SO}_4^{=}$ and liberate H_2S gas. (Some reduction of $\text{SO}_4^{=}$ may occur in magmas at temperatures in excess of about 600°C in the presence of carbon.) Bacteria of the Desulfovibrio genus and Clostridium nigrificans are sulfate-reducing bacteria. The latter is a thermophile variety that tolerates temperatures as high as 65°C.

The food or energy source of these bacteria consists of organic matter. These bacteria can be expected, therefore, in almost any environment containing organic matter and sulfate solutions. A few examples are: soil, swamps, water-wells, oil-field waters, salt domes, the bottom muds and sands in either marine or fresh-water bodies, carbonaceous "trash-pockets" formed in fluvial-formed sandstone channels, and so forth.

With this knowledge, the importance of anaerobic bacteria in mineral-forming processes is quite apparent. For example, native sulfur in salt-dome cap rocks is derived from oxidation of H_2S that was produced by anaerobic bacteria through their reduction of $\text{SO}_4^{=}$ occurring in the cap rock (Feely and Kulp, 1957; Thode, Wanless, and Wallouch, 1954). Oil associated with the salt-dome trap provides the organic food or energy source for the bacteria. Therefore, it is reasonable to expect that native sulfur only occurs in those salt domes that are associated with oil and are located at intermediate or shallow depths where the lower temperatures do not affect the viability of the bacteria. Syngenetic sedimentary sulfides are also formed by organically produced H_2S reacting with available metal sulfates or chlorides in solution, resulting in the precipitation of insoluble sulfides. Furthermore, during the conversion of organic matter to hydrocarbons or petroleum, H_2S gas is also produced, much of which escapes through the water into the atmosphere, and some undergoes primary migration with the petroleum during the escape of connate water and petroleum from the source rock. Possibly H_2S gas may continue to be produced, not only during primary and secondary migration of oil, but even after accumulation in a trap, because of the presence of anaerobic bacteria, sulfate connate waters, and oil as the food source. Determination of $\text{S}^{32}/\text{S}^{34}$ ratios of H_2S in sour crudes, organic sulfur in petroleum, mineraloids, and asphaltites, and sulfur in sulfate connate

waters may improve our understanding of the origin, migration, and source rocks of petroleum. An example of knowledge obtained from this source is discussed in a later section of this paper. First however, the geologic role that anaerobic bacteria have played in forming sandstone-type uranium deposits is presented.

RESULTS

Sandstone-Type Uranium Deposits

An initial study of the significance of S^{32}/S^{34} variations of sulfides associated with sandstone-type uranium deposits has been presented elsewhere (Jensen, 1958). Figure 93 shows some of the results of that study plus more recent studies (Field, C.) of sulfur ratios obtained from specimens from the Marysvale, Utah, district. The noticeable difference in (a) average ratio values and (b) relative spread in ratios between deposits, listed under A and B, is quite striking.

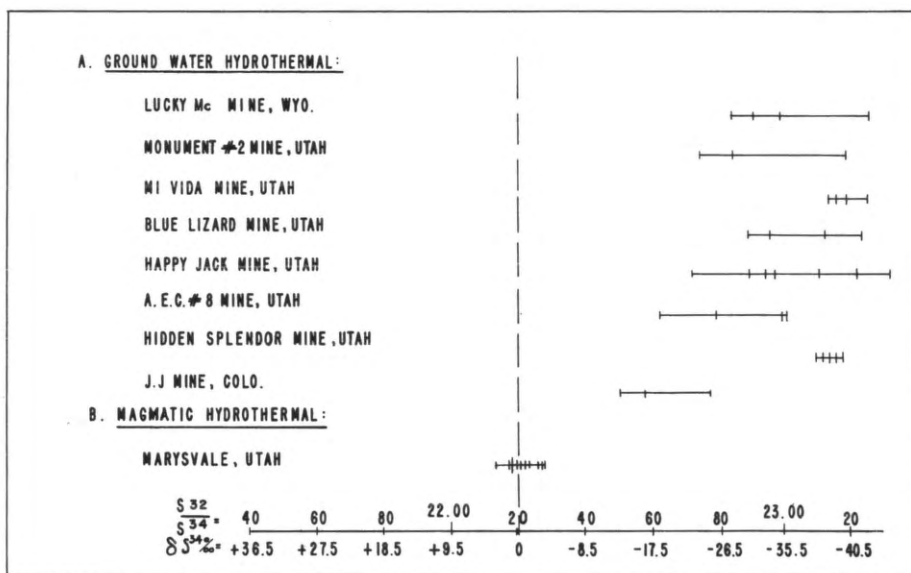


Figure 93. Sulfur isotopic ratios of sulfides collected from uranium mines and prospects in Utah, Colorado Plateau, and Wyoming.

As an explanation of the "Ground Water Hydrothermal" (Jensen, 1959) ratios shown in Figure 93, it is not unreasonable to assume that sulfate-reducing bacteria became incorporated in, for example, the Salt Wash member of the Morrison formation during the deposition of this fluvial member. Organic matter present in the form of logs, stems, twigs, roots, leaves, or carbonaceous "trash" pockets in portions of the sandstone channels provided a food supply for these bacteria. Sulfate waters of either or both meteoric and connate origin

could have been reduced by these organisms, and H_2S , thereby, liberated, even as early as during diagenesis, although the process continued during continued burial. Some of the early formed H_2S may have migrated through the sandstone short distances into shale or clay horizons, which, if iron, in any chemical form, was then encountered, provided the reducing agency for the formation of sulfides (where, in fact, some sulfides are found) at a rather early stage. Incidentally, even though this indicates a lack of contemporaneity in the formation of the sulfides in barren rock versus sulfides associated with uranium, it is understandable why there is no consistent difference in the ratios of the barren versus ore-associated samples, inasmuch as all of the H_2S had the same organic origin. Much of this gas, however, may have remained until a later time, possibly as recent as 20 million years ago or as long as 60 to 70 million years ago, before reacting with uraniferous solutions, which possibly were squeezed out of the overlying volcanic-ash-rich Brushy Basin member (Waters and Granger, 1953) and transported by connate water (ground water hydrothermal solutions)¹ into the more porous and permeable channels of the Salt Wash member, through which they migrated until H_2S locales were encountered. The soluble U^{+6} ion would then be reduced to the insoluble U^{+4} ion, and ferrous sulfate solutions would react with H_2S to form iron sulfides. If the solutions were unusually rich in copper sulfate, admittedly not a common condition, but certainly quite possible, copper sulfides would naturally be concentrated by the H_2S (as in the Happy Jack deposit) and these copper sulfides would exhibit the typically high ratios comparable to iron sulfides of the province, as they do in the Happy Jack deposit (Figure 93). It is somewhat of an enigma why many economic geologists assert that dense, massive, and crystalline sulfides have formed from magmatic hydrothermal solutions, when these same persons are quite aware of sedimentary sulfides having the same features.

Although it is well known that lignitic, woody, or carbonaceous material is effective in concentrating uranium, the presence of uranium in an area where there is a lack of carbonaceous material is not easily explained. It might, however, be explained by the presence of H_2S that had migrated from the locale of the organic food supply needed by the anaerobic bacteria to an organic barren zone. In so doing, it thereby provided the reducing environment for the concentration of a uraniferous deposit, even though there may now be no evidence of the cause of the reducing environment, as the H_2S is no longer present.

An example where the H_2S is now present is offered by the numerous occurrences of uranium oxide deposits in the Wind River formation, Gas Hills district, Wyoming, where uranium mineralization is not generally accompanied by plant carbonaceous material; in fact, the material is mostly missing in much of the best ore.

Gas seeps, however, are prevalent in the area from which H_2S is escaping into the atmosphere. It has been suggested that at the north end of the Gas Hills anticline, where several seeps are present, the gas is derived from the underlying Frontier formation, which is known to be a reservoir rock for oil and gas in this area.

It is interesting, therefore, to quote from a field study of this area by Eugene Grutt (1957), wherein he suggests that "under the conditions occurring in the Gas Hills area, evidence suggests that H_2S may be mainly responsible

1. As this member was overlain by roughly 10,000 feet of younger sediments during post-Cretaceous time, an average geothermal gradient of $30^{\circ}C/km$ would result in a temperature in excess of $100^{\circ}C$ for these solutions.

for the formation of important uranium deposits, because plant carbonaceous material is not abundant, and even when present it is not always mineralized, even though in or near uraninite ore deposits." Four iron sulfide samples (Figure 93) from the Lucky Mc mine, Gas Hills district, which were isotopically analyzed (Jensen, 1958) have "typical" (for this study) S^{32}/S^{34} ratios, varying between 22.85 to 23.28, which, as I have already indicated, are remarkably high in ratio and spread over a broad range, and are, therefore, quite suggestive of sulfur derived from H_2S of organic origin. It will be interesting to determine the S^{32}/S^{34} ratio of not only the H_2S gas from these seeps, but also of the abundant, finely-divided ferrous sulfide that forms below the water surface in the seeps by a reaction between ferrous sulfate and H_2S , which is most likely the same reaction that has formed most of the sedimentary sulfides and the sulfides associated with sandstone-type uranium deposits. The analysis will be even more interesting if ratios can be obtained from the sulfate (presumably enriched in S^{34}) that is also present in the water.

Grutt (1957) postulated a petroleum origin for the H_2S gas. Because of the widespread occurrence of some uranium throughout almost all of the plateau area, even though petroleum is much more prevalent in portions of the Colorado Plateau than previously realized, it is still much more reasonable to infer that the food for the bacteria was not petroleum, but was, instead, the almost ubiquitous plant carbonaceous matter that is present in these beds. Furthermore, sulfur isotopic analyses of H_2S from petroleum samples in North America (Thode, Monster, and Dunford, 1958) indicate ratio values, for the most part, below the meteoritic value. In fact, half a dozen petroleum samples (Thode, Monster, and Dunford, 1958) from the Lakota and Frontier formations, which Grutt (1957) has suggested as the source of H_2S in the Gas Hills district, exhibit δS^{34} values between -0.3 to -3.6‰. The four sulfide samples from the Lucky Mc mine, mentioned above, vary between -28.8 to -48.2‰.

There are two main reasons for the great difference between these two groups of values. First, anaerobic bacteria rarely, if ever, reduce SO_4^{2-} to H_2S at even approaching equilibrium conditions. Isotopic fractionation as great as 1.5‰ is unusual when theoretically it should approach 7‰ near 20°C. When the organic food source is as abundant as it would be in organically rich sediments (in which petroleum is being formed), the bacteria reduce SO_4^{2-} with little or sometimes no fractionation. Second, the SO_4^{2-} from which the bacteria extract oxygen is enriched in S^{34} . Sea-water sulfate today has a remarkably uniform δS^{34} of about -20‰. During Phanerozoic time, there has probably been less than several permil δS^{34} increase in this present value. Slight fractionation of the sulfur of oceanic sulfate during reduction results, of course, in H_2S that may still be heavier than meteoritic sulfur, or, at the best, only slightly enriched in S^{32} over meteoric sulfur, as are the petroleum samples from Wyoming. As the sulfur associated with sandstone-type uranium deposits averages about -40‰ (although individual samples vary considerably from the average), the H_2S from which this sulfur was derived was considerably fractionated, but possibly repetitively oxidized and reduced, as it is decidedly different in isotopic composition and spread over a broader range than sulfur from H_2S associated with petroleum.

The ratios obtained from the Marysvale samples are consistent with ratios obtained from sulfides occurring in hydrothermal deposits associated with intrusive bodies of the Cordilleran. Magmatic hydrothermal solutions (Jensen, 1959) must become consolidated and well-mixed or homogenized in the cupolas of intrusives during the last stages of crystallization of these bodies. The

subsequent release of these magmatic hydrothermal solutions results in the deposition of sulfide minerals of remarkably uniform sulfur isotopic composition that are usually very near the isotopic composition of meteoritic sulfur. Note that the average of the Marysvale values (Figure 93) is about identical with the meteoritic value (22.21).

Uinta Basin Petroleum Deposits

Very little research has been done on the significance of S^{32}/S^{34} ratios of sulfur-bearing constituents associated with petroleum. Yet, because of the common occurrence of, for example, organic sulfur, hydrogen sulfide, and sulfate connate waters with petroleum, this field of research is pregnant with possibilities. An excellent example is provided by two recent noteworthy studies (Harrison and Thode, 1958; Thode, Monster, and Dunford, 1958). Of special interest is the study by Harrison and Thode (1958) pertaining to the significance of isotopic studies of sulfur in oil, asphaltites, and mineraloids of the Uinta Basin. The results of this isotopic geologic study, combined with the results of numerous field geologic studies of the Uinta Basin, provide an excellent example of the corroborating evidence and dove-tailing relationships obtained from these two quite different kinds of investigations.

During much of early Tertiary time, in fact, during about 20 million years of essentially Eocene time, several large structural basins existed about the Uinta Mountains. The Green River and Wasatch basins formed to the north, whereas south of the Uinta Mountains two broad, connected basins, the Uinta and Piceance Creek basins existed. Outcrops of the fluvial and deltaic sediments of the Wasatch formation rim the Piceance Creek basin and the southern side of the Uinta Basin, while, stratigraphically above, an average thickness of 2,000 feet of predominantly thinly-laminated, bituminous-rich marlstone (oil-shale) of the Green River formation covers the interior portions of the basins. The fluvial sediments of the Bridger formation, that underlie and intertongue with the lower portion of the Green River formation, occur almost entirely along the northern rim of the Uinta Basin. The younger Uinta formation occurs stratigraphically above the Green River formation.

Liquid petroleum, mineraloids, or asphaltic and bituminous sandstones occur in all three formations, but it is in the Green River formation, especially the Parachute Creek member, where the well known, rich oil-shale beds occur. Even though these beds are non-marine in origin, they are accepted with little doubt as the source rocks of the associated hydrocarbons. A study by Hunt, Stewart, and Dickey (1954) has provided substantial chemical evidence for this belief. After referring to the obvious field relationships and occurrences of mineraloids, asphalts, and oils, not only oozing from outcrops of the Eocene formations, but also occurring in joints, fractures, fissures, crystal cavities, and in pores of the beds, Hunt, Stewart, and Dickey state that in these strata "there are four chemically different types of free hydrocarbons. Each type is found closely associated with one particular stratigraphic unit, so that the source rock of each type can be identified by field geology. In addition to the free hydrocarbons, there are other hydrocarbons that can be extracted by organic solvents from the sediments of the various stratigraphic units. Chemical data, such as infrared spectra, elemental analyses, and various physical properties show that the extract from each unit is identical with the free hydrocarbons from the same unit, but differs from the extracts and free hydrocarbons of other units. These chemical data, together with the supporting geological data, are believed to constitute an identification of the source rocks of the Uinta Basin hydrocarbons."

It is of interest that not only do the free hydrocarbons contain sulfur, but that the extracted hydrocarbons, sulfates, and pyrites from closely associated rocks also, of course, contain sulfur. Harrison and Thode (1958) have determined the sulfur isotopic composition of these constituents. Their results are shown graphically in the far right column of Figure 94 where the δS^{34} composition is plotted diagrammatically for the various constituents as labeled. For example, in the

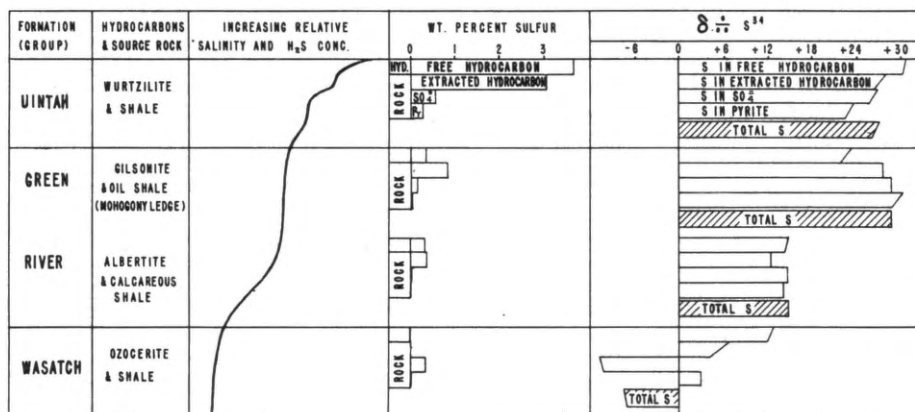


Figure 94. Sulfur content and isotopic composition of hydrocarbons and oil shale from Eocene formations of the Uinta Basin, from Harrison and Thode (1958), and Hunt, Stewart, and Dickey (1954).

Uinta formation, isotopic analyses of sulfur extracted from samples of wurtzilite from the Country Gentlemen mine, Indian Canyon, Utah, indicate an enrichment in S^{34} , varying between 30.6 to 31.0 permil for the two fractions analyzed. Extracted hydrocarbons, SO_4 and pyrite from a bituminous shale sample of Uinta age, but not, however, collected from the same geographic location as the wurtzilite, were enriched in S^{34} between 26.4 and 28.4 permil for the extracted hydrocarbon, 26.1 to 27.2 permil for the extracted SO_4 , 22.7 to 23.7 permil for the extracted pyrite, and 26.8 to 27.2 permil total sulfur, which is the weighted average of the ratios. Information on the weighted abundance of the different constituents needed for this calculation is indicated graphically in the "wt. percent S" column of Figure 94. Three more pairs of mineraloids and stratigraphically associated rock samples were also studied by Harrison and Thode (1958) for which results are indicated on Figure 94. Incidentally, the samples were obtained from the Jersey Production Research Company and are the same samples studied by Hunt, et al. (1954).

In general, the isotopic results indicate an increased enrichment of S^{34} (or depletion of S^{32}) in the younger samples. Furthermore, with the exception of ozocerite, there is generally good agreement between the δS^{34} composition of the free hydrocarbons and the extracted hydrocarbons and, for that matter, with the isotopic composition of sulfur in the sulfate and in the pyrite. The isotopic similarities between the extracted and free hydrocarbons support the belief that

the specific rock units are the respective source beds. It should be reported that Harrison and Thode (1958) quote J. M. Hunt as reporting "that the hydrocarbon-source rock relationship for ozocerite is much less definite than for the other hydrocarbons."

An understanding of these relationships and the cause of the depletion of S^{32} in the younger beds must stem from an understanding of the limnology of Lake Uinta. Actually, the primary sedimentary features in the Green River formation indicate that organic material accumulated in the bottom sediments during two quite different conditions of the lake. According to Bradley (1931), "The regular beds of great persistence with their thin laminae seem to indicate stages when the ancient Lake Uinta was not only relatively broad and deep, but also, probably, thermally stratified, so that the lower stagnant layer of water was favorable to the accumulation of the organic ooze that later became oil shale. The short lenticular beds, the mud cracks, and the shale breccias indicate stages when the water level was low and the organic matter accumulated in more or less isolated residual pools."

Under the reducing condition in the bottom muds of Lake Uinta, anaerobic bacteria would be so active in reducing sulfate to H_2S that the water could have become rapidly saturated with this gas, following which further evolution, especially during spring, summer, and fall months, resulted in a thicker toxic zone concentrated with this gas. With turnover of the lake during mid-winter, as the cooler, more dense, H_2S -concentrated layer neared the surface, the reduced pressure enabled much of the gas to escape to the atmosphere. When the pluvial conditions resulted in low water-level conditions, even much more H_2S was lost to the atmosphere because of the greatly decreased amount of water present in which the gas could be dissolved. Even with rising water conditions, H_2S gas could still have been produced so rapidly under the existing optimum conditions that much of it still escaped from the water. The second column of Figure 94 is taken from Hunt, et al. (1954) wherein they have graphically indicated the increased relative salinity and H_2S concentration of the lake.

It is evident that the amount of H_2S produced was enormous. The environment was ideal for the continued viability of anaerobic bacteria. An enclosed lake, brackish during its early history, having an almost continuous influx of sulfate from streams, would not only have quite favorable reducing conditions at the bottom of the lake, but also a thick zone of stagnation above, through which organic material from the overlying warm zone, teeming with life, would settle and in which anaerobic bacteria would also produce H_2S . Of course, some of the H_2S , especially that formed near the bottom muds, resulted in the formation of syngenetic sulfides, but much more was lost to the atmosphere. It is apparent, however, from the third column of Figure 94, that the amount of sulfur incorporated in the younger hydrocarbons and sediments underwent a great increase with continued evaporation of the water of Lake Uinta.

As discussed in a previous section, the extent of isotopic fractionation resulting from reduction of sulfate to H_2S is never as great as it would be under equilibrium reactions. In fact, the rate of reduction by bacteria is correlative with the degree of fractionation. Anaerobes existing at moderate temperatures in an adequate sulfate concentration and having a plentiful food supply fractionate sulfur isotopes rarely to the extent of 1.5 per cent. "Starved" anaerobes, on the other hand, have produced H_2S enriched as much as 2.7 per cent in S^{32} in laboratory experiments (Feely and Kulp, 1957). Therefore, the fractionation of sulfur isotopes under the optimum conditions of Lake Uinta must have been of

little extent. But the extent of fractionation during about one score million years resulted in a fractionation of possibly two or three per cent. Therefore, as H_2S , that was only slightly enriched in S^{32} was lost, the sulfate remaining behind gradually became enriched in S^{34} . Subsequent H_2S that was evolved, therefore, was reduced from heavier sulfate, and, though still slightly enriched in S^{32} , it was composed of heavier sulfur than was earlier H_2S . By referring to the results shown on Figure 94, it is evident from the generally similar δS^{34} composition of each unit that the hydrocarbons, pyrite, and SO_4^{2-} incorporated in the rocks of the respective units were formed, essentially, syngenetically with the enclosing rock. Furthermore, there has been little, if any, change in the sulfur isotopic composition of any of these constituents since diagenesis. Mass spectrometric analyses of the organic sulfur derived from free hydrocarbons that escaped from the rocks closely reflects the isotopic composition of sulfur existing at about the time of entrapment of the organic matter in the sediments which are believed to be the source rocks for the specific hydrocarbons.

Only two δS^{34} measurements for Utah petroleum samples have been reported in the literature (Thode, Monster, and Dunford, 1958). Nevertheless, these two samples represent the extreme δS^{34} values yet obtained from petroleum samples. One sample from the Green River formation, containing 0.11 per cent sulfur, has a δS^{34} composition of +28.2 permil; the other, Rozel Point asphalt, containing 13.42 per cent sulfur, has a δS^{34} value of -8.7 permil. These extreme variations are most likely the result of a non-marine origin for these petroleum samples. Hydrocarbons formed in a marine environment exhibit a much more narrow spread in $\text{S}^{32}/\text{S}^{34}$ ratios, as the source of sulfur, the enormous sea-water sulfate reservoir, has varied little in sulfur isotopic composition during Phanerozoic time. Sulfate in the very small volume of Lake Uinta, on the other hand, became enriched in S^{34} by more than several per cent by fractional distillation and loss of S^{32} from the lake in the form of a volatile H_2S .

CITED REFERENCES

- Ault, W. U., 1957, Isotopic geochemistry of sulfur: Columbia Univ., Lamont Geol. Observatory, Ph.D. thesis. Published version--1959, in *Geochim. et Cosmochim. Acta*, v. 16, p. 201-255.
- Bradley, W. H., 1931, Origin and microfossils of the oil shale of the Green River formation of Colorado and Utah: U.S. Geol. Survey Prof. Paper 168, 58 p.
- Feely, H. W., and Kulp, J. L., 1957, Origin of Gulf Coast salt-dome sulfur deposits: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 1802-1853.
- Field, C., Ph.D. dissertation: Sulfur isotopes and the origin of sandstone-type uranium deposits, Yale University, New Haven, Connecticut.
- Grutt, E., 1957, Environment of some Wyoming uranium deposits: 2nd Nuclear Eng. Conf., Paper 57-NESC-69, p. 1-12.
- Harrison, A. G., and Thode, H. G., 1958, Sulfur isotope abundances in hydrocarbons and source rocks of Uinta Basin, Utah: Am. Assoc. Petroleum Geol. Bull., v. 42, p. 2642-2644.
- Hunt, J. M., Stewart, F., and Dickey, P. E., 1954, Origin of hydrocarbons of Uinta Basin, Utah: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 1671-1698.
- Jensen, M. L., 1958, Sulfur isotopes and the origin of sandstone-type uranium deposits: Econ. Geology, v. 53, p. 598-616.
- _____, 1959, Sulfur isotopes and hydrothermal mineral deposits: Econ. Geology, v. 54, p. 374-394.
- Thode, H. G., Monster, J., and Dunford, H. B., 1958, Sulfur isotope abundances in petroleum and associated materials: Am. Assoc. Petroleum Geologists Bull., v. 42, p. 2619-2641.
- Thode, H. G., Wanless, R. K., and Wallouch, R., 1954, The origin of native sulfur deposits from isotope fractionation studies: *Geochim. et Cosmochim. Acta*, v. 5, p. 286-298.
- Waters, A. C., and Granger, H. C., 1953, Volcanic debris in uraniferous sandstone, and its possible bearing on the origin and precipitation of uranium: U.S. Geol. Survey Circ. 224, p. 1-26.

— B —

**THE GREAT BASIN
AND THE
SOUTHWESTERN CORNER
OF UTAH**

INDEX TO SECTION B

<u>Paper</u>		<u>Page</u>
26	OIL AND GAS POSSIBILITIES OF UTAH, WEST OF THE WASATCH AND NORTH OF WASHINGTON COUNTY, by Edgar B. Heylmun	287
	Introduction	287
	Paleozoic Systems	287
	Mesozoic System	291
	Cenozoic Systems	291
	Structure	296
	Wells	296
	Summary	300
	Cited References	301
27	GEOLOGY AND OIL POSSIBILITIES OF WASHINGTON COUNTY, by E. F. Cook	303
	Outline of Geologic Relations	303
	Tectonic Structures	306
	Structural Relations of Intrusive Rocks	309
	Exploration Targets	311
	Favorable Beds	315
	Making Use of a Geologic Mask	316
	Summary	317
	Cited References	317

Paper 26 OIL AND GAS POSSIBILITIES OF UTAH, WEST OF THE WASATCH AND NORTH OF WASHINGTON COUNTY

by Edgar B. Heylmun¹

INTRODUCTION

The towering Wasatch Range and the adjoining High Plateaus of central and southern Utah mark the eastern edge of the Great Basin, a vast, semi-arid region of sweeping valleys and isolated mountain ranges. The Great Basin, a part of the Basin and Range physiographic province, occupies western Utah and most of the state of Nevada, as well as sizeable portions of Oregon, California, and Idaho. The discussion here will be confined to Utah, although frequent references to geology in Nevada will be necessary. The validity of the Great Basin as a genuine oil and gas province has been questioned in some quarters, but the writer will attempt to point out some facts that should cause even the most conservative oil man to ponder the possibilities.

PALEOZOIC SYSTEMS

The Great Basin of Utah contains some of the thickest Paleozoic sequences in North America, as most of the deposits were laid down in the great Cordilleran, or Rocky Mountain, miogeosyncline. No attempt will be made here to analyze each system, as space will not permit an adequate discussion. Over 30,000 feet of Paleozoic sediments accumulated in parts of the region. The three deepest basins within the miogeosynclinal belt of Utah are the Confusion basin in the west-central part of the state, the Oquirrh basin in the north-central part, and the Utah-Idaho basin in the northern part. Limestones and dolomites predominate throughout the stratigraphic column in most areas, although sandstones and dark shales are also common. Positive areas occurred at various times in the Paleozoic which resulted in non-deposition or erosion, and locally certain systems are not present. The most profound of the Paleozoic uplifts occurred in northwestern Utah during the Pennsylvanian, resulting in erosion of the Mississippian units and non-deposition of the Pennsylvanian and Permian units. The positive area, known as the Raft River uplift, may have been contiguous with the Uncompahgre uplift that occurred in western Colorado and eastern Utah at the same approximate time (Heylmun, 1959, p. 172), and it is certain that it has a relationship to the Northeast Nevada highland of Steele (1959, p. 1105).

There are a large number of formational names in use in the Great Basin, as each mining district has its own nomenclature. The major oil companies, however, have been able to extend the Confusion basin-Gold Hill nomenclature over much of western Utah and eastern Nevada, and the Confusion basin section is now accepted as somewhat of a standard. Only in the deeper parts of the Oquirrh basin and the Utah-Idaho basin is it necessary to use additional or different formational names. The Confusion basin section, taken from the Deep Creek, House, and Confusion Ranges, is as follows:

1. Consultant, Salt Lake City, Utah.

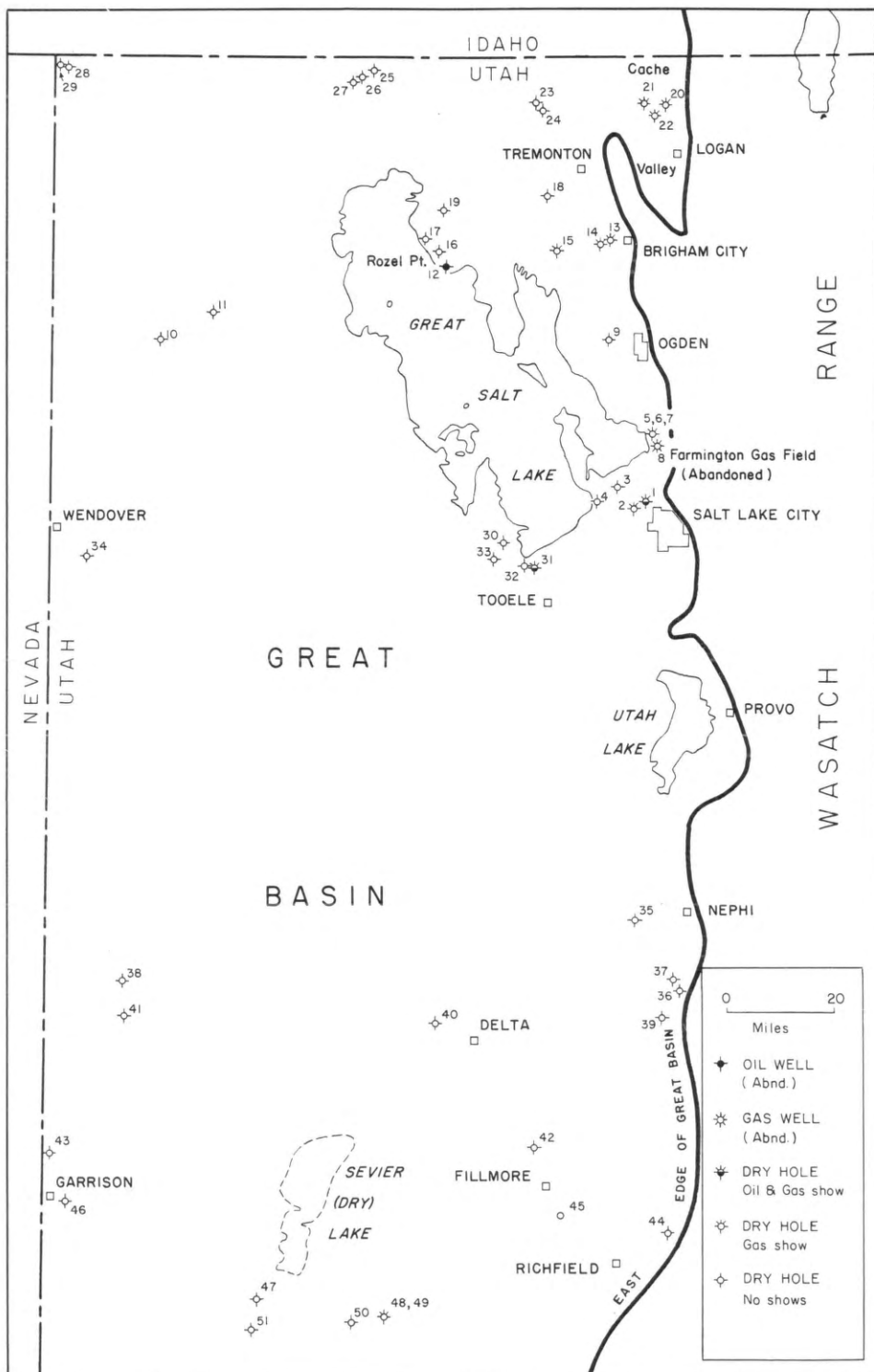


Figure 95. Map of the Great Basin of Utah, showing places mentioned in text and principal wells. Well numbers are keyed to the accompanying index.

WELL INDEX FOR FIGURE 95

Well	Location	Total Depth	Lowest Fm.	Shows	Fm.
1. Western Petrol. Drlg. No. 1 Nebeker	21- 1N- 1W	1,985	Tertiary	O & G	Q-T
2. Geotronic Dev. No. 1 Jacketta	30- 1N- 1W	565	Quaternary	O & G	Q
3. Byrd-Frost No. 1 Irving	3- 1N- 2W	1,916	Tertiary	None	
4. L.E. Whitlock No. 1 Morton Salt	24- 1N- 3W	4,231	Precambrian	None	
5. Guffey & Galey No. 1 Farmington	25- 3N- 1W	2,000?	Tertiary	Gas	Q
6. Hickey No. 1 Wilcox	26- 3N- 1W	3,005	Tertiary	Gas	Q
7. G.H. Anderson No. 2 Farmington	26- 3N- 1W	3,525	Tertiary	Gas	Q-T
8. Farmington Gas Field (abnd.)	36- 3N- 1W	2,060-dpst	Tertiary	Gas	Q
9. J.A. Nak No. 1 Ben Lomond	28- 6N- 2W	619	Quaternary	None	
10. Gulf No. 1 Williams	14- 6N-16W	2,894	Pennsylvanian	None	
11. So. Pacific R.R. No. 1 Lemay	29- 7N-14W	2,502	Paleozoic	None	
12. Rozel Point Oil Field (abnd)	8N- 7W	over 2,000	Tertiary	O & G	Q-T
13. Stacey No. 1 Brigham City	21- 9N- 2W	1,220	Tertiary	Gas	Q
14. Rhine Pet. No. 1 Brigham City	30- 9N- 2W	2,308	Precambrian?	Gas	Q
15. U.S. Biological Survey No. 2	35- 9N- 4W	1,028	Tertiary	Gas	Q
16. Lakeside No. 1 Rozel	31- 9N- 7W	2,710	Tertiary	None	
17. Leonora No. 2 Raddatz	14- 9N- 8W	2,280	Tertiary	None	
18. Utah Pennsylvanian No. 2 Penrose	3-10N- 4W	4,100	Pennsylvanian	None	
19. Utah Southern No. 1 Bar-B	17-10N- 7W	7,918	Devonian	None	
20. Cache Valley Dairy No. 1 Gossner	19-13N- 1E	5,500	Paleozoic	Gas	T
21. Karmis-Gold Zone No. 1 Brown	10-13N- 1W	5,251	Mississippian	Gas	T
22. Cache Valley Oil No. 1 Gossner	25-13N- 1W	1,650	Miss. ?	Gas	T ?
23. Promontory No. 1 White Valley	7-13N- 4W	7,321	Cambrian	None	
24. Northern No. 1 White Valley	17-13N- 4W	2,013	Mississippian	None	
25. Utah Southern No. 2 Curlew	6-14N- 9W	7,569	Devonian	None	
26. Utah Southern No. 1 Gabrielson	14-14N-10W	4,765	Mississippian	None	
27. Utah Southern No. 1 Curlew	22-14N-10W	4,420	Devonian	None	
28. Eagle No. 1 Goose Creek	2-14N-19W	812	Tertiary	Oil ?	
29. Walden No. 1 Goose Creek	3-14N-19W	842	Tertiary	None	
30. National No. 1 Burmester	31- 1S- 5W	1,127	Pennsylvanian	Gas	
31. Hickey No. 1 Cassidy	13- 2S- 5W	5,486	Pennsylvanian	gas	Penn.
32. Walker-Wilson-Whitlock No. 1 Cassidy	14- 2S- 5W	7,969	Tertiary	None	
33. Bonneville No. 1 Worthington	14- 2S- 6W	3,115	?	?	
34. Shell Oil No. 1 Salduro	4-22S-18W	2,950	Intrusion	None	
35. Sage Valley No. 1 Brough	12-13S- 2W	1,200	Crataceous ?	None	
36. Standard of Cal. No. 1 Levan	17-15S- 1E	Drilling			
37. Mt. Nebo No. 1 Levan	1-15S- 1W	2,900	?	None	
38. Standard of Cal. No. 1 Desolation	8-15S-17W	6,200	Devonian	None	
39. Great Basin No. 1 Sevier	10-16S- 8W	3,510	Tertiary	None	
40. Gulf No. 1 Gronning	24-16S- 8W	8,161	Tertiary	None	
41. Gulf No. 1 Bishop Springs	8-16S-17W	9,058	Silurian	None	
42. Tom Kearns No. 1 Fillmore	13-20S- 5W	1,920	?	?	
43. Shell No. 1 Baker Creek	19-20S-19W	4,218	Cambrian	None	
44. Standard of Cal. No. 1 Sigurd	32-22S- 1W	9,638	Jurassic	None	
45. Shell No. 1 Sunset Canyon	21-22S- 4W	Location			
46. Standard of Cal. No. 1 Burbank	3-22S-19W	6,955	Ordovician	None	
47. Von Glahn No. 1 Wah Wah	33-24S-13W	1,971	?	None	
48. El Capitan No. 1 James	17-25S- 9W	3,682	Tertiary	?	
49. Beaver Valley No. 1 Black Rock	20-25S- 9W	3,500	Tertiary	?	
50. El Capitan No. 1 Paxton	29-25S-10W	3,379	Tertiary	?	
51. Premium No. 1 Preuss Valley	32-25S-13W	1,050	Tertiary	None	

Triassic	Thaynes fm.	1,900+feet
	Gerster fm.	1,100
Permian	Plympton fm.	690
	Kaibab ls.	480
	Arcturus fm.	2,700
	Ely ls.	2,000
Pennsylvanian	Chainman sh.	1,200
Mississippian	Joana ls.	200
	Pilot sh.	900
	Guilmette fm.	1,200
Devonian	Simonson dol.	500
	Sevy dol.	2,000
Silurian	Laketown dol.	1,200
	Fish Haven dol.	600
	Swan Peak qtzite.	400
Ordovician	Eureka qtzite.	450
	Pogonip group	3,500
	Notch Peak ls.	1,500
	Orr fm. (	3,500
	Weeks fm. (	
	Marjum ls.	1,500
	Wheeler fm.	450
	Swasey ls.	400
Cambrian	Dome ls.	300
	Burnt Canyon ls.	200
	Burrows ls.	350
	Millard ls.	250
	Busby qtzite.	150
	Pioche sh.	250
	Prospect Mtn. qtzite.	1,000+
Total thickness exposed		30,400 feet

Between 1950 and 1956 ten deep wells tested various sequences of Paleozoic rocks in the Great Basin of Utah. Most of the wells were in the Confusion basin area. Only a few relatively insignificant showings of oil and gas were encountered, and there has been no recent drilling in the basin involving Paleozoic units.

Some of the younger Paleozoic formations, such as the Kaibab, Arcturus, and Chainman, have beds exhibiting good porosity and permeability interbedded with organic shales and limestones. In general, the younger Paleozoic rocks appear to hold the most promise for oil and gas production, although certain zones in the Devonian, Silurian, and Ordovician are known to be petroliferous. Much of the Paleozoic is hard and tight and has been subjected to considerable structural deformation in some areas. Fresh water has been encountered in fractures at great depths in some wells, suggesting connections with the surface. However, since oil and gas shows have been encountered in the Paleozoic in western Utah, certain formations must be considered important objectives for future drilling.

MESOZOIC SYSTEMS

The Mesozoic rocks of western Utah are poorly known, inasmuch as they are exposed at only a few localities within the Great Basin proper. There are extensive exposures of Mesozoic rocks in the Wasatch Range, the High Plateaus, and in southwestern Utah, but these are mostly outside of the region included here.

Triassic sequences, largely incomplete, are known at a few localities in western Utah, including the Confusion, Hogup, Big Davis, Tintic, Pavant, Mineral, and Topache Mountains. The Triassic rocks exposed in the Pavant Range can be correlated with the Triassic in the Colorado Plateau province, and the Triassic limestone exposed along the east side of the Confusion Range compares favorably with the Thaynes limestone in the Wasatch Range. It is almost certain that considerably more Triassic is concealed under the broad valleys in the deeper, down-faulted parts of the Great Basin.

The Jurassic system, dominated by the thick Arapien group along the eastern edge of the Great Basin in central Utah, has not been found in western Utah. There are, of course, excellent exposures of Jurassic rocks in southwestern Utah, and there are a few outcrops in eastern Nevada, but these are outside of the region of this report. A great uplift, known as the Sevier arch (Harris, 1959, p. 2,639), apparently started to form in western Utah during the late Jurassic, causing the removal of any Jurassic rocks that may have been deposited.

There are no known Cretaceous beds in western Utah, aside from the thick conglomerate deposits along the eastern fringes of the Great Basin. The Sevier Arch developed into a superior north-south mountain system during the Cretaceous, and it shed coarse debris both to the east and to the west. The Indianola group and other Cretaceous conglomerates are best exposed in the Canyon Range (Christiansen, 1951, p. 8) and adjacent areas along the eastern edge of the Great Basin. The coarse conglomerates grade eastward into the Cretaceous sandstones and shales of the Colorado Plateau province. There are isolated exposures of conglomerates in western Utah that have not been accurately dated; these could be Cretaceous in age, but, for all practical purposes, it can be said that the Cretaceous is missing over most of the region under discussion.

The Virgin oil field, outside of the Great Basin in southwestern Utah, produces oil from Mesozoic rocks, but it does not appear likely that the Mesozoic offers much potential for oil or gas production in the Great Basin proper, at least in Utah. Only two wells, the Standard of California No. 1 Sigurd, in sec. 32, T-22-S, R-1-W, Sevier County, and the Standard of California No. 1 Levan, in sec. 17, T-15-S, R-1-E, Juab County, penetrated significant thicknesses of Mesozoic rocks within the region under discussion. The Sigurd well struck the top of the Navajo at 8,897 feet and bottomed in this formation at a total depth of 9,638 feet. It encountered no significant oil or gas shows. The Levan well was plugged and abandoned at 7,526 feet in Triassic rocks.

CENOZOIC SYSTEMS

Paleocene Strata

There are no known Paleocene rocks in the Great Basin of Utah, except along the eastern edge in the central part of the state. At those localities the Paleocene can be correlated with units on the Wasatch Plateau and in the Uinta Basin. It is possible that some of the scattered conglomeratic sequences in the

Great Basin, like those on the east side of the Stansbury Range or on the lower slopes of the Canyon Range, are Paleocene or Eocene in age, but no fossil evidence has been found to confirm this.

Eocene Strata

Like the Paleocene, the Eocene is represented at places like Long Ridge, on the eastern fringe of the Great Basin. In addition, the Eocene is also represented in the form of the White Sage formation near Gold Hill in extreme western Utah (Nolan, 1935, p. 42). The occurrence of fresh-water limestones, shales, and sandstones of Eocene age near Gold Hill is of great interest, inasmuch as they may be intimately associated with a great Eocene lake system that probably covered much of northeastern and eastern Nevada at that time (Heylman, 1958, p. 139).

Eocene deposits were not well known in eastern Nevada until the Shell Oil Company drilled its first Eagle Springs well in Railroad Valley, southwest of Ely, in 1954. This was Nevada's first commercial oil discovery, with an initial production of 373 barrels of 27.8° gravity oil per day. The producing interval in the first well is a welded rhyolitic tuff that overlies a petroliferous Eocene section of limestone, shale, and sandstone, totaling some 500 feet thick. The source of the oil was probably in the Eocene section, and the second well at Eagle Springs produces from the Eocene. The Eocene sediments are correlated with the Sheep Pass formation (Winfrey, 1958, p. 77), the type locality of which is in the Egan Range south of Ely. At that locality it is approximately 3,200 feet thick.

The oil and gas possibilities in the broad desert valleys of eastern Nevada are excellent, although geophysical surveys would be necessary in locating structures beneath the valley fill. Since there is very little Eocene known in western Utah, it is doubtful that it can be considered as an objective there. Except along the eastern fringe of the Great Basin, no wells have encountered Eocene rocks in western Utah.

Oligocene Strata

The Oligocene was a time of great structural unrest and widespread volcanic eruptions, and, therefore, holds little promise for oil and gas. It is interesting to note, however, that oil is produced from an Oligocene tuff at the Eagle Springs oil field in Railroad Valley, Nevada. The welded rhyolitic tuff merely acts as a reservoir for the high pour-point oil which was probably generated in the underlying Eocene sediments. Most of the Oligocene volcanic material has been included in the so-called Lower Volcanic group (Harris, 1959, p. 2, 638) which is found over much of western Utah and eastern Nevada. The complex sequences of ignimbrites and flows blanket wide areas and, in places, are many hundreds of feet thick. The Lower Volcanic group has been dated by the potassium-argon method and is of Late Eocene and Oligocene age. The value of the Lower Volcanic group as a marker zone in the Tertiary is just now being realized.

In parts of north-central and northern Utah, beds probably belonging to the Lower Volcanic group apparently interfinger with the overlying lake sediments of Miocene age. For example, at Jordan Narrows, south of Salt Lake City, the Salt Lake group has been divided into several formations, the basal one of which is the Traverse volcanics. The traverse volcanics probably belong to the Lower Volcanic group and should be separated from the overlying Salt Lake group. The Fowkes formation, formerly the Norwood tuff, found in the Wasatch Range, is also of Oligocene age (Eardley, 1944, p. 845, 1959, p. 167).

The Late Eocene and Oligocene volcanic rocks, though widespread, are not everywhere present. They rest on the previously described Eocene lake beds in parts of eastern Nevada and extreme western Utah, but over most of western Utah, the volcanics rest upon a highly irregular surface of complexly folded and faulted pre-Tertiary rocks.

Miocene and Pliocene Strata

The heterogeneous Salt Lake group contains the Miocene and Pliocene sediments in western Utah. The Salt Lake group probably correlates in large part with the equally thick Humboldt formation in northern Nevada, except for that portion of the Humboldt that is now considered to be Eocene or Oligocene in age. Recent work by the writer suggests that the Salt Lake group will ultimately be divided into a number of distinct and mappable units.

The thickest and best developed exposures of the Salt Lake group are in Cache Valley (Adamson, Hardy, and Williams, 1955, p. 1) and in the Goose Creek area (Mapel and Hail, 1956, p. 1), but there are other exposures near Park Valley, at Rozel Point, in the Pilot Range, at Jordan Narrows, around the Tintic and West Tintic Mountains, and the Gold Hill area. In Cache Valley, the Salt Lake group is locally over 12,000 feet thick, the thickest occurrence known in Utah. In Beaver Valley in southern Utah, beds similar to the Salt Lake group may be observed (R. E. Redden, unpublished report), and several wells in the southern part of the Great Basin in Utah have encountered Tertiary beds characteristic of the Salt Lake group. The Gulf Oil No. 1 Gronning, sec. 24, T-16-S, R-8-W, Millard County, Utah, penetrated over 7,000 feet of late Tertiary sedimentary and volcanic units. It is likely, therefore, that equivalents of the Salt Lake group can be found under the broad desert valleys through much of western Utah. Some of the relationships of the Salt Lake group are shown in Figure 96.

The rocks most commonly represented in the Salt Lake group are fresh-water limestone and marlstone, shale, sandstone, conglomerate, lignite, tuff, welded tuff, and basalt. Most of the sediments, including the limestones, are more or less tuffaceous, indicating continued volcanic activity in the region. Some of the limestones, however, are distinctly petroliferous. Most of the beds were laid down in a vast system of fresh-water lakes that covered much of the Great Basin. Since the topography in the Miocene and Pliocene was similar to the present topography, the lakes occupied the areas that are now valleys. Therefore, exposures can be found only at places that have been subjected to recent structural uplift or at places that have been exhumed by erosion. Virtually every well that spudded in valley alluvium in western Utah encountered the Salt Lake group at relatively shallow depths. In some wells, oil and gas shows were recorded.

The Salt Lake group, over much of the region, rests on effusives belonging to the Lower Volcanic group, although at a number of localities the beds are known to rest directly on pre-Tertiary rocks, these usually being Paleozoic limestones, dolomites, or quartzites. Two wells northwest of Logan, Utah, encountered the contact between the Salt Lake group and the underlying Paleozoics at a depth of around 5,000 feet.

Petroliferous limestone, organic shale, and lignite are common in the Salt Lake group, particularly in northern and northwestern Utah. In addition to these excellent source beds for oil and gas, numerous tuffaceous sandstones are present as potential reservoir beds.

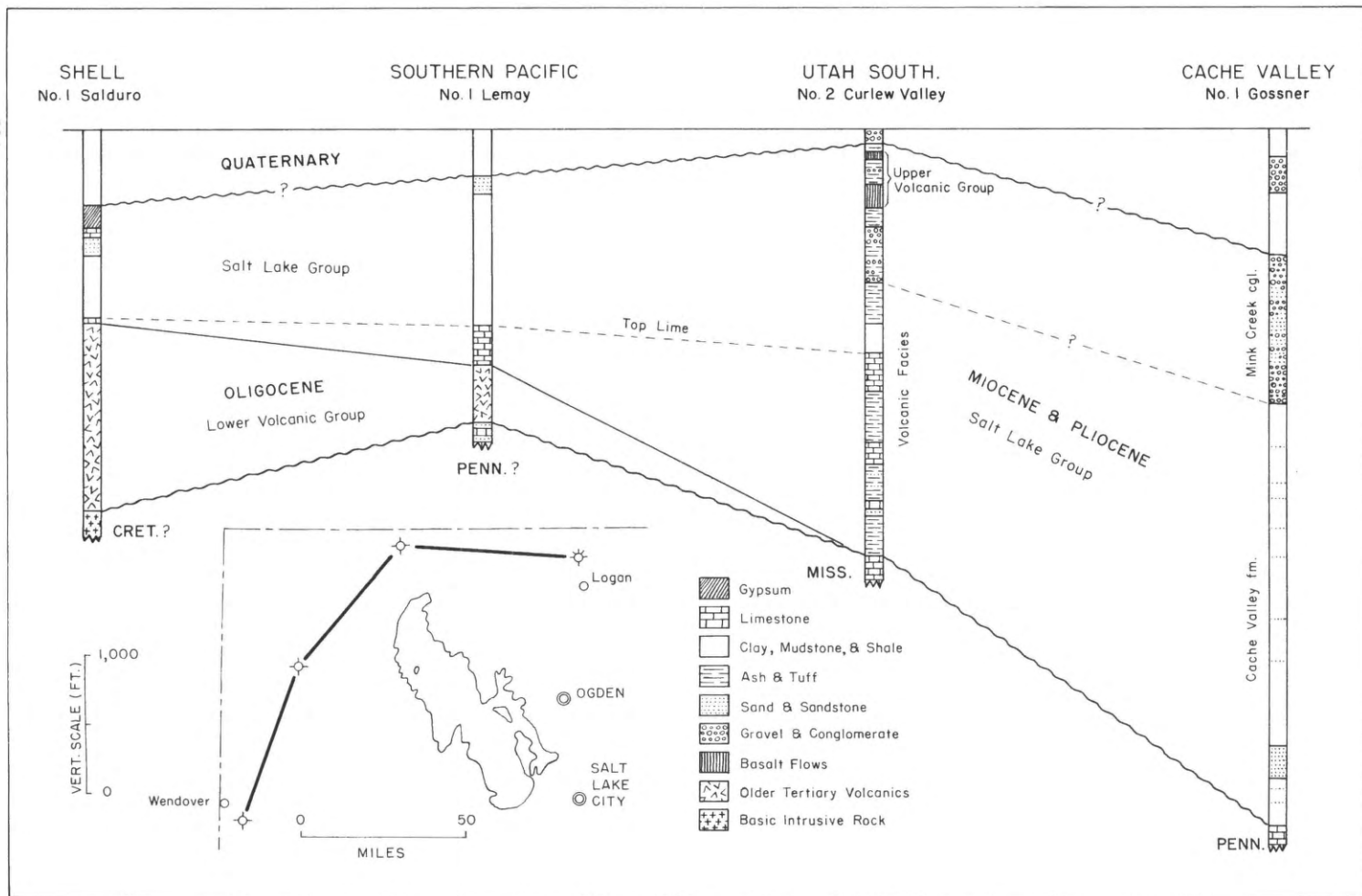


Figure 96. Stratigraphic Cross-section of Cenozoic rocks from the Bonneville Salt Flats to Cache Valley. Principal lithologic types and possible correlations are shown. Notice thinning in western Utah which may be due to continued influence of the Sevier arch.

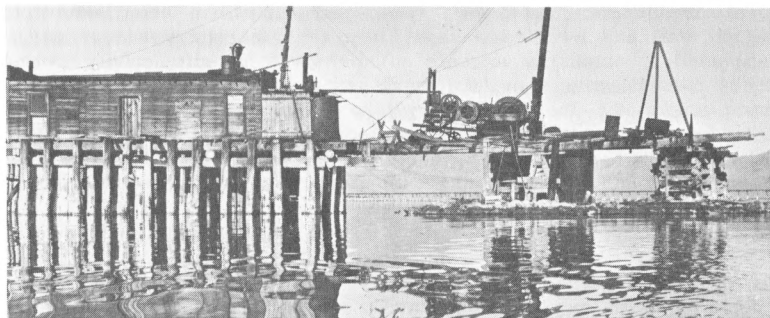
Vesicular basalts belonging to the Salt Lake group contain black asphaltic oil in wells drilled at Rozel Point (A. J. Eardley, unpublished report). In addition to these unusual shows of oil, important gas shows have been encountered in sands of the Salt Lake group in wells near Logan, Farmington, and Salt Lake City. Asphaltic sand and gas was reportedly encountered in a well in Milford Valley near Black Rock, Utah. Some of the individual wells are discussed later.

Quaternary Strata

At many localities in western Utah, the Quaternary sands, gravels, and clays are quite thick. In the broader valley regions the Quaternary is frequently over 1,000 feet thick. At the abandoned Farmington gas field, the Quaternary is around 900 feet thick. In addition to sand, gravel, and clay, peat is an important constituent in the area bordering the Wasatch Range, while in western Utah, on the Bonneville Salt Flats, the Shell No. 1 Salduro, sec. 4, T-2-S, R-18-W, Tooele County, Utah, encountered considerable gypsum in the Quaternary or latest Tertiary.

The base of the Quaternary is often characterized by a massive, poorly indurated conglomerate or fanglomerate. Generally speaking, the sediments become finer-grained in the valley areas away from the mountain ranges, and, in most wells drilled far out in valleys, clays predominate over sands or gravels. Even in Salt Lake (Jordan) Valley, bordering the Wasatch Range, the Quaternary green clays (Jones and Marsell, 1955, p. 92) are locally over 700 feet thick.

Numerous oil and gas shows have been obtained in wells drilled through Quaternary sediments in Utah. The extensive asphalt seeps along the north shore of Great Salt Lake at Rozel Point have apparently originated in Quaternary or Late Tertiary lake beds. Since the oil at Rozel Point has properties similar to ichthyol, or "fish oil," it is possible that the oil originated in some Late Tertiary or Quaternary lake as the result of giant fish kill.



An operation attempting to produce the viscous oil from the seeps and shallow wells at Rozel Point, about 1933. (Photograph courtesy of A. J. Eardley)

A water well near Beaver, Utah, encountered oil in Quaternary sediments at only 140 feet (Lee, 1908, p. 24), and a well drilled for oil and gas near the Salt Lake City airport reportedly encountered asphaltic sand at 694 feet in Quaternary lake sediments. Good gas shows have been reported in a number of wells. The principal areas of gas occurrences are in Quaternary sands near Logan, Brigham City, Farmington, and Salt Lake City, and, in some cases, the gas has been used locally.

The presence of gasoline fractions in some of the gas, along with the fact that gas bubbles breaking on the surface of water at some gas seeps leave an oil slick, leads the writer to believe that at least some of the gas is a pure petroleum product rather than marsh gas. The presence of organic clay and peat along with numerous sand and gravel beds is encouraging for the production of oil or gas from the Quaternary, although there may be some doubt as to whether sufficient reserves could be established at shallow depths to be economically profitable. A surprisingly large amount of gas, however, was produced from the Farmington gas field at a time when production methods were certainly very primitive.

STRUCTURE

Aside from broad warpings and regional tilting, no structural activity is known to have affected pre-Mississippian Paleozoic rocks. In the Mississippian, some effects of the Antler orogeny in Nevada can be observed in western Utah, and the Wendover arch was formed in the western parts of Tooele and Box Elder Counties. Later, perhaps in the early Pennsylvanian, the Raft River uplift commenced to form in northwestern Utah. In the area of the Raft River uplift, the Mississippian was partly or wholly removed by erosion, and no Pennsylvanian rocks were deposited. The first really intense structural upheaval, however, did not occur until the close of the Jurassic, when the Sevier Arch commenced forming in western Utah. Great structural deformation accompanied the formation of the arch, and many north-south trending folds were developed. As the intensity of the uplift increased to a climax in the Late Cretaceous, widespread overthrusting occurred. The great uplifting at this time was part of the Laramide orogeny. Igneous intrusions occurred during the later stages.

Orogenic activity subsided in the Eocene, permitting fresh-water lakes to form in eastern Utah and in eastern Nevada, but in the Oligocene more unrest occurred accompanied by extensive volcanic outpourings. Sporadic activity continued until the present, mostly in the form of normal faulting, with a few localized volcanic eruptions. The late Tertiary lake sediments are, therefore, locally interbedded with basaltic flows and ash beds, and have been block faulted and locally folded. The pre-Tertiary deposits, of course, have been much more severely folded and faulted than have the Tertiary units, for the Tertiary may be nearly flat-lying at certain localities.

WELLS

The following is a brief summary of the important wells drilled in the Great Basin of Utah. To avoid a lengthy repetition in giving the location of each well, the number in parenthesis refers to the table accompanying Figure 95.

Western Petroleum Syndicate No. 1 Nebeker (1): This well, just north of the Salt Lake municipal airport, was drilled to a total depth of 1,985 feet in 1931,

testing the top part of the Salt Lake group. Asphaltic sand was found at 694 feet, and a gas sand was reported between 750 and 756 feet. Both shows were in beds of Quaternary age. Another good gas show was reported in Tertiary beds at the total depth. An adjacent water well produced 874 B.T.U. gas for a number of years for use in a nearby farm house. The gas contained 84.6% methane and 14.4% nitrogen. A number of other shallow water wells in the same general area emit quantities of inflammable gas.

Geotronic Development No. 1 Jacketta (2): At least five separate gas shows were recorded between 188 feet and 551 feet, and an oil show was reported, but not confirmed by the writer. The well was converted to a water well after going to 565 feet.

L. E. Whitlock No. 1 Morton Salt (4): The Whitlock well went to a total depth of 4,231 feet in 1956. From an examination of the electric log and discussion with men connected with the drilling, the writer assumes that the Quaternary-Tertiary contact was at 1,432 feet, at the base of a thick fanglomerate, and the contact between the Tertiary Salt Lake group and the Precambrian was at 3,654 feet. There were no oil or gas shows.

Gerald H. Anderson No. 2 Farmington (7): This well went to a total depth of 3,525 feet, bottoming in Tertiary rocks, in 1950. Several gas shows were reportedly encountered, and one between 2,700 and 2,800 feet was in beds belonging to the Salt Lake group. No attempt was made to produce the gas.

Farmington Gas Field (8): Between 1891 and 1897 approximately 20 shallow gas wells were drilled in a one square mile area. Most wells were less than 700 feet deep, although two went to about 1,400 feet. A test drilled in 1955 went to 2,060 feet, bottoming in the Salt Lake group. In 1896 and 1897 the wells produced for a period of 19 months, supplying Salt Lake City, via a wooden pipeline, with 833 B.T.U. gas. As many as 9 different sands produced from the Quaternary section, and none were reported as water-bearing. The maximum monthly production was 17,000,000 cubic feet, and it is estimated that the field produced around 150,000,000 cubic feet of gas before abandonment (Richardson, 1905, p. 481). The gas contained 80.6% methane, no ethane, and 10.4% nitrogen. The maximum initial production recorded was 4,901,720 cubic feet per day from a well completed in 1892. The average well-head pressure was between 200 and 250 psi.

J. A. Nak No. 1 Fee (9): This well was drilled to a depth of 619 feet at a location west of Ogden, being the only well drilled specifically for oil or gas between Farmington and Brigham City. Since nearby water wells are deeper, the test was inadequate. The well was drilled in 1960 and bottomed in Quaternary lake beds.

Southern Pacific Railroad No. 1 Lemay (11): The Southern Pacific Railroad drilled a 2,502 foot water well near Lemay on the Great Salt Lake Desert (Schreiber, 1954, p. 5). No oil or gas shows were recorded. The contact between the Salt Lake group and probable Oligocene volcanics was at 1,690 feet, and the contact between the volcanics and the late Paleozoic was at 2,108 feet.

Rozel Point Oil Field (12): A large area of asphalt seeps on the north shore of Great Salt Lake prompted the first drilling at Rozel Point before 1904. Over 20 wells, the deepest being 2,710 feet, have been drilled in the area. The Rozel Point oil field is covered in detail by Eardlev and Haas (1936, p. 76) and by

Slentz and Eardley (1956, p. 32). In wells, most of the asphalt is in vesicular basalt belonging to the Salt Lake group, at depths ranging between 130 and 300 feet. The impression is that the asphalt originated in the Quaternary lake sediments which overlie the basalts. However, the Leonora No. 1 Saboda well had asphalt and gas in basalt flows at depths between 1,240 and 1,375 feet, so the origin of the hydrocarbons is somewhat in doubt. Carbon 14 dating indicates a Quaternary age for the asphalt. In 1956, the Liquid Asphalt No. 1 Eller well, in section 16, T-8-N, R-7-W, was reportedly producing around 5 barrels of asphaltic oil per day (A. J. Eardley, unpublished report).

Rhine Petroleum Industries No. 1 Brigham City (14): This well was drilled to a depth of 2,308 feet in 1958. The test penetrated Quaternary and Tertiary sediments and may have bottomed in the Precambrian which apparently underlies the Salt Lake group in this area. There were several zones which had minor gas shows. Ralph Arnold (unpublished report) lists several wells immediately west and northwest of Brigham City, some of which reportedly had substantial flows of gas.

U.S. Biological Survey No. 2 Water Well (15): The federal government drilled a 1,028-foot water well in the Bear River marshes west of Brigham City in the 1920's. The contact between the Quaternary lake sediments and the Tertiary Salt Lake group was probably at 514 feet. Several gas zones were encountered, the best being at 340 feet. Another water well drilled at the location also produced quantities of gas. An analysis of the gas showed it to contain 87.9% methane and 5.5% nitrogen. Ralph Arnold (unpublished report) reports a well-head pressure of 134 psi in 1948.

Utah Southern Oil Co. Wells (19, 25, 26, 27): The Utah Southern Oil Company drilled four tests in northern Utah between 1951 and 1956. The drilling of these wells is covered in detail by Peace (1956, p. 17) and will not be reviewed here. The wells were drilled for Paleozoic objectives, and no significant shows of oil or gas were encountered.

Cache Valley Dairy Assoc. No. 1 Gossner (20): This test was drilled north of Logan, Utah in 1956 and went to a total depth of 5,500 feet. The base of the Quaternary is tentatively placed at 900 feet. The contact between the Salt Lake group and the Pennsylvanian is at 5,024 feet. Numerous gas shows were encountered, the most important of which were at 3,600, 4,760, and 4,825 feet in sands of the Salt Lake group.

Karmis-Gold Zone No. 1 Brown (21): This San Franciscan company drilled a well to a depth of 5,251 feet, west of the aforementioned well, in 1957. The test encountered several gas shows in the Salt Lake group and bottomed in late Paleozoic rocks.

Hickey Oil Corp. No. 1 Cassity (31): This test was drilled to 5,486 feet in 1955, east of Grantsville, Utah. Quaternary and Tertiary sediments, mostly clay, marl, and sand, were penetrated to a depth of 4,830 feet, where a hard Pennsylvanian limestone and sandstone sequence was tapped. A ten-foot sand, belonging to the Salt Lake group, was topped at 2,925 feet and had a minor gas show, while zones at 5,290, 5,400, and 5,460 feet in the Pennsylvanian were reported by the operator to have been saturated with high gravity oil and also to have contained gas. Whether these shows were of commercial quality is not known, as no attempt was made to complete the well.

Walker-Wilson Drilling No. 1 Cassity (32): Located less than a mile west of the aforementioned Hickey well, the Walker-Wilson test went to 7,979 feet in 1956. The well never encountered the Pennsylvanian rocks found in the Hickey well and remained in the Salt Lake group to the total depth. There were no significant gas shows in the Quaternary and Tertiary sediments penetrated.

Shell Oil No. 1 Salduro (34): Shell drilled this well on the Bonneville Salt Flats in 1956, going to a total depth of 2,950 feet. The Quaternary or latest Pliocene section contained much gypsum. There were few sands in either the Quaternary or the Tertiary, the sediments being mostly clays. The contact between the Salt Lake group and volcanics possibly belonging to the Oligocene Lower Volcanic group was at 1,375 feet, and a basic intrusive rock was topped at 2,742 feet. There were no oil or gas shows.

Standard of California No. 1 Levan (36): This well went to a total depth of 7,526 feet, bottoming in Triassic red beds. The well penetrated over 4,000 feet of red beds referable to the Chinle and Moenkopi formations, an anomolous situation that suggests complex structure at this locality. There were no oil or gas shows.

Gulf Oil No. 1 Gronning (40): Gulf drilled a 8,161 foot test northwest of Delta, Utah, in 1957. Late Tertiary sediments, possibly belonging to the Salt Lake group, were penetrated from 970 feet to the total depth. This is one of the thickest occurrences known in Utah. Several basalt flows were interbedded between 2,500 and 3,500 feet, but the majority of the beds were clay, ash, sand, and silt. There were no oil or gas shows.

Gulf Oil No. 1 Bishop Springs (41): Gulf drilled a well on a prominent surface anticline in the Confusion Range. The well went to 9,058 feet in 1952 and tested the Paleozoic section from near the base of the Mississippian to the Silurian. There were no significant oil or gas shows.

Shell Oil No. 1 Baker Creek (43): This well went to a depth of 4,218 feet. It was drilled in 1956 at a location north of Garrison, Utah. The probable top of the Salt Lake group was at 730 feet and the contact between the Salt Lake group and the Cambrian Prospect Mountain quartzite was at 4,180 feet. The Salt Lake group consists of ash, sand, silt, clay, dolomite, limestone, and gypsum at this locality. There were no oil or gas shows.

Shell Oil No. 1 Sunset Canyon (45): The Shell Oil Company drilled a well on a prominent surface anticline on the west side of the Pavant Range, southeast of Fillmore, Utah. The well began in Triassic rocks, reached a total depth of 8,962 feet, and bottomed in Silurian dolomite. No significant shows were reported. No other wells have been drilled for oil or gas in the immediate area.

Standard of California No. 1 Burbank (46): Standard of California drilled a well to a total depth of 6,955 feet in 1952, on a surface anticline in the Burbank Hills east of Garrison, Utah. The endeavor tested the middle Paleozoic section, bottoming in beds of probable Ordovician age. There were no important oil or gas shows.

El Capitan No. 1 James (48): Several shallow to moderately deep wells were drilled in Milford Valley near Black Rock, Utah. The captioned well went to a total depth of 3,682 feet in 1950, apparently bottoming in late Tertiary sediments. The reports of oil and gas shows in some of the wells in the area appear to be reliable, but have not been confirmed by the writer. The shows, if present, would be in Quaternary or Tertiary beds.

SUMMARY

Over 80 tests have been drilled for oil and gas in the Great Basin of Utah. Of these, about 20 were in or around the abandoned Farmington gas field, and another 20 or so were around the Rozel Point asphalt seeps. Aside from these, about 15 other wells had important showings of oil and gas, so that altogether, approximately 45 of the wells drilled in the region had oil or gas shows. In addition to the abandoned gas production at the Farmington gas field, a small amount of black asphaltic oil has been produced at Rozel Point.

The overwhelming majority of the oil and gas shows to date have been in beds of Quaternary or Tertiary age. The Quaternary and Tertiary sediments were laid down, for the most part, in vast fresh-water lakes. Fresh water sediments generally are not considered favorable for the generation of oil and gas. However, in view of the recent discoveries of non-marine oil fields in Utah and adjacent areas, having similar characteristics to some of the lake beds west of the Wasatch, the Cenozoic sediments of western Utah become worthy of further exploration.

The subsurface information available indicates that the most attractive area for Cenozoic production, particularly gas, is immediately west of the Wasatch Range, in Utah, Salt Lake (Jordan), and Cache Valleys, as well as along the east shore of Great Salt Lake. In those areas the sands and gravels of the Quaternary and Tertiary are pinching out in a westwardly direction. At many places the sand pinchouts are known to occur in an up-dip direction. In addition to the presence of sand pinchouts, numerous channel-sand and beach deposits are known to exist. Along the east shore of Great Salt Lake, an area of shallow gas sands is known to occur west of a belt of artesian water wells (Eardley and Haas, 1936, p. 74).

Thick Quaternary and Tertiary sections, containing many sand beds, are known in Tooele Valley and in the Sevier Desert, so oil and gas possibilities could exist at numerous localities in the Great Basin of Utah. However, most of the petroliferous limestones of the Salt Lake group seem to be in northern Utah, and the peat beds in the Quaternary are found primarily adjacent to the Wasatch Range.

Since detritus and alluvium mask the underlying structure of Quaternary and Tertiary beds almost everywhere, gravity or seismic surveys would be necessary to determine the subsurface structure. With the location of a suitable structural situation in an area of favorable Cenozoic stratigraphic conditions, oil or gas production could possibly be established within the Great Basin of Utah.

CITED REFERENCES

- Adamson, R. D., Hardy, C. T., and Williams, J. S., 1955, Tertiary rock of Cache Valley, Utah and Idaho: Utah Geol. Soc. Guidebook, no. 10, p. 1-22.
- Christiansen, F. W., 1951, A summary of the structure and stratigraphy of the Canyon Range: Intermountain Assoc. Petroleum Geologists Guidebook, no. 6, p. 19-25.
- Eardley, A. J., 1944, Geology of the north-central Wasatch Mountains, Utah: Geol. Soc. America, v. 55, p. 819-894.
- _____, 1955, Tertiary history of north-central Utah: Utah Geol. Soc. Guidebook, no. 10, p. 37-44.
- _____, 1959, Review of Geology of northeastern Utah and southwestern Wyoming: Intermountain Assoc. Petroleum Geologists Guidebook, 10th Ann. Field Conf., p. 166-171.
- Eardley, A. J., and Haas, Merrill, 1936, Oil and gas possibilities in the Great Salt Lake Basin: Utah Acad. Sci., Arts, and Letters Proc., v. 13, p. 61-80.
- Harris, H. D., 1959, Late Mesozoic positive area in western Utah: Am. Assoc. Petroleum Geologists Bull., v. 43, p. 2636-2652.
- Heylman, E. B., 1958, Great Basin, giant sleeper of the West: Oil and Gas Jour., v. 56, no. 49, p. 138-141.
- _____, 1959, The ancestral Rocky Mountain system in northern Utah: Intermountain Assoc. Petroleum Geologists Guidebook, 10th Ann. Field Conf., p. 172-174.
- Jones, D. J., and Marsell, R. E., 1955, Pleistocene sediments of lower Jordan Valley, Utah: Utah Geol. Soc. Guidebook, no. 10, p. 85-112.
- Lee, W. T., 1908, Water resources of Beaver Valley, Utah: U.S. Geol. Survey Water Supply Paper 217, 57 p.
- Mapel, W. J., and Hall, W. J., 1956, Tertiary stratigraphy of the Goose Creek district, Cassia County, Idaho, and adjacent parts of Utah and Nevada: Utah Geol. Soc. Guidebook, no. 11, p. 1-16.
- Nolan, T. B., 1935, The Gold Hill mining district, Utah: U.S. Geol. Survey Prof. Paper 177, 168 p.
- Peace, F. S., 1956, History of exploration for oil and gas in Box Elder County, Utah and vicinity: Utah Geol. Soc. Guidebook, no. 11, p. 17-31.
- Richardson, G. B., 1905, Natural gas near Salt Lake City: U.S. Geol. Survey Bull. 260, p. 480-483.
- Schreiber, J. F., 1954, Tertiary well logs in the Salt Lake desert: Utah Geol. and Mineralog. Survey RS 39, 11 p.
- Slentz, L. W., 1955, Salt Lake group in lower Jordan Valley, Utah: Utah Geol. Soc. Guidebook, no. 10, p. 23-44.
- Slentz, L. W., and Eardley, A. J., 1956, Geology of Rozel Hills: Utah Geol. Soc. Guidebook, no. 11, p. 32-40.
- Steele, Grant, 1959, Basin and Range structure reflects Paleozoic tectonics and sedimentation (abs.): Am. Assoc. Petroleum Geologists Bull., v. 43, p. 1105.
- Van Houten, F. B., 1956, Reconnaissance of Cenozoic sedimentary rocks of Nevada: Am. Assoc. Petroleum Geologists Bull., v. 40, p. 2801-2825.
- Winfrey, W. M., Jr., 1958, Stratigraphy, correlation and oil potential of the Sheep Pass formation, east-central Nevada: Geol. Records, Rocky Mountain Sec., Am. Assoc. Petroleum Geologists, Petroleum Information, p. 77-82.

Paper 27 GEOLOGY AND OIL POSSIBILITIES OF WASHINGTON COUNTY

by Earl F. Cook¹

OUTLINE OF GEOLOGIC RELATIONS

A sequence of sedimentary rocks, almost 20,000 feet thick, overlying Precambrian rocks and overlain by 6,000 feet of volcanics, mark a long period of marine and continental deposition, with intermittent emergence and erosion, but without folding.

In the Late Jurassic or Early Cretaceous, the region was moderately warped, and Upper Jurassic rocks were beveled by erosion. Geosynclinal or foreland trough sedimentation began in the early Late Cretaceous with deposition of a basal conglomerate, followed by a thick accumulation of shale and sandstone. This type of deposition was interrupted once by uplift at about the end of Colorado time. Renewed sedimentation, recording an orogenic pulsation to the west, began, probably in Montana time, with the spreading of the basal conglomerate of the Kaiparowits formation.

The area was then uplifted during the Late Cretaceous, and at least three folds (one of them the Virgin-Kanarra anticline) developed along northeast axes, became overturned toward the east, and locally broke into thrusts of small displacement. The lack of evidence for orogenic movement within either Upper Cretaceous rocks or the overlying Claron formation closely brackets this main Laramide movement as being after the deposition of the Kaiparowits but preceding the deposition of the Claron. The age of the basal Claron is still uncertain.

After erosion of the Laramide folds, renewed uplift spread basal Claron conglomerate eastward. Following the deposition of lacustrine limestones and sandstones of the Claron, a short interval of local crustal disturbance and preliminary explosive volcanism was the prologue to a series of great eruptions which formed ignimbrites, lavas, mud flows, and breccias.

Following the volcanics the Pine Valley laccolith, some 3,000 feet thick, spread between them and the underlying Claron. The Stoddard laccolith intruded Upper Cretaceous rocks, and laccoliths at Iron Springs intruded the Jurassic Carmel. Unconformities within the volcanics, some marked by lacustrine limestone and quartzite gravels, suggest orogenic disturbances or periods of intrusive folding. During or following the intrusions an asymmetric anticline, produced by compression or magma withdrawal, formed in the Hurricane fault zone on the flank of one of the Laramide folds.

The following comments are in addition to Table XVII, an index to the stratigraphy of Washington County (see also Cook, 1960b, and Utah Geological Survey Map 14).

1. Director, Idaho Bureau of Mines and Geology, Moscow, Idaho;
Dean, College of Mines, University of Idaho, Moscow, Idaho.

Table XVII. Index to Stratigraphy of Washington County.

AGE		UNIT		THICKNESS (FEET)		
QUATERNARY	<u>Recent</u>	Silt, sand, gravel		0-200		
	<u>Pleistocene</u>	CULBERT BRECCIA		0-150		
QUATERNARY AND TERTIARY (?)	<u>Late Tertiary (?) to Recent</u>	Basalt		0-900		
	<u>Late Tertiary or Pleistocene</u>	Dacite		500+		
TERTIARY	<u>Pliocene and Pleistocene (?)</u>	MUDDY CREEK FORMATION		FLATTOP MOUNTAIN SUITE	0-1400	0-1200
	18MY	OX VALLEY TUFF			0-400	
		COVE MOUNTAIN FORMATION		KANE POINT TUFF	0-2200	300+
				PINE VALLEY LATITE		
				MAPLE RIDGE PORPHYRY	IRON TOWN MEMBER	
	SHOAL CREEK BRECCIA		0-200	0-300		
	22MY	RENCHER FORMATION			0-1000	
	27MY	QUICHAPA FORMATION			0-1800±	
		ISON FORMATION			0-170	
		CLARON (WASATCH) FORMATION			0-1500±	
	UPPER CRETACEOUS	KAIPAROWITS FORMATION			0-1200	
STRAIGHT CLIFFS AND MAHWEEP SANDSTONES			0-1800			

AGE	UNIT	THICKNESS (FEET)
UPPER CRETACEOUS	TROPIC FORMATION	0-1000
	DAKOTA(?) SANDSTONE	0-108
UPPER JURASSIC	WINSON FORMATION	0-188
	CURTIS FORMATION	0-60
	ENTRADA SANDSTONE	0-250
UPPER AND MIDDLE JURASSIC	CARMEL FORMATION	0-675
JURASSIC AND JURASSIC (?)	NAVAJO SANDSTONE	1800-2200
JURASSIC (?)	KATENTA FORMATION	640-740
TRIASSIC (?)	MOHAVE FORMATION	455-475
UPPER TRIASSIC	CHINLE FORMATION	385±
	SHINARUMP CONGLOMERATE	75-185
MIDDLE (?) AND LOWER TRIASSIC	MOENKOPF FORMATION	1545-2115
LOWER PERMIAN	KAINAB LIMESTONE	800-1050
	SUPAI-COCONINO SANDSTONE	1785-1850
PENNSYLVANIAN	CALLVILLE LIMESTONE	1496-1620
MISSISSIPPIAN	REDWALL LIMESTONE	1120±
DEVONIAN AND ORDOVICIAN (?)	Limestone and dolomite	2100±
CAMBRIAN	PIOCHE SHALE	215
	PROSPECT MOUNTAIN QUARTZITE	533
ARCHEAN	VISHNU SCHIST(?)	2000+

PRECAMBRIAN

Vishnu schist (?) ... gneiss, schist, and granitic rocks crop out along the southwestern foothills of the Beaver Dam Mountains.

CAMBRIAN

Prospect Mountain quartzite ... red-brown metaquartzite outcrops in the Beaver Dam Mountains ... roughly equivalent to the Tintic quartzite of central and northern Utah.

Pioche shale ... reddish brown to green micaceous shale in the Beaver Dam mountains ... grades downward into Prospect Mountain quartzite and upward into Cambrian limestones.

Cambrian limestones--undifferentiated.

ORDOVICIAN (?) - SILURIAN (absent ?) - DEVONIAN

Limestones, interbedded with dolomites, occur in the western part of the Beaver Dam Mountains. Poorly identified rocks which may be either Cambrian or Ordovician, or both, are quite certainly represented, and McNair (1952, p. 46) indicates that Ordovician (?) is overlain by Devonian Muddy Peak limestone.

MISSISSIPPIAN

Redwall (Rogers Spring, Monte Cristo, Madison Lower Mississippian) limestone ... grey, dense, hard, cherty, cliff-forming ... light to dark, medium to fine grained. Campbell (1952) lists 559 feet in the St. George No. 1 well of the California Company and approximately 1,000 feet in the Beaver Dam Mountains have been ascribed to this formation.

Blue Point (Brazier, Upper Mississippian) limestone. Campbell (1952) lists 210 feet of cherty limestone in the St. George No. 1 well. This interval may have been included in the upper part of the Redwall in the Beaver Dam Mountains.

PENNSYLVANIAN

Callville limestone ... thin-bedded. In the Beaver Dam Mountains the basal 530 feet is cherty limestone. Above this is 500 feet of tan to light-grey dolomite, overlain by 530 feet of fine-grained limestone containing abundant thin beds of sandstone that were formerly mapped as Callville, but which may be of Permian Pakoon age (McNair, 1952, p. 46).

PERMIAN

Pakoon (Bird Spring, Upper Callville) limestone ... In addition to rocks assigned to the Pakoon in the Beaver Dam Mountains (McNair, 1952, p. 46), 830 feet of Pakoon limestone occurs in the St. George No. 1 well. (Campbell, 1952, p. 88).

Supai-Coconino (Queantoweap) sandstone ... massive, fine grained, light colored, cross-bedded sandstones with small uniformly distributed spots of iron oxide ... occurs in the Beaver Dam Mountains, in the St. George No. 1 well (five miles south of St. George) and along the Hurricane fault scarp.

Toroweap formation ... red and yellow mudstone (McKee, 1952) overlain by a thick-bedded, cliff-forming marine limestone, which is overlain by red beds ... limestone member thickens northwestward towards southwestern Utah and where red beds are absent the unit is often mapped as a part of the overlying Kaibab limestone.

Kaibab limestone ... massive, hard, cherty, fossiliferous, gray limestone in two thick beds separated by 150 feet of gypsum-anhydrite.

TRIASSIC

Moenkopi formation ... six subdivisions: Timpoweap impure limestone and conglomerate, lower red gypsiferous shale, Virgin limestone, middle red gypsiferous shale, Shnabkaib sandy shale and gypsum, upper red gypsiferous and arenaceous shale.

Shinarump cong. ... Mapped separately because of economic and stratigraphic significance, but considered basal Chinle. Fine to coarse, gray to purple sandstone, conglomeratic in lower part. Grades upward into typical Chinle. Contains silicified wood.

Chinle fm. ... variegated, sandy, conglomeratic shale and fine calcareous sandstone (Painted Desert and Petrified Forest in Arizona).

TRIASSIC OR JURASSIC

Moenave ... the lowermost member of the Glen Canyon group replaces some of what has hitherto been called Chinle and Wingate. It includes two members: the lower, the Dinosaur Canyon sandstone and siltstone and the upper, the ledge-forming Springdale sandstone which contains the Silver Reef bed (Averitt, 1962). (Wingate) ... beds formerly assigned to the Wingate in this area are now considered Moenave.

Kayenta ... red-brown sandstone and mudstone intercalated with light grey siltstone. An early or middle Jurassic dinosaur from the basal portion of the Kayenta indicates Jurassic age (Welles, 1954, p. 597), but Triassic-like Tritiodontoids found 10 feet below the base of the Navajo 7 miles northeast of Kayenta, Arizona (Harshbarger, et al., 1957, p. 10) leave the age in doubt.

JURASSIC

Navajo ... cross-bedded quartz sandstone, forming massive cliffs. Color predominantly red, although upper part in places, notably in Zion Park, is white. Fossils found are not diagnostic.

Carmel (upper and middle Jurassic): Platy, argillaceous grey limestone; grey and brown arenaceous limestone; soft red sandstone, gypsiferous shale, and gypsum.

Entrada (upper Jurassic) ... friable red-chocolate and greenish-white sandstone overlies the Carmel and occurs as a narrow band of soft rocks on both sides of the Pine Valley Mountains.

Curtis ... basal gypsum overlain by calcareous sandstone and limestone conglomerate east of the Hurricane fault where it overlies the Carmel.

Winsor ... evenly bedded, thinly laminated, fine-grained red and white sandstone. East of the Hurricane fault it overlies the Curtis and is considered to be the youngest of the Jurassic formations.

LOWER CRETACEOUS ... absent (?) ... may be represented by part of Winsor.

UPPER CRETACEOUS

Dakota (?) sandstone ... poorly sorted pebble conglomerate with sandstone lenses. Contains quartzite, chert, and black limestone pebbles. Essentially a basal conglomerate of the Tropic formation, it is probably Colorado in age. East of the Pine Valley Mountains, it unconformably overlies the Entrada, and in places the Carmel, and grades upward through an 800-foot section into the Tropic shale.

Tropic shale ... alternating silty gray shales and thin, grey, yellow-brown, red, and black sandstones with some coal beds. Becomes more arenaceous westward. Roughly equivalent to Mancos shale of east central Utah.

Straight Cliffs and Wahweap sandstones ... sandy, blue-grey shale and lignite alternating with massive, cross-bedded buff sandstone in beds 5-80 feet thick. Richardson (1927, p. 467-8) concludes that this and the Tropic shale are Colorado in age, whereas the Kaiparowits is Montana in age.

Kaiparowits formation ... thin-bedded, lenticular, friable light-grey to buff sandstone, fine-to-medium grained, with silty red shale and quartzite cobble conglomerate at base; highly cross-bedded; numerous iron concretions.

TERTIARY

Claron (Wasatch) formation ... lower conglomerate member, which in area northwest of Gunlock comprises entire formation, is a cobble to boulder conglomerate; medial siltstone member includes some pink limestone and black limestone pebble conglomerate; upper grey massive lacustrine limestone member includes interbedded pink to green hornblende-biotite quartz latite crystal tuff (Needle Range Tuff).

Tertiary volcanics ... For a discussion of the identifying characteristics of the individual formations within this group, see Cook, 1960a, and Table XVII in this volume.

PLIOCENE (?)

Muddy Creek formation ... fine light colored locally tuffaceous sedimentary rocks.

Flat Top Mountain suite ... rhyolitic flows and shallow intrusive bodies.

PLEISTOCENE TO RECENT

Basalt cinder cones and decite flows.

Culbert breccia ... mudflows

RECENT

Silt, sand, gravel - alluvium and hillwash.

TECTONIC STRUCTURES

In Southwest Utah the structural transition from Plateau structure on the east to basin-range structure on the west is accomplished within a fault block west of the Hurricane fault.

The western part of the Colorado Plateau province is a group of high plateaus, cut in flat-lying sedimentary rocks, which descend in great steps toward the south. These plateaus are cut by a few, long, northerly-trending faults that determine the major features of the topography and follow the lines of older monoclines that dip east.

The eastern part of the Basin and Range province appears to be characterized by thrust faults and steeply-tilted fault blocks. The transition zone differs from the Basin and Range province. Apparently it had no post-Laramide thrusting, and folding and tilting are moderate. On the other hand, the transition zone contains asymmetrical and overturned and thrust-faulted Laramide anticlines, which the Plateau province lacks.

Two structural trends intersect in the transition area. The first, marked by a well-defined set of northeasterly aligned intrusions, folds, and faults, developed during the Laramide orogeny between the old foreland to the east and the geosyncline to the west. The second, developed during the Tertiary, is expressed by north-south faults. Later movements have followed both trends: the Hurricane fault follows a Laramide anticline for part of its length, then follows the Tertiary trend southward into Arizona (Figure 97).

The Hurricane fault is marked by a high, west-facing escarpment known as the Hurricane Ledge or Cliffs. North of Anderson Ranch where the scarp is over 1,500 feet high, exposed Permian and Triassic beds in the upthrown block dip steeply eastward away from the scarp, then flatten in the valley of LaVerkin Creek, east of which the beds are horizontal. Along part of the ledge, Permo-Triassic strata have been dragged into an asymmetrical anticline. Northward, the east dip of the beds forming the back slope of the ledge continues to increase, until, in the vicinity of Kanarrville, about 10 miles northeast of New Harmony, these beds are overturned. Gregory and Williams (1947) regarded these east-dipping strata in the Hurricane Cliffs as the east flank of an asymmetrical, locally overturned Laramide anticline ancestral to the Hurricane fault which they called the Kanarra fold (Figure 98).

The rocks of the downthrown side, concealed in most places along the fault trace by alluvium and hill wash, are exposed in a hill west of Toquerville and a few miles south of Toquerville in the banks of the Virgin River where it crosses the fault (where outcrops dip steeply westward away from the fault). In both localities, as well as near the base of the ledge east of Pintura, exposed fault planes dip 60° - 75° west.

Tertiary folding produced a broad anticline west of the Hurricane scarp and may even have reversed the dip of the truncated Mesozoic strata in the west limb of the Laramide Kanarra fold. A portion of the Kanarra fold probably broke into a reverse or thrust fault. The Kanarra fold was planed off by erosion before deposition of the Claron formation. At least the lower ignimbrite of the Quichapa formation was laid down across the Kanarra fold before normal movement on the Hurricane fault began. The first major displacement in the Hurricane zone occurred later than the formation of the Oligo-Miocene volcanics, possibly during the period of platy latite extrusion and laccolithic intrusion in the Pine Valley Mountains.

Following the first major episode of mid-Tertiary (?) faulting, the area was eroded to low relief; a low scarp remained on the resistant Kaibab limestone of the upthrown eastern block, and boulder alluvium spread from the Pine Valley Mountains to the base of the scarp. Basalt, contained on the west by the foothills of the Pine Valley Mountains, overflowed the Kaibab scarp in a few places. Then, in the Quaternary period, came the second period of major faulting; the basalt was broken and the eastern segments were raised 1,500 feet. The Quaternary faulting is normal, like the displacement of smaller faults which parallel the Hurricane in the plateau country to the east.

The Hurricane fault displacement is difficult to estimate. At three localities in Washington County, rocks of the downthrown block can be seen in contact with the fault. In each of these, rocks of the Moenkopi formation dip steeply west, parallel the dip of the fault plane, and rest against Kaibab limestone on the upthrown side. The stratigraphic separation can most accurately be estimated in Toquerville Hill, where the Shinarump conglomerate, exposed on both sides, indicates a throw of about 2,500 feet. In the Pintura area the shift, much greater than the slip, is estimated at about 10,000 feet; whereas the slip, practically impossible to estimate because the wall-rocks parallel the fault plane, is certainly less than half this.

The Pine Valley laccolith rests in a broad, shallow, northeast-plunging syncline which may have started as a Laramide downwarp that was further depressed during the intrusion of the laccolith.

*Some
Structural Features
of
UTAH'S DIXIE*

EXPLANATION

-  Laccolithic intrusive body
- ① Grafton dome
- ② Virgin oil field
- ③ Pintura structure
- ④ Harrisburg dome
- ⑤ Washington dome
- ⑥ Punch Bowl dome
- ⑦ Bloomington dome
- ⑧ Beehive dome
- ⑨ White Butte dome

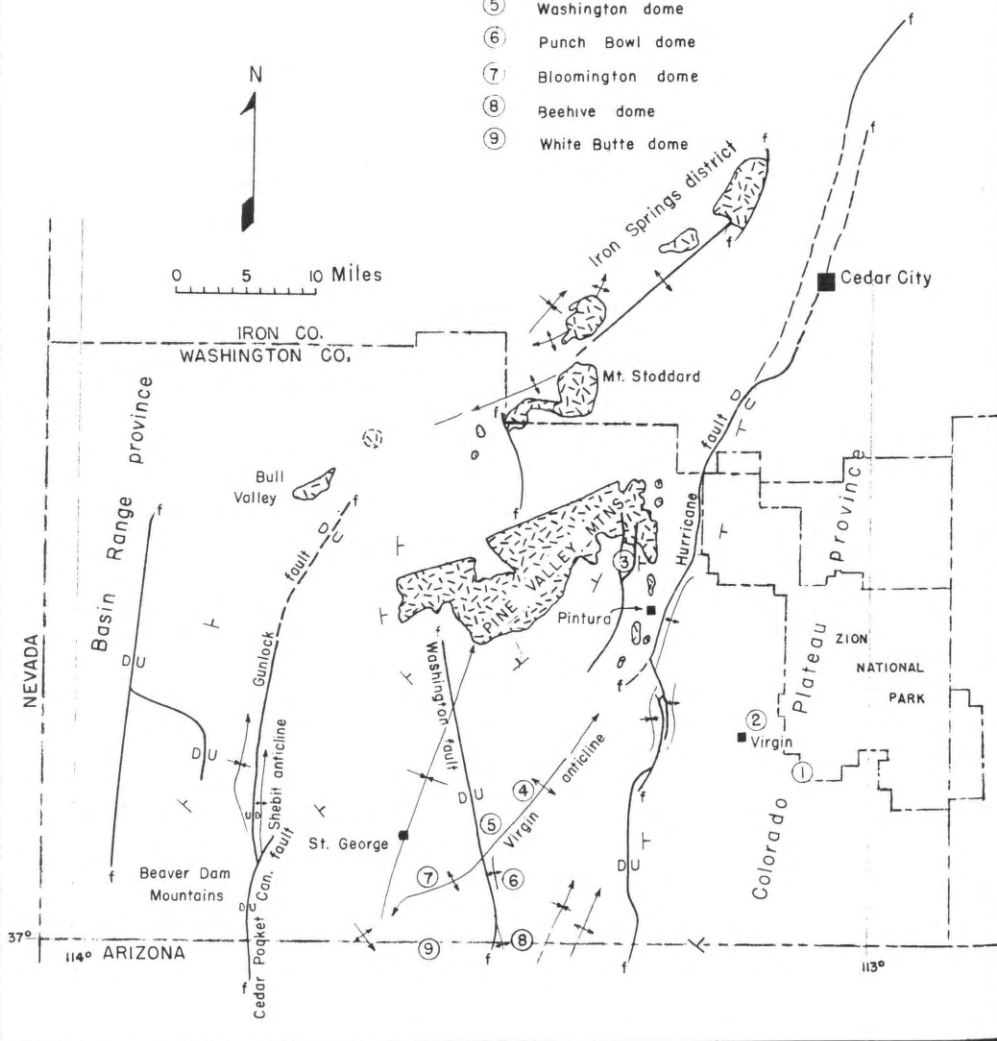


Figure 97.

In the area north of the Pine Valley Mountains, the Upper Cretaceous rocks, the Claron formation, and the Leach tuff thin toward a northeast line that bisects the outcrop of the Stoddard laccolith. This line probably represents an extension of the Iron Springs Gap anticline, a Laramide fold in the Iron Springs district which was beveled by pre-Claron erosion, as was the Kanarra fold. Evidence in the Iron Springs district suggests slight renewed arching in post-Claron time (Mackin, 1947, p. 12).

The western margin of the transition block is defined by a set of en echelon subparallel faults, along which the Basin and Range country of the west has subsided. The main member of this set is the Gunlock fault. Northward, the Veyo fault, which starts within the uplifted block, becomes the dominant and marginal fault. Southward, the Gunlock fault is replaced by the Shebit (also spelled Shivwits) fault, along which displacement is reversed. In the latitude of the Shebit fault, the transition zone is widened by the inclusion of the Beaver Dam Mountains, and the west marginal fault is the Beaver Dam Wash fault. Two north-plunging folds, the Shebit syncline and the Shebit anticline, are spatially and genetically associated with the zone of displacement reversal at and near the juncture of the Gunlock and Shebit faults.

The Virgin anticline (Figure 98), a Laramide structure 20 miles long, extends from a point near the "corner" north of Toquerville, where the Hurricane fault abruptly changes direction, southwest to a point south of St. George. Three doubly-plunging portions of the Virgin anticline are known as the Harrisburg, Washington, and Bloomington domes. Just southwest of Washington dome the Virgin anticline is crossed and displaced by the Washington fault, which trends north-northwest and has its down thrown side on the west.

Three other small folds in southern Washington County have been the object of oil exploration interest. One, the Punch Bowl dome, is about a mile south of the southwest end of the Washington dome and immediately east of the Washington fault. The other two are small, low domes: one, just north of the Arizona line south of St. George, is White Butte dome; the other, six miles east of the first, is Bee Hive Dome.

According to Wegemann and Bauer (1952) only at South Wash, about 1.5 miles south of Grafton and 11 miles east of the Hurricane fault, is the regular north-east dip of the rocks in the plateau portion of southwest Utah interrupted by anticlinal folding. Here a sharp, narrow anticline may be traced northward to the flat of the Virgin River and for a mile-and-a-half up Coalpits Wash, beyond which it gradually merges with the general dip. In Coalpits Wash, it is faulted along its crest. South of Grafton the beds dip westward from its crest into a shallow syncline, only a few feet in depth, which dies a short distance farther

STRUCTURAL RELATIONS OF INTRUSIVE ROCKS

Pine Valley Laccolith

Earlier authors have regarded the porphyritic body, 3,000 feet thick, which forms the main bulk of the Pine Valley Mountains as extrusive. Three lines of evidence demonstrate it is intrusive: (1) the absence of extrusive features; (2) the intrusive nature of the basal contact, and (3) the intrusive fault character of the lateral contact of the body. No structural or lithologic evidence of separate



Figure 98. The northeast-plunging Virgin anticline, looking northeast. Note the "corner" in the right middle distance where the projection of the Laramide anticlinal fold is cut obliquely by the later north-south Hurricane fault, the trace of which is marked by the low saddle in the middle distance. The highlands (Kolob Plateau) in the upper right are east of the Hurricane fault. (Photograph by J. R. Shelton and R. C. Frampton.)

extrusions or intrusions is recognized. Evidence of an erosion surface beneath the porphyry, which might be expected had the rock been emplaced as a single thick flow, is absent. In general, the basal contact follows one horizon, but small intricately branching porphyritic apophyses reach into the limestone several inches away from the main contact. This irregularity, and the absence of glass, breccia, chalcedony, and erosion surface criteria, suggest that the contact is intrusive.

On the north and northwest, the Pine Valley laccolith is in intrusive fault contact with members of the volcanic sequence. The intrusive faults do not displace the underlying sediments; two places are known where the Claron formation passes unbroken and apparently unchanged in thickness from beneath the laccolith to beneath the volcanics.

Stoddard Laccolith

The Stoddard laccolith is marked by a dissected, dome-shaped mountain of nearly circular plan. Except for its southern margin, where it has apparently intruded the lower part of the volcanic sequence, the laccolith is in more or less concordant contact with sharply upturned and overturned shales and sandstones of the Upper Cretaceous Tropic formation. The base of the body is not visible; the laccolithic form is inferred from the generally concordant upper contact.

Core drilling in the anticlinal valley west of Stoddard Mountain has revealed monzonite porphyry of Stoddard type beneath rocks that resemble the Tropic formation at a depth less than 600 feet. This relation strongly suggests that the anticline is an intrusive structure overlying a westward extension of the Stoddard laccolith. The small and discordant Pinto Peak intrusive body on the south side of the anticlinal valley is probably connected at depth to the extended Stoddard laccolith. Pinto dome, also, probably overlies this same intrusive body and is itself an intrusive feature. Cores from drill holes show a sharp contact between the intrusive rock and the overlying sediments and a striking lack of change in either rock near the contact.

Structural relations of the laccoliths of the Iron Springs district have been described in detail by Mackin (1947a).

The intrusive masses of southwest Utah tend to follow stratigraphic horizons. The Three Peaks, Granite Mountain, and Iron Mountain laccoliths of the Iron Springs district all intruded along a single horizon in the Jurassic Carmel formation; the concordant contact of the Stoddard laccolith is near the base of the Upper Cretaceous section; and the Pine Valley laccolith moved in near the top of the Upper Cretaceous (?) - Eocene Claron formation.

EXPLORATION TARGETS

Virgin Oil Field

The following description of the Virgin oil field and its petroleum production and possibilities has been written by Edgar B. Heylman, consulting geologist of Salt Lake City:

"The Virgin field, first developed in 1907, is the oldest oil field in Utah. It is located about 1 1/2 miles northeast of the village of Virgin, immediately to the west of Zion National Park. The region is semi-arid and rich in stark desert beauty. Most of the oil production is from shallow wells located in the narrow valley of North Creek, which flows south and empties into the Virgin River. An imposing mesa, capped by the Triassic Shinarump conglomerate, rises to the north and northwest, while another mesa, capped by Quaternary basalt, rises to the east of the field. The Middle Red shale member of the Early Triassic Moenkopi formation forms most of the surface in the area of the Virgin Field, where the average elevation is around 3,625 feet. Oil seeps in the region prompted the first drilling (Figure 99).



Figure 99. Oil seep in the Timpoweap formation.

"The producing zone is a sandy to pure limestone that ranges between 1 and 8 feet in thickness at the top of the Timpoweap, or Rock Canyon, limestone member of the Moenkopi. The Timpoweap member ranges from 120 to 160 feet in thickness in the area of the field and unconformably overlies the petroliferous Kaibab limestone of Permian age. Both the Timpoweap and the Kaibab are noted for their vuggy porosities. The depth of the producing zone ranges between 475 and 750 feet, depending upon structural position and topography.

"About 140 wells have been drilled at the Virgin field and in the immediate vicinity, mostly to depths of less than 1,000 feet. Only 8 wells are reported to have penetrated below the Timpoweap member into the Kaibab limestone. Numerous oil shows have been encountered in the Kaibab, but there has been no production from it. The deepest test to date is the E. R. Bardwell No. 1 Venton, located in the NW 1/4 SW 1/4 of section 13, T-41-S, R-12-W (Heylman, 1961). It went

to a total depth of 4,538 feet in 1958, probably bottoming in the Redwall limestone of Mississippian age. Oil shows were encountered in several zones, the best being in limestones and sandstones of the Pakoon or Callville between 3,405 and 3,495 feet. These excellent shows were drill-stem tested, but the results of the testing did not offer any encouragement for commercial oil or gas production. The Bardwell test is the only well in the Virgin field that has penetrated the Pakoon and Callville formations.

"The cumulative production at the Virgin oil field is about 195,000 barrels. About 30 wells have been productive, and approximately 440 acres are proved. There are currently 3 wells in the field capable of producing about 10 barrels of oil per day. Two of the wells produce a small amount of dark brown paraffin-base oil with a gravity of 31° A.P.I. The third well, Hurricane Producing and Refining's No. 3-A, located in the NW 1/4, NW 1/4, SW 1/4 of section 13, T-41-S, R-12-W, is capable of producing about 8 barrels per day of sour, black asphalt-base oil with a gravity of 24° A.P.I. There is no immediate explanation for the occurrence of two types of oil. It is to be noted that a number of wells in the field encountered a zone of sulfur water in close proximity to the pay zone. A small topping plant, located in the field, is operated periodically; the oil is refined into fuel oil and diesel fuel, and the products are marketed locally. The Virgin field has been shut-in during 1962.

"A few wells reportedly initially produced in excess of 30 barrels per day, but most wells produced much less. The usual completion practice has been to set casing on top of the pay and then drill into the oil zone. Many of the wells have been shot with nitroglycerine or dynamite, and a few acidizing procedures have been employed.

"Structurally, the Virgin oil field lies in a small synclinal pocket near the axis of a broad, low-relief, anticlinal trend that plunges gently toward the north (Figure 100). Because of differences in the thickness of the Lower Red Shale member of the Moenkopi, the structural picture at Timpoweap depth does not correspond to the picture obtained by mapping on top of the Virgin limestone member.

"There are a number of oil seeps in the general area, and in all probability the Virgin field is a form of subsurface "oil seep." Being close to the surface, the reservoir pressures have been dissipated, and oil migration by gravity drainage into the structurally low "pockets" has been tempered to some extent by porosity and permeability changes within the producing formation, and by the local fracture patterns. Another factor that may have some bearing on the development of porosity and permeability is ground-water activity along the course of North Creek. Most of the oil production has been from wells in close proximity to the creek.

"Synclinal oil production is not uncommon, being well-known in the eastern United States and in California. The shallow Mexican Hat oil area in southeastern Utah is located in a syncline, and may be similar to the Virgin oil field. Additional shallow oil prospects may exist elsewhere in southwestern Utah, with similar structural and stratigraphic situations. It is unlikely that major oil reserves exist at the Virgin field. However, the deeper stratigraphic possibilities, particularly in the Pakoon formation and in the Mississippian Redwall limestone, must not be overlooked."

Virgin Anticline

Boshard (1952) summarized the history of exploration drilling on the Virgin anticline. The first test was on the Harrisburg dome, which has a possible closure of 900 feet; the well was begun in 1918 and after intermittent drilling reached a total depth of 3,400 feet. Dobbin reported the hole to have possibly bottomed in the upper part of the Pennsylvanian Callville limestone. No reliable shows of oil were reported. Harrisburg dome is about three miles long and three-fourths of a mile wide.

Bloomington dome, five miles south of St. George, is almost five miles long by two miles wide and has a closure of 1,100 feet. It has been the scene of eight wells, the last three of which were deep tests. The first went to a depth of 2,530 feet between 1927 and 1931, with no significant shows of oil. In 1931, a well was started and was completed after 1932 to a depth of 4,114 feet. It drilled into the Callville limestone and questionable oil shows were reported. In 1951, the California Company drilled a 6,347-foot test. Cores having pinpoint shows of oil were reported in this well. The thickness of the formations penetrated were published by Campbell (1952).

VIRGIN OIL FIELD

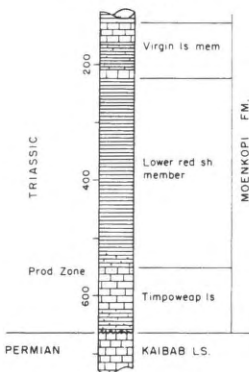
WASHINGTON CO., UT.

LEGEND

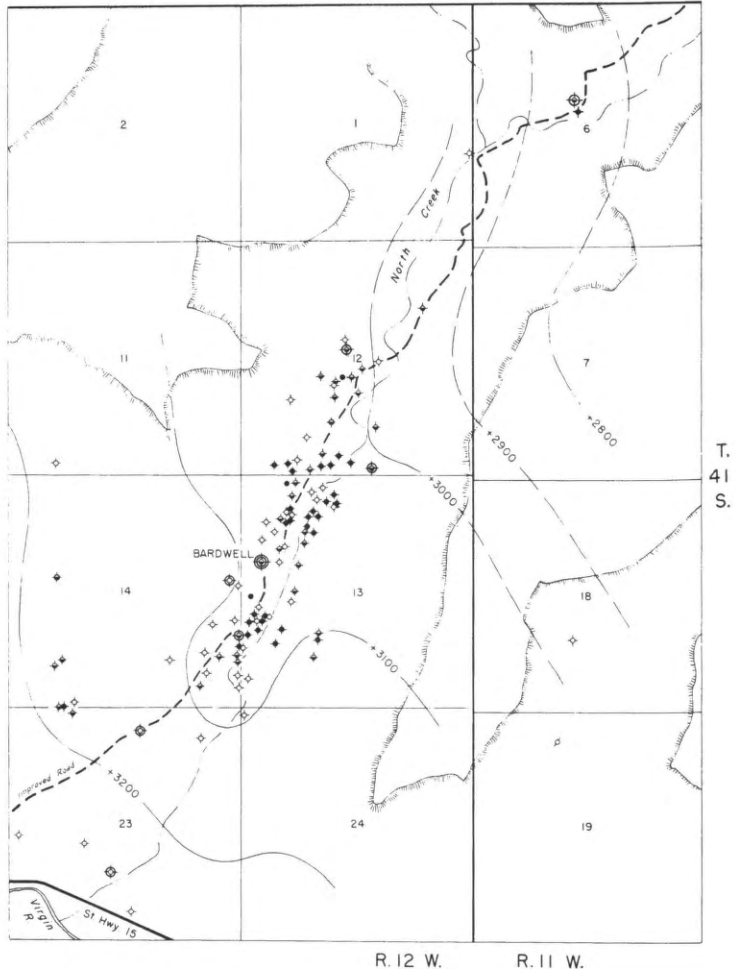
- Oil Well (Timpoweap member - Moenkopi fm.)
- ✦ Oil Well (Moenkopi) Abandoned
- ✦ Dry Hole (Moenkopi) Oil Show
- ✦ Dry Hole (Moenkopi)
- ✦ Dry Hole (Permian)
- ✦ Dry Hole (Mississippian) Oil Shows
- ◻ Inadequate Test

STRUCTURE CONTOURS ON TOP OF THE
TIMPOWEAP (ROCK CANYON) LS.

TYPICAL WELL LOG



BY E. B. HEYLMUN 1960



Punch Bowl, Bee Hive, White Butte, Pintura, and Shebit (Shivwits) Structures

A well on Punch Bowl dome, a symmetrical $3/4 \times 3/8$ mile structure, was drilled to a depth of 2,540 feet between 1929 and 1936. A complete section of Kaibab was penetrated, and the hole bottomed in sandstone of Permian age. According to Dobbin, three different shows of oil were reported in the sandstone section below a depth of 2,190 feet.

Two small surface anomalies, Bee Hive dome and White Butte dome, have had shallow wells which penetrated the productive horizon of the Virgin oil field. Neither reported oil shows.

The Pintura structure (Neighbor, 1952), drilled by Sun Oil Company to a total depth of 5,496 feet without encountering any shows of oil or gas, was mapped on the basis of a color break in the Navajo sandstone and is about three and one-quarter miles west of the Hurricane fault. It is a northwest-trending, slightly symmetrical anticline with a mapped closure of approximately 1,400 feet. A second well was drilled to a depth of 9,501 feet by Pan American Petroleum Corporation in 1961, bottoming in the Devonian. There were no important oil and gas shows.

Shebit (Shivwits) Anticline

The Shebit anticline is a north-plunging structure, parallel to the Shebit fault, and largely contained within the Shebit Indian Reservation about 11 miles west of St. George. Although the anticline has been the object of some exploration interest, it has not been drilled, probably because there is no surface closure. The Shebit anticline is truncated on the south by the Cedar Pocket Canyon fault. If this fault forms a seal, the Shebit anticline and the Cedar Pocket Canyon fault, together, constitute a large structural trap. The structure, which is expressed at the surface in beds of the Moenkopi formation, is about seven miles long. It is asymmetrical, with the steeper flank on the west against the Shebit fault.

FAVORABLE BEDS

The Mississippian Redwall or Rogers Spring limestone, though massive and lacking sandy zones which might serve as reservoirs, contains large coral festoons, and some of the limestone of the upper beds has a fetid odor when broken. Reef accumulation of oil in the Redwall is a possible exploration target.

The Callville limestone of southwest Utah, which as mapped may include some Permian Pakoon limestone at the top, is one of the most favorable formations in the column for oil because of its sandstone content. Only three wells in southwest Utah have passed through the Callville formation.

The only oil production in southwest Utah has come from a thin sandy to pure limestone in the Timpoweap (Rock Canyon) member of the Moenkopi formation in the Virgin oil field. This same member has been tested without success in other structures, including the nearby Grafton fold.

Although a composite thickness of 5,000 feet of Upper Cretaceous and Eocene sedimentary rocks includes fossiliferous marine shales, this portion of the stratigraphic column in southwest Utah has yet to be tested for oil because no favorable structure has been recognized in which these strata are involved. Known anticlines west of the Hurricane fault in which Cretaceous and Tertiary sedimentary beds are found are probably of intrusive origin.

MAKING USE OF A GEOLOGIC MASK

It has only lately been realized that the volcanic rocks of the Great Basin area which extend into southwestern Utah can be used structurally and stratigraphically; far from masking geologic relations, these rock units may be the only basis of determining structure in subjacent sedimentary rocks. Most of these volcanic rock units are ignimbrites, sheet-like pyroclastic deposits of probable nueé ardente origin. Overlapping ignimbrites have been studied by Cook (1958, 1960a) in eastern Nevada, and by Mackin (1960) in western Utah, in an area of about 50,000 square miles. Individual units have been traced more than 100 miles linearly; some of these units probably had an original extent of more than 5,000 square miles. Several measured sections exceed 2,000 feet in thickness and include more than a dozen ignimbrites. At least one unit is more than 1,000 feet thick, but the average thickness is about 200 feet.

Original horizontality, modified only by differential compaction, and the great extent of some individual units, make these ignimbrites and their stratigraphic relations useful in working out pre-volcanic geology and geography, contemporaneous deformation, and post-volcanic movements. Many of them, extensive and distinctive, can be correlated from range to range. In many of them, lateral lithologic variation is small, whereas the variety among units is great. Correlation criteria include the ratio between lithic, crystal, and vitric components; identifiable minerals and their proportions; vertical variations in degree of welding within units; and the presence and nature of planar and discoidal structures. Field relations indicate that each ignimbrite was deposited with a horizontal upper surface, modified only by differential compaction, subsequent erosion, and deformation. The extent of each ignimbrite was determined largely, if not entirely, by the basin or depression in which it formed. Although the more extensive and, consequently, the more useful of the Basin Range ignimbrites probably were formed within the Tertiary period and thus represent a relatively brief segment of geologic time, they document by their stratigraphic relations some of the major events in the tectonic history of the region.

Also, planar structures within ignimbrites which are parallel to the attitude of the unit may be used to determine strike and dip of the units, just as in sedimentary rocks. Tertiary volcanics in southwestern Utah rest disconformably on Tertiary sedimentary rocks; thus, if any of the Tertiary sedimentary rocks contain oil, it may be trapped by overlying volcanic rocks whose measurable attitudes will reveal the trapping structures. But caution is to be observed in distinguishing between tectonic and intrusive structures in the ignimbrites.

Dips in Paleozoic and Mesozoic rocks may have been caused by pre-Tertiary folding, by tilting during Tertiary block faulting, by Tertiary intrusion, or by a combination of these things. The study of the Tertiary volcanics serves to distinguish the relative effect of each of these phenomena.

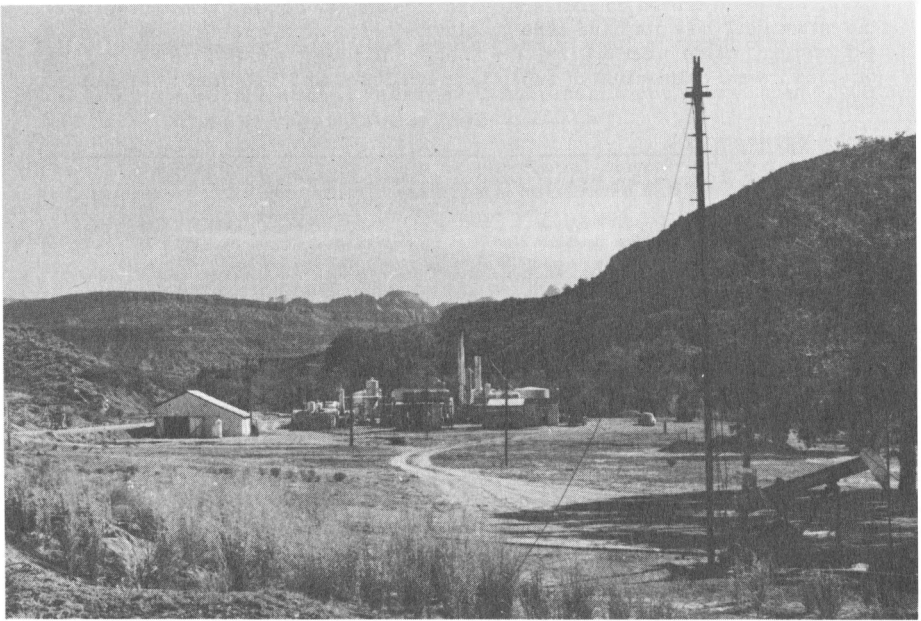
SUMMARY

Favorable source beds and reservoir rocks exist in the upper part of the Paleozoic and the lower part of the Mesozoic section in Washington County. Although oil has been produced from one small field, the value of the oil has not repaid the costs of exploring even that field. Drilling in other areas of southwest Utah has generally been discouraging, although oil shows have been encountered in some wells.

On the other hand, all exploratory drilling outside the Virgin oil field has been on surface structures which may be shallow and which may not reflect the structure at the depth of a favorable horizon. By analogy with a parallel anticline of the same age in the Iron Springs district, it seems clear that the Virgin anticline may be a décollement structure, formed by rumpling of an upper crustal sheet as it slid on a lubricating layer or layers. In the Virgin anticline, the gypsum layers in the Kaibab may have provided such slip surfaces. In that case, the wells drilled on Harrisburg and Bloomington domes, although tests of the structures, may not have been conclusive tests of favorable beds. Future exploration, aside from drilling the Shebit anticline, should, therefore, be directed toward delineation of subsurface structures and potential stratigraphic traps.

CITED REFERENCES

- Averitt, Paul, 1962, Geology and Coal Resources of the Cedar Mountain Quadrangle, Iron County, Utah: U.S. Geol. Survey Prof. Paper 389.
- Boshard, J. R., 1952, Summary of the history of exploratory drilling of Virgin anticline, Washington County, Utah: in Intermountain Assoc. Petroleum Geologists Guidebook, no. 7, p. 84-85.
- Campbell, G. S., 1952, Bloomington Dome, Washington County, Utah: Intermountain Assoc. Petroleum Geologists Guidebook, no. 7, p. 86-89.
- Cook, E. F., 1960a, Great Basin Ignimbrites: Intermountain Assoc. Petroleum Geologists Guidebook to the Geology of East Central Nevada, p. 134-141.
- _____, 1960b, Geologic Atlas of Utah-Washington County: Utah Geol. and Mineralog. Survey Bull. 70, 124 p.
- Dobbin, C. E., 1939, Geologic structure of the St. George district, Washington County, Utah: Am. Assoc. Petroleum Geologists Bull., v. 23, p. 121-144.
- Gregory, H. E., and Williams, N. C., 1947, Zion National Monument, Utah: Geol. Soc. America Bull., v. 58, p. 211-244.
- Harshbarger, J. W., Repenning, C. A., and Irwin, J. H., 1957, Stratigraphy of the Uppermost Triassic and the Jurassic rocks of the Navajo Country: U.S. Geol. Survey Prof. Paper 291.
- Heylman, E. B., 1961, Results of Deep Drilling in Southwestern Utah: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 2, p. 252-255.
- Mackin, J. H., 1960, Structural significance of Tertiary volcanic rocks in southwestern Utah: Am. Jour. Sci., v. 258, p. 81-131.
- McKee, E. D., 1952, Uppermost Paleozoic strata of northwestern Arizona and southwestern Utah: Utah Geol. Soc. Guidebook, no. 7, p. 52-55.
- McNair, A. H., 1952, Summary of the pre-Coconino stratigraphy of southwestern Utah, northwestern Arizona, and southeastern Nevada: Utah Geol. Soc. Guidebook, no. 7, p. 52-55.
- Richardson, G. B., 1909, The Harmony, Kolob, and Kanab coal fields, southern Utah: U.S. Geol. Survey Bull. 341, p. 379-400.
- Wegemann, C. H., and Bauer, C. M., 1952, Geology of Petroleum Reserve No. 7, Washington Co., Utah: Oil and Gas Possibilities of Utah, Utah Geol. and Mineralog. Survey, publishers.
- Welles, S. P., 1954, New Jurassic dinosaur from the Kayenta formation: Geol. Soc. Am. Bull., v. 65, no. 7, p. 591-8.



Virgin Oil Field, Washington County, Utah. Small refinery in middle distance (Photo by E. B. Heylmun).²

— C —

**THE TRANSITION ZONE
BETWEEN
THE GREAT BASIN
AND
THE CANYONLANDS**

INDEX TO SECTION C

<u>Paper</u>		<u>Page</u>
28	OIL AND GAS POSSIBILITIES OF THE MARKAGUNT AND KOLOB PLATEAUS, by Richard L. Threet _____	321
	Introduction _____	321
	General Geology _____	321
	Summary of Drilling Results _____	324
	Prospects for Future Exploration _____	325
	Cited References _____	326
29	OIL AND GAS POSSIBILITIES OF THE TRANSITION ZONE IN CENTRAL UTAH, by F. W. Christiansen _____	327
	Introduction _____	327
	General Geology _____	327
	Wasatch Mountain Area _____	329
	San Pitch-Sevier Arch _____	331
	Southern Volcanic Area _____	335
	Cited References _____	338

Paper 28 OIL AND GAS POSSIBILITIES OF THE MARKAGUNT AND KOLOB PLATEAUS

by Richard L. Threet¹

INTRODUCTION

Between U. S. Highways 89 and 91, from the northern boundary of Iron and Garfield Counties to the southern border of Utah (except eastern Washington County), there lies an area of over one million acres which has been tested for oil and gas by only three closely-spaced holes in western Kane County. Past insignificant interest in the Markagunt and Kolob Plateaus, as well as portions of the Wygaret Terrace in the southeastern corner of the area, is due to: (1) remoteness of markets, pipelines, and railroads; (2) concealment of Paleozoic formations, even in immediately surrounding areas, and sparse subsurface control for evaluation of specific objectives; (3) lack of demonstrable evidence of Paleozoic basinal conditions conducive to large hydrocarbon accumulation; (4) extensive erosion of up-dip portions of Mesozoic and early Tertiary strata in an area of high relief, resulting in generally unfavorable hydrologic conditions in those objectives, (5) widespread Cenozoic faulting and volcanic activity, especially in the western and northern portions of the area, complicating the entire geologic picture and suggesting escape possibilities for oil and gas.

With such an outlook, most operators have moved very cautiously and conservatively in exploration of the area. Until 1960, the Markagunt-Kolob area had remained an exploration no-man's land. The Markagunt-Kolob area is about the only Utah region not yet covered by a field trip and guidebook by either the Utah Geological Society or the Intermountain Association of Petroleum Geologists, thus re-emphasizing the lack of general knowledge of the area. Only a narrow strip along the east edge of the area was included by Heylman (1958) in his evaluation of oil and gas possibilities of a large part of southern Utah.

GENERAL GEOLOGY

Most published Markagunt-Kolob Plateau information is from the commendable pioneering work by H. E. Gregory and his colleagues. Under a 1954-55 research grant from the National Science Foundation, the present writer extended Gregory's reconnaissance mapping on the north end of the Markagunt Plateau (Threet, 1956) and studied the geology of the Cedar City area in detail. The simplified geologic map which accompanies this paper (Figure 101) incorporates the NSF work and some modification of Gregory's maps for the Markagunt-Kolob area.

Except for the strongly faulted western margin of the Markagunt Plateau from Cedar City to the vicinity of Parowan, the geology of the area is rather simple--a great block of concordant Paleozoic, Mesozoic, and early Tertiary strata, capped by early Tertiary ignimbrites and agglomerates, bounded by the Hurricane and Sevier Faults and tilted gently northeastward, eroded deeply around the southern and western edges, and covered locally by geologically recent basaltic lavas. Along the southwestern margin of the area, an eastward-facing late Cretaceous monocline had been truncated and covered discordantly by early Tertiary sediments.

1. Department of Geology, San Diego State College, San Diego, California;

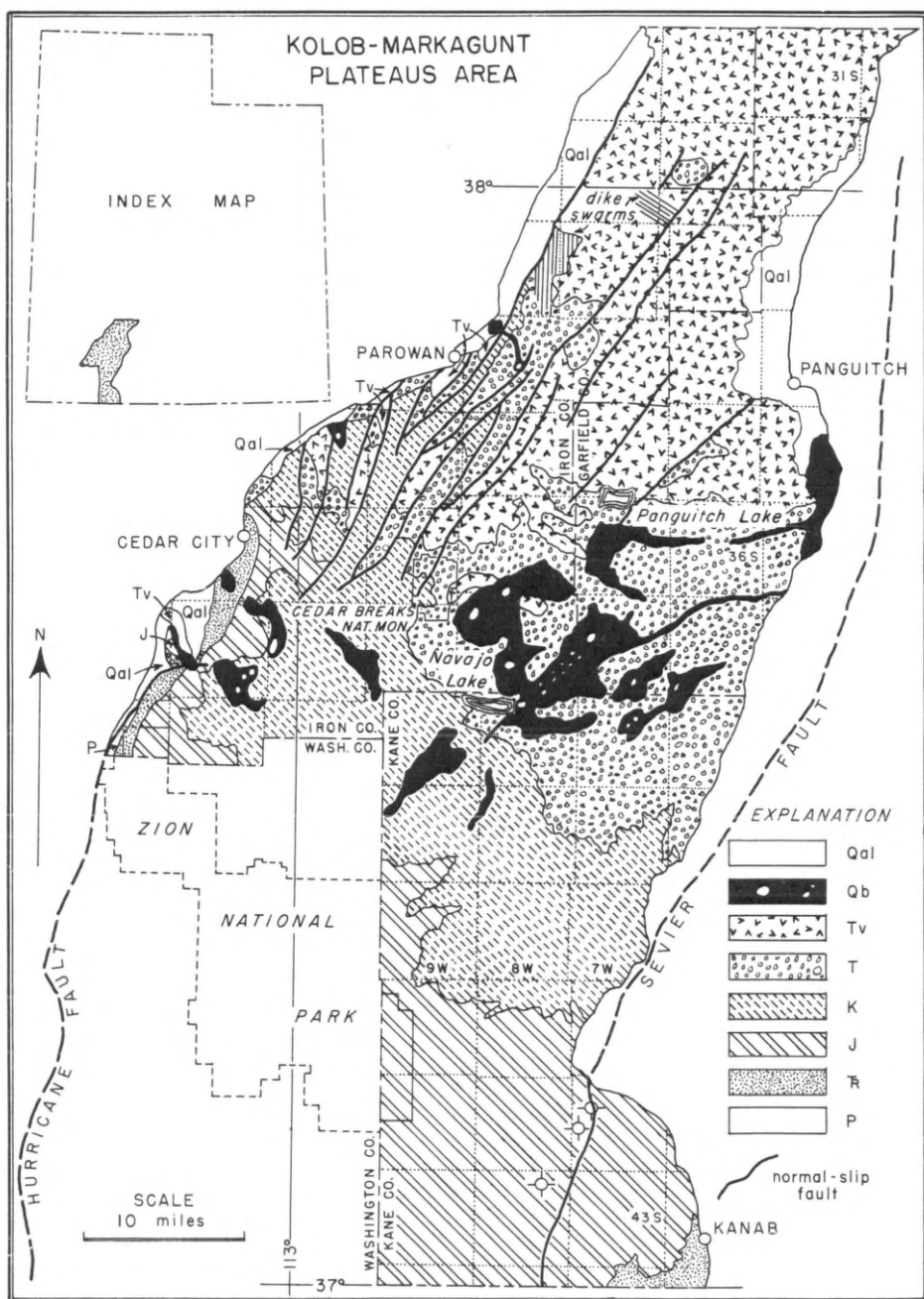


Figure 101. Simplified geologic map of the Kolob-Markagunt Plateaus area with adjacent portions of Iron, Garfield, and Kane Counties, bounded by U. S. Highway 91 through Parowan and Cedar City and U. S. Highway 89 through Panguitch and Kanab. Qal—alluvium of Sevier and Cedar City Valleys; Qb—geologically recent basaltic lava flows and cinder cones; Tv—Eo-Oligocene ignimbrites, lava flows and agglomerates of acidic to intermediate composition; T—Eocene fluvial, lacustrine, and pyroclastic sediments of the "Wasatch" and "Brian Head" formations; K—Cretaceous sandstones and shales; J—Upper Jurassic limestones, sandstones, and evaporites of the Carmel, Entrada, Curtis, and Winsor formations, lying on continental sandstones of the Moenave, Kayenta, and Navajo formations; Tr—Triassic red beds of the Chinle, Shinarump, and Moenkopi formations; P—Paleocene rocks, with only the upper part of the Permian Kaibab limestone exposed in the markagunt-Kolob area.

and volcanics, only to be exhumed when streams dissected the westward-facing Hurricane Fault scarp in late Cenozoic time (Gregory and Williams, 1947). Northward from Cedar City the Hurricane Fault is replaced by several faults en echelon that splinter a northwestward-facing mid-Cenozoic monocline which obliquely unfolded the eastward-facing Laramide monocline. The details of plateau margin geology between Cedar City and Parowan will be described in a forthcoming paper by the writer.

The following notes on stratigraphic units may be helpful in evaluating exploration prospects in the Markagunt-Kolob area:

Qal -- geologically recent basin alluvium (probably resting on Mio-Pliocene basin fills of variable thickness) as much as several hundred to a few thousand feet thick adjacent to Hurricane Cliffs in Cedar City Valley and related fault scarps in Parowan Valley (Thomas and Taylor, 1946); probably not more than a few tens to a few hundred feet thick in Sevier Valley, where late Cenozoic Sevier River formation is chiefly pediment gravels across early Tertiary sediments and volcanics in the vicinity of Panguitch.

Qb -- geologically recent basaltic lava flows and cinder cones (one conspicuous group of small cones aligned along a major fissure running northeastward from Navajo Lake) only locally extensive and rarely more than a few tens of feet thick; very fresh flows and cones lie on a low-relief karst landscape of early Tertiary limestone in the southern Markagunt Plateau, with abundant tubes and caverns which might cause drilling difficulties without proper casing program; somewhat older basaltic flows lie on stripped benches of Kolob Plateau, with considerable erosional destruction of cones and inversion of relief on flows.

Tv -- Eocene-Oligocene ignimbrites, flows, and agglomerates concordant with underlying "Wasatch" and "Brian Head" formations (Threet, 1952, 1956); widespread andesite lava and rhyolite welded tuff at base of volcanic sequence total about 500 feet in thickness; because of deep erosion of up-dip edges and depositional variations in thickness of agglomerates of flow breccias, upper part of volcanic sequence may range up to a few thousand feet in thickness in the area north and northwest of Panguitch (average thickness probably less than 1,000 feet). Stratigraphically, these early Tertiary volcanic units are almost as simple as the concordantly underlying sedimentary formations; they pre-date the major faulting in the High Plateaus; and they have no close relationship with the Qb flows, from which they are separated by a profound unconformity. Except for lamprophyre dike swarms which fed various parts of the Tv volcanic sequence in the northern part of the area, intrusive bodies are small and rarely found; the small dome which exposes the early Tertiary sediments in the north end of the area, at the summit of Utah State Highway 20 across Bear Valley, probably is due to a deep-seated plug or laccolith.

T -- Eocene or Paleocene fluvial sandstones and marlstones of the "Wasatch" formation overlain by pyroclastics, fluvial sandstones, and tuffaceous marlstones of the "Brian Head" formation, with an average total thickness of about 2,000 feet, interfinger with the basal part of Tv volcanic sequence; algal biostromal limestones in upper-middle part of interval may have some interest as objectives for oil and gas, especially where associated with friable and permeable fluvial sandstones; lower half in interval mostly tight, silty limestones with coarse conglomerate at base.

K -- Cretaceous brackish-water sandstones and marine shales with a total thickness of 2,000 to 2,500 feet; uppermost several hundred feet, Kaiparowits formation, very friable and permeable sandstone; several hundred feet of underlying Straight Cliffs-Wahweap formations composed of Mesaverde sandstones with oyster biostromes; lower half of Cretaceous sequence is coaly Tropic shale with basal Dakota (?) friable sandstone and conglomerate which are extremely permeable and cause serious landslide problems along Utah State Highway 15 east of Zion National Park. Significant facies changes take place in an east-west direction in these Cretaceous rocks, changes which may lead to favorable reservoir and trap conditions (as well as source) in the subsurface toward the north end of the Markagunt-Kolob area.

J -- Upper Jurassic marine and lagoonal limestones, sandstones/shales, and evaporites (Carmel, Entrada, Curtis, and Winsor formations) from 700 to 1,200 feet thick, underlain by 2,000 to 3,000 feet of eolian and fluvial sandstones (Navajo, Kayenta, and Moenave formations). Facies changes and westward thickening of Carmel and Curtis limestone/evaporite intervals offer most promising objectives in Jurassic interval.

T -- Triassic red beds, generally not promising for oil and gas, except for 100 to 300 feet of Timpoweap limestone at base of Moenkopi section which is producing zone at Virgin oil field in Washington County; Triassic sequence consists of 400 to 1,000 feet of restricted Chinle variegated mudstones, underlain by as much as 200 feet of Shinarump grit, and 1,000 to 2,000 feet of Moenkopi red beds.

P -- Paleozoic rocks are exposed only along the extreme western side of the area, where the upper part of the Permian Kaibab limestone crops out in the core of the Laramide Kanarra fold at the base of the Hurricane Cliffs (Gregory and Williams, 1947). The formational tops reported by Petroleum Information for the J. Ray McDermott State No. 1 well in western Kane County indicate about 500 feet of Kaibab limestone, but due to the vagaries associated with the Moenkopi-Kaibab contact, this figure is somewhat doubtful. Thomas and Campbell (1961) drew attention to "a record thickness of Permian evaporites" in the underlying Troweap, with a total Pennsylvanian-Permian section of about 3,000 feet. Some of the most appealing Paleozoic objectives in southern Utah have been in the 900-foot section of Mississippian carbonates, but tests have been generally disappointing. Middle Paleozoic sections evidently are poorly developed in the Grand Canyon region and in southwestern Utah (Heylman, 1958), with rarely more than a few hundred feet of Devonian carbonates and some sandstone present. Reports from the McDermott State No. 1 well indicated a Cambrian section of nearly 2,000 feet, the upper half chiefly limestone which was cored and tested extensively to yield surprisingly good shows and the lower half the usual Bright Angel shale and Tapeats sandstone.

SUMMARY OF THE DRILLING RESULTS

The only tests for oil and gas in the Markagunt-Kolob area have been three holes drilled for the J. Ray McDermott Company in western Kane County, near the east edge of the downthrown block of the Sevier fault. The two older wells, drilled in 1954 (Govt. No. 1 -- SE NW Sec. 19, T-42-S, R-7-W and Govt. No. 2 -- NE NW Sec. 17, T-42-S, R-7-W), were comparatively shallow tests of the zone in the vicinity of the Moenkopi-Kaibab contact (TD for each well about 3,700 feet). The wells were located on what appears to be an obscure dome in the Carmel limestone, breached and stripped to the upper Navajo sandstone; the dome has some geomorphic expression on the Kanab Quadrangle 1:62,500

topographic map. Reportedly, the Govt. No. 2 was about 100 feet structurally higher than Govt. No. 1, which condition would require a 300 foot reversal in regional dip. Govt. No. 1 was listed as a stratigraphic test, however, and it is not certain to what extent structure was considered in selecting the locations.

The domal structure appears to plunge southwestward and then southward toward the location of State No. 1 (SW SW Sec. 2, T-43-S, R-8-W), but the basis of location of that well drilled in 1959-60 is not known to the present writer. This deep test (TD 10,503 feet) bottomed in the Precambrian and afforded important subsurface information in an area where such information is almost lacking. Thomas and Campbell (1961) emphasized shows in the Chinle, Shinarump, Mississippian, and Cambrian, and Petroleum Information reported extensive coring and testing, but the well was plugged and abandoned in February 1960.

PROSPECTS FOR FUTURE EXPLORATION

Prospects for Paleozoic objectives seem limited to the southern part of the area where wells of reasonable depth can test the entire Paleozoic section. Structural prospects seem rather unlikely in the southern part of the area, but stratigraphic tests can be shallowly by about a thousand feet by drilling on the upthrown side of the Sevier fault. Much more subsurface stratigraphic information and interpretation is needed before Paleozoic paleogeography can be prospected for stratigraphic traps.

In the northern half of the area, only Mesozoic and early Tertiary objectives lie within reasonable depths, where the most promising zones are the upper "Wasatch", the upper half and basal part of the Cretaceous sequence, the Carmel limestone and friable Entrada sandstone capped by the widespread Curtis gypsum, the Shinarump grit, and the basal limestone (Timpoweap) of the Moenkopi formation. The up-dip cliffs or weathering escarpments around the south and west edges of the Markagunt and Kolob Plateaus provide an excellent cross section for facies studies in the Mesozoic rocks, facies studies which may give a clue to the location of buried trends in a down-dip direction in the vicinity of Panguitch.

Several investigators have clearly established the general extent and paleotectonics of a late Mesozoic positive area immediately west and northwest of the Markagunt-Kolob region. The positive area was accompanied by a marginal trough, to the southeast, in which thick Upper Cretaceous sequences with rapid facies changes accumulated from southern Nevada to northern Utah. In the northernmost Markagunt Plateau, at depths between 5,000 and 8,000 feet, there should be Cretaceous conditions very similar to the Indianola-Mancos relationships which have been important in Wasatch Plateau gas developments. To some extent, early Tertiary conditions mimicked and continued those of the latest Cretaceous, although with emphasis on continental conditions. Restricted lacustrine conditions in the upper "Wasatch" beneath the northern Markagunt Plateau may have developed limited oil and gas occurrences similar to those in the early Tertiary of eastern Nevada.

Because Wasatch Line and Cordilleran geosyncline paleotectonics played a major part in determining shoreline positions and marine/non-marine facies relationships during earlier mesozoic time, rather weak possibilities for stratigraphic traps in the basal Moenkopi and in the Carmel-Entrada-Curtis exist at various depths between 4,000 and 10,000 feet beneath the western edge of the Markagunt Plateau.

From a structural standpoint, too little is known about the Markagunt Plateau to outline prospects at this time. Although a cross-section by Gregory (1950a) shows an attractive anticline immediately north of Cedar City, it is now known that the east limb of the "anticline" is due to the late Cretaceous folding, and the west limb of the "anticline" is due to the Miocene monoclinial warping which obliquely unfolded the Laramide flexure. It seems likely, however, that this composite structure might still be a good prospect for deep Paleozoic objectives; just beyond the mouth of Shurtz Canyon south of Cedar City (NW part of T. 37 S., R. 11 W.) the top of the Mississippian should be encountered in a structurally high (possibly closed) position at a depth of 3,000 to 5,000 feet.

In an area of much less complex geology, a vague dome covering several square miles seems to have geomorphic expression in an area southwest of Panguitch and southeast of Panguitch Lake. A test in that area should encounter the top of the Cretaceous at a depth of about 1,000 feet and the top of the Navajo at about 4,500 to 5,000 feet.

CITED REFERENCES

-
- Dutton, C. E., 1880, Report on the geology of the High Plateaus of Utah: U.S. Geogr. and Geol. Survey, Rocky Mtn. Region Report.
- Gregory, H. E., 1945, Post-Wasatch Tertiary formations in southwestern Utah: Jour. Geol., v. 53, p. 105-115.
- _____, 1949, Geologic and geographic reconnaissance of eastern Markagunt Plateau, Utah: Geol. Soc. America Bull., v. 60, p. 969-998.
- _____, 1950a, Geology of eastern Iron County, Utah: Utah Geol. and Mineralog. Survey Bull. 37.
- _____, 1950b, Geology and geography of the Zion Park region, Utah and Arizona: U.S. Geol. Survey Prof. Paper 220.
- _____, 1951, The geology and geography of the Paunsaugunt region: U.S. Geol. Survey Prof. Paper 226.
- Gregory, H. E., and Williams, N. C., 1947, Zion National Monument, Utah: Geol. Soc. Am. Bull., v. 58, p. 211-244.
- Heyimun, E. B., 1958, Paleozoic stratigraphy and oil possibilities of Kaiparowits region, Utah: Am. Assoc. Petroleum Geologists Bull., v. 42, p. 1781-1811.
- Thomas, A. R., and Campbell, Graham, 1961, Oil and gas developments in Utah and Nevada in 1960: Am. Assoc. Petroleum Geologists Bull., v. 45, p. 932-937.
- Thomas, H. E., and Taylor, G. H., 1946, Geology and groundwater resources of Cedar City and Parowan Valleys, Utah: U.S. Geol. Survey Water Supply Paper 993.
- Threert, R. L., 1952, Some problems of the (Tertiary) Brian Head formation in southwestern Utah (abs.): Geol. Soc. America Bull., v. 53, p. 1386.
- _____, 1956, Cenozoic structure and volcanic stratigraphy of the Markagunt Plateau, Utah (abs.): Geol. Soc. America Bull., v. 67, p. 1802.

Paper 29 OIL AND GAS POSSIBILITIES OF THE TRANSITION ZONE IN CENTRAL UTAH

by F. W. Christiansen

INTRODUCTION

The Transition zone between the High Plateaus to the east and the Basin and Range province to the west, as herein discussed, includes all of Sevier County and parts of eight other counties (170 Townships) (Figure 102). Paralleling north-east-southwest trending belts of varying geologic features, bordered on the west by the Wasatch line, it forms an irregularly shaped linear belt from Park City on the north to Antimony on the south. Its eastern edge is arbitrarily defined by roads and county boundaries. Paper 28 by R. L. Threet discusses the southern continuation of this zone.

The area is served by a network of hard surfaced and dirt roads, and jeep trails; however, the rugged terrain of the higher portions presents costly access problems for drilling.

Some drilling has been done, mainly in the eastern and southeastern parts. Gas and oil shows were reported in a few of the deeper tests, but no oil or gas has been discovered. Geologic studies are continuing, but there are no exploratory wells presently being drilled. Clear Creek, Joes Valley, Flat Canyon, Ferron and Last Chance gas fields have been developed in the adjacent area to the east (Figure 102). The western half of this zone and the area north of Nephi (Figure 102), except for the eastern foothills belt and a section eastward to Soldiers Summit, have been unattractive for oil and gas potentialities. San Pitch Valley, Sevier Valley and particularly eastern and central Sevier County, western Wayne County and perhaps eastern Piute County offer more promise and may thus receive additional exploration.

The area discussed has been divided into three parts: (1) the Wasatch Mountain area, between Nephi and Park City, plus the eastern foothills belt bordering the Uinta Basin (Figure 103); (2) the San Pitch-Sevier area between Nephi and Richfield; and (3) the southern volcanic area extending from Richfield south to Antimony.

GENERAL GEOLOGY

Structural and stratigraphic relationships suggest that this zone has been intermittently active from the Precambrian to the present, either as a "hinge line" between Paleozoic geosynclinal development on the west to shelf or cratonic deposition on the east, or later as a zone of Cretaceous orogenesis on the west with geosynclinal development to the east. Early Tertiary continental basin deposition followed by late Tertiary epeirogeny developed a broad zone of normal faults and structural basins. Associated volcanic activity and continental basin deposition has continued through to the Recent.

In general, the area may be divided into three parallel belts: (1) a western zone of Laramide closed folds and the associated (Charleston, Nebo, Canyon Range, and Pavant) thrusts; which grades eastward to (2) a central transition belt of less

1. Professor of Geology, University of Utah, Salt Lake City, Utah.

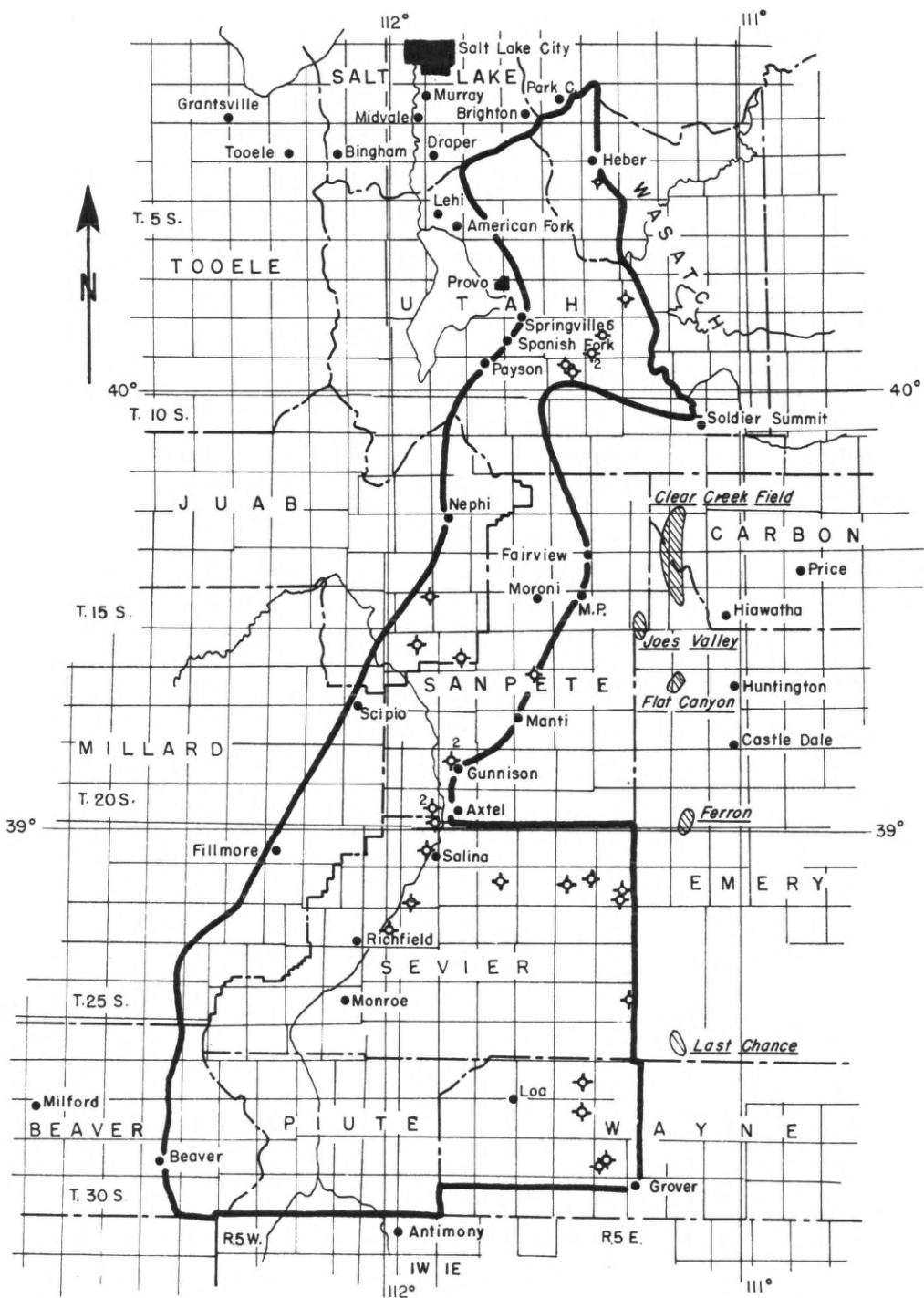


Figure 102. Index map showing the area of the report.

intense folds, faults, and salt structures, which gives way to (3) an eastern belt of open folds and normal faults (Plateau Province). The associated volcanism as measured by the number of stocks, plugs, and dikes of varying sizes and the volume of extrusive rocks, decreases eastward from the Laramide zone into the Plateau Province, where scattered laccolithic structures, small dikes, and relatively small volumes of volcanic material occur.

The Pennsylvanian-Permian, Jurassic, and Cretaceous systems include abrupt sedimentary facies changes, viz., the Oquirrh-Weber, Arapain-Carmel, and Indianola-Mancos relationships. These and other equivalent stratigraphic units have been considered favorable for oil and gas accumulations, particularly in the eastern part of the area. To the east some of these units are producing oil and gas (Figure 102). The complex nature of the geology to the west, including most of the Wasatch Mountains and the western half of the San Pitch-Sevier and southern volcanic areas, has not been considered favorable for oil and gas accumulations.

On the other hand, the eastern portions of the San Pitch-Sevier and southern volcanic areas, and the eastern foothills of the southern Wasatch belt appear to be more favorable, as the structural and stratigraphic conditions are essentially similar to those of the petroliferous parts of the High Plateaus and Uinta Basin. The open anticlines, monoclines, domes, basins, and homoclines of varying sizes (Figure 105) have locally been displaced by Tertiary normal faults. Known fold or other structural trends, bordering the mostly covered southern volcanic area, may be expected to continue underneath the volcanics. Additional detailed geologic studies of the border areas and "windows" within the volcanics may lead to specific objectives beneath the covered area.

In the central belt between the Laramide thrusts on the west and the Plateau Structure on the east, exploration for stratigraphic traps may eventually prove successful. Here are numerous facies changes and many local and broad unconformities within the Late Jurassic, Cretaceous and Early Tertiary systems. Consideration should also be given to the possibility that San Pitch and Sevier Valleys may be in part collapsed anticlinal valleys, initiated in Late Jurassic time by upflow of evaporites. Later Laramide forces may have accentuated the salt structures and folded the underlying strata. During and following Late Tertiary normal faulting, ground water solutions may have dissolved and removed some of the soluble salts, causing collapse of the overlying formations. The very complex structural and stratigraphic features bordering the valleys can be explained by this kind of phenomenon.

In the central and eastern belts, stratigraphic units with oil and gas potential range in age from the Mississippian through the Early Tertiary. These units vary greatly in composition, distribution, and shape, and range from widespread sedimentary blankets such as the Nugget and Morrison formations to more restricted lenses such as the Arapain and Indianola formations.

WASATCH MOUNTAIN AREA

This area includes the southern part of the Central Wasatch Mountains, the Southern Wasatch Mountains and a part of the foothills belt, which extends easterly to Soldiers Summit (Figure 102). Most of the area is considered unfavorable for oil and gas accumulations. The Cottonwood and Uinta uplifts have been deeply eroded, and Precambrian crystalline and younger granitic rocks have

been exposed. Between the Cottonwood uplift and the westward-plunging nose of the Uinta fold are a series of stock-like bodies, and many smaller intrusions. Tertiary volcanics and related small Tertiary intrusions cover large areas between the Uintas and the Cottonwood uplift, as well as the region east and northeast of the head of Salt Creek, near Nephi. Extending around the Cottonwood uplift and western Uinta nose, and plunging into the structural depression between the Cottonwood uplift and the Uinta structure, are sedimentary sequences of essentially every system from the Cambrian to the Tertiary. These, however, have been tightly folded, thrust, and locally metamorphosed. Southward to Nephi along the western half of the area the geologic features consist of tightly folded, thrust, and locally metamorphosed sediments.

The Mississippian to Tertiary sedimentary units exposed south and southeast of the Cottonwood uplift and north and south of American Fork Canyon are listed as follows:

PALEOZOIC, MESOZOIC AND CENOZOIC
STRATIGRAPHIC UNITS OF THE CENTRAL AND SOUTHERN WASATCH*

		<u>North</u>	<u>South</u>
	"Crab Creek formation	0	500
	Uinta formation	500	0
T	Green River formation	250	175
	Colton formation	0	600
	Flagstaff limestone	600	0-1200
K	North Horn-Price River formations	2000	0-950
	Morrison formation	1240	Not exposed
	Curtis formation	510	Not exposed
J	Entrada sandstone	1270	Not exposed
	Twin Creek limestone (Carmel)	1106	800
	Nugget sandstone	1500	1100-1400 Nava. 500 Wing.
	Ankareh shale	1530	125 Chinl 125 Shina
A			1250 Moen
	Thaynes formation	1340	1290
	Woodside shale	315	Not exposed
	Park City formation	1890	1000-3000
P	Diamond Creek (Coconino) sandstone	835	600-1000
	Kirkman limestone	1600	500
Cp	Oquirrh formation	26000	12,000-15,000
	Manning Canyon shale	1650	1000
	Great Blue limestone	2700	500-1200
	Long Trail shale member		
Cm	Humburg formation	580	660
	Deseret limestone	600	720
		665 limestone	
	Gardner limestone	286 dolomite	520

*Modified after Hintze, et al., Geology Studies, B.Y.U., vol. 9, pt. 1.

In contrast to the above zone, along the foothill belt of the Wasatch Mountains, and eastward along the northward-plunging Wasatch Monocline to Soldier Summit, the structural and stratigraphic conditions are considered to be relatively favorable. Several exploratory wells have been drilled. The general structure and stratigraphic features are illustrated by L. F. Wells' NW-SE cross section (Figure 103) through the Strawberry Valley area (personal communication). As illustrated in this cross section and particularly in the Cretaceous and Tertiary systems, several types of favorable structural and stratigraphic relationships exist. Here, the presence of several known source beds adds to the possible oil and gas potential.

Summary of wildcat drilling in this area follows:

<u>Well Location</u>	<u>Company</u>	<u>T.D.</u>
Wasatch County		
21-4S-5# SW NE NE	Syndicate Oil & Mineral Mining #1 Fee, Heber, 515'	
Utah County		
16-8S-5E C SW SW	Sun Oil Co., #2, Diamond Fork, 5632 to Park City	
16-8S-5E SE NW	Diamond Oil Co., #1 Fee, Diamond Fork, 3980', Penn.	
16-8S-5E S SE NW	Utah Drilling & Devel. Co., Buskirk #1, Diamond Fork 3990 TD, Ppc.	
17-8S-5E SW SE NE	Sun Oil Co., #1, Diamond Fork, 3921 TD, Ppc.	
29-8S-5E NE NE	Diamond Oil Co., #3 Fee, Diamond Fork, 1691', Permian	
29-8S-5E NE NE	Diamond Oil Co., #1 Unit, Diamond Fork, 10' TD.	
3-9S-4E NW SW	Diamond Oil Co., #2 Fee, Diamond Fork, 2151'.	
10-9S-4E SE NE	Diamond Oil Co., #1 Fee, Diamond Fork, 941'.	
19-7S-6E	Shell Oil Company #1 West Portal Unit, 4200'.	
4-10S-4E	Thistle, 2000' TD.	
16-8S-5E NW SW SE	D. Feldman, Diamond #1, 5431 TD.	
16-8S-5E NE SW SW	D. Feldman, #2 Sun, Diamond Fork, 5632', Ppc.	
?-10S-5E	Spanish Fork Oil Co. #1 Unit, Thistle, 875'.	
21-10S-5E SE SE NE	Walter Nelson, Finlayson #1 South Diamond Fork, 1000' approx.	

SAN PITCH-SEVIER ARCH

The San Pitch-Sevier area extends south from Nephi to the northern border of the central Utah volcanic field near Richfield. It includes the Gunnison Plateau, Cedar Hills, Valley Mountains, the southern part of Long Ridge, the northern Pavant Range, the southern tip of the Wasatch Plateau, the northern part of the Sevier and Fish Lake plateaus, the western half of San Pitch Valley and all of Sevier Valley (Figure 105).

The Laramide complex fold and thrust systems extending through the western part (including the Cedar Hills, Gunnison Plateau, Valley Mountains and vicinity, and the Pavant Mountains) and the thick sequences of Cretaceous and Early Tertiary orogenic conglomerates combine to form an unfavorable geologic setting for oil and gas accumulations (Figure 104, Spieker, 1949). Surficial structures in the Tertiary rocks have been mapped and some drilling completed, but only the thick Cretaceous and perhaps older conglomerates were encountered at depth.

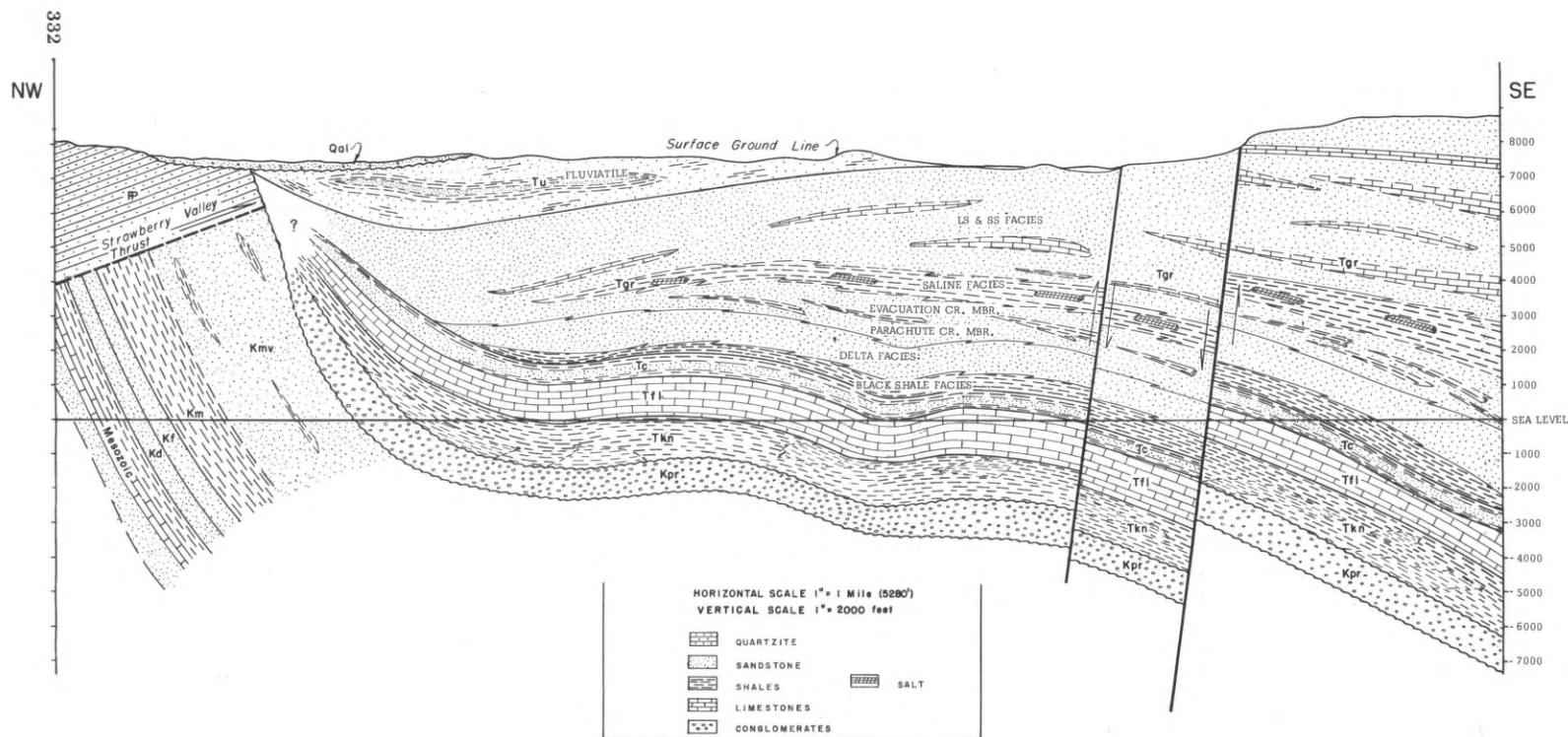


Figure 103. Northwest-Southeast cross section, Strawberry Valley area.

The area to the south and east, including the Sevier and San Pitch Valleys and the Wasatch, Sevier and Fishlake Plateaus immediately north and south of Salina Canyon, however, is more favorably located, although exploratory work has been disappointing. It is believed that further and perhaps more detailed geologic studies are warranted. Such investigations may result in the delineation of other objectives worthy of exploratory drilling.

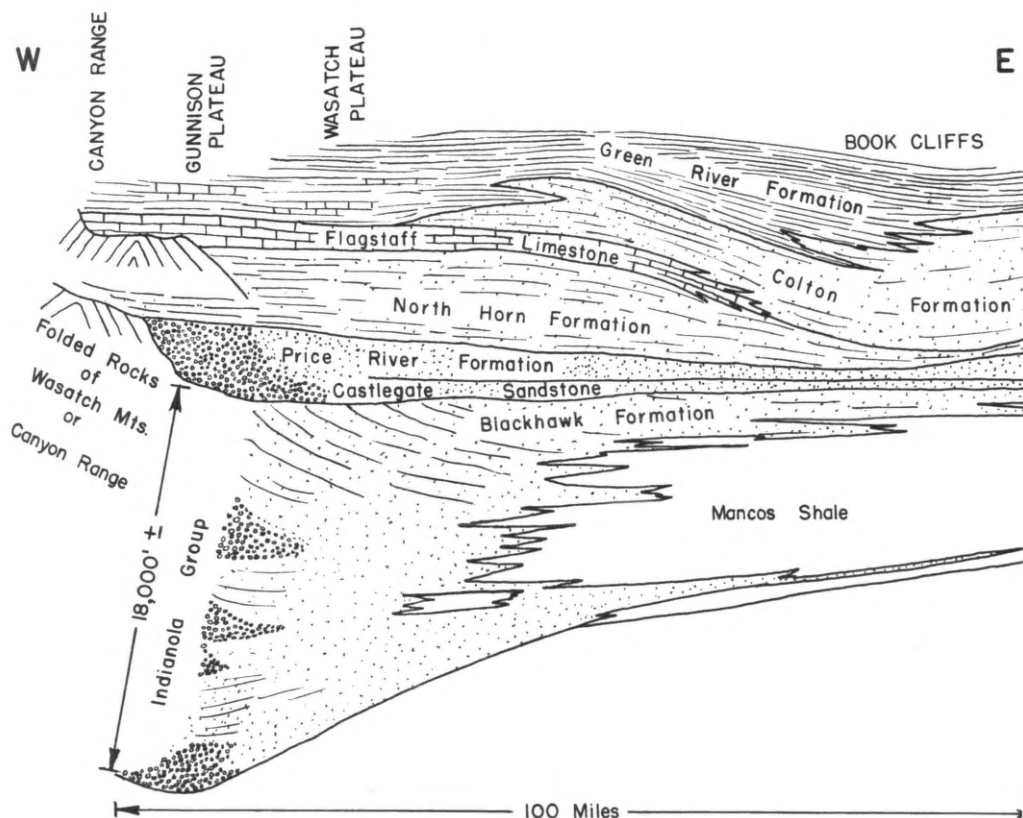


Figure 104. West-east Cross Section.

Little is known about the bedrock geology of the Sevier and San Pitch Valleys. They are mostly covered with alluvium. Marginal structural and stratigraphic features indicate that these valleys may be in part collapsed salt anticlines. Inception of salt anticlinal development may have occurred in Late Jurassic time following the deposition of the evaporite sequences known to be present in the Arapien. Successive stages of evaporite and related argillaceous-rock "intrusions" developed local unconformities over and marginal to the "intrusions." Compressional stresses of the Laramide orogeny probably intensified these earlier developed structures and folded the Navajo and older formations into anticlinal structures paralleling the present valley trends. These events were followed by epeirogeny, normal faulting and volcanism. Uplift and faulting would have accelerated the solution of the evaporites, causing the collapse of

the rocks they were supporting. Because the Navajo and older formations were not involved in the development of the salt structures nor in their subsequent collapse, they should retain the configuration developed during the several pulsations of the Laramide orogeny.

Perhaps deeply buried and completely masked broad open folds exist in the Navajo and older formations immediately east of the Laramide thrust belt and in the transition zone between the thrust belt and the Colorado Province. If so, these open fold structures of older rocks are relatively deep and completely masked by the complicated overlying structures in the younger rocks. Relatively extensive and expensive exploration programs will be necessary to explore these lower zones.

Between Sevier and San Pitch Valleys and Castle Valley across the Wasatch Plateau are abrupt lithologic and tectonic transitions. The complicated structures occurring in the Alpien and younger strata grade in very short distances to relatively simple open fold and normal fault structures characteristic of the Plateau Province.

The abrupt facies changes and the sudden decrease in the magnitude of tectonic changes found in the area present an exciting challenge to the petroleum geologist. A section for the San Rafael Swell and Emery County areas adjacent to the east follows (Stokes, 1956):

AGE		FORMATION
Cenozoic	Tertiary	Igneous dikes and sills
		Green River formation
		Wasatch undivided
		Colton formation
		Flagstaff limestone
		North Horn formation
		Price River formation
		Castlegate sandstone
		Black Hawk formation
		Star Point sandstone
	Cretaceous	Masuk shale
		Emery sandstone
		Blue Gate sandstone
		Ferron sandstone
		Tununk shale
		Mesa Verde formation
		Mancos shale
		Dakota formation
		Cedar Mountain formation
Mesozoic	Jurassic	Morrison-Cedar Mountain undivided
		Brushy Basin (Morrison)
		Salt Wash (Morrison)
		Morrison, undivided
		Summerville formation
		Curtis formation
		Entrada formation
		Carmel formation
		Navajo sandstone
		Kayenta formation

	Wingate sandstone
	Chinle formation
	Shinarump formation
	Moenkopi formation
Triassic	Kaibab limestone
Permian	Coconino sandstone
Pennsylvanian	Hermosa formation

Below is a summary of drilling to date in this area:

Well Location	Company	T.D.
Sanpete County		
3-17S-3E NE SE	Producers Oil Co. #1, Ephraim, 921'.	
8-19S-1E W NW NE	Gunnison Oil Co. #1, Gunnison, Wildcat, 1800'.	
24-20S-1W SE SW	Ben H. Bullock, et al., #1 Unit, Redmond, 85'.	
24-20S-1W NE SW	Sanpete Oil Co., #1 Unit, Redmond, 1462'.	
8-19S-1E NW NW NE	Brookline Oil Co. Marion #1, Wildcat, 1922'.	
Sevier County		
36-20S-1W SW NE	Sanpete Oil Co., #2, Redmond Anticline, 250'.	
15-22S-2E SW NE NE	El Paso Nat. Gas #1, Salina Canyon, 6117'.	
12-22S-4E SW SW SW	Gordon Gray Co., #1, Emery, 3973'.	
23-22S-5E NE SW NE	K.D. Owen, #1, Sevier, 3710', Curtis fm.	
13-25S-5E C SW SW	American Liberty Oil Co., #1 North Last Chance, 4493', Coconino sandstone	
26-21S-1W	Cosco Oil Co., #1 Shorty, Wildcat, 722'.	
34-22S-1W NW SE	Standard Oil Co., #1, Sigurd, Wildcat, 9638'.	
25-21S-1W SW SE	Albrecht & Assoc., Morre-Elkhorn #1, Wildcat, 934'.	
17-22S-4E SE NW SW	Mountain Fuel Supply Co., Accord Lakes #1, Accord Lakes Unit, 5471', Jm.	
34-22S-5E C SW SE	Skelly Oil Co., Emery-Federal #1, Wildcat, 10,740' TD	
27-23S-2W SW	Earl N. Ramey, Fee - R - 1, Wildcat, 460' TD	
Juab County		
1-15S-1W	Mt. Nebo Oil Co., #1, Juab, 2,900'.	
17-15S-1E	Camay Standard, Levan #1, Levan, 7526'.	
27-16S-1E NW NE	Carter Oil Co., Wheatley #1, Coon Springs	
10-16S-1W C SE SW	Great Basin Petroleum, Chase #24-10, Wildcat, 3520', Limestone	

SOUTHERN VOLCANIC AREA

This volcanic region consisting of the Tushar Mountains, Piute Valley, Sevier Plateau, Grass Valley, Fishlake Plateau, Rabbit Valley, Thousand Lake Mountain and the northern part of the Awapa Plateau, is transected by the northeasterly-trending Laramide thrust and fold belt on the west, the parallel central transition belt and the eastern plateaus. The chief difference between this area and those to the north is the presence here of large volumes of volcanic material which cover most of its surface, and the presence of several relatively large intrusive bodies particularly in the western belt.

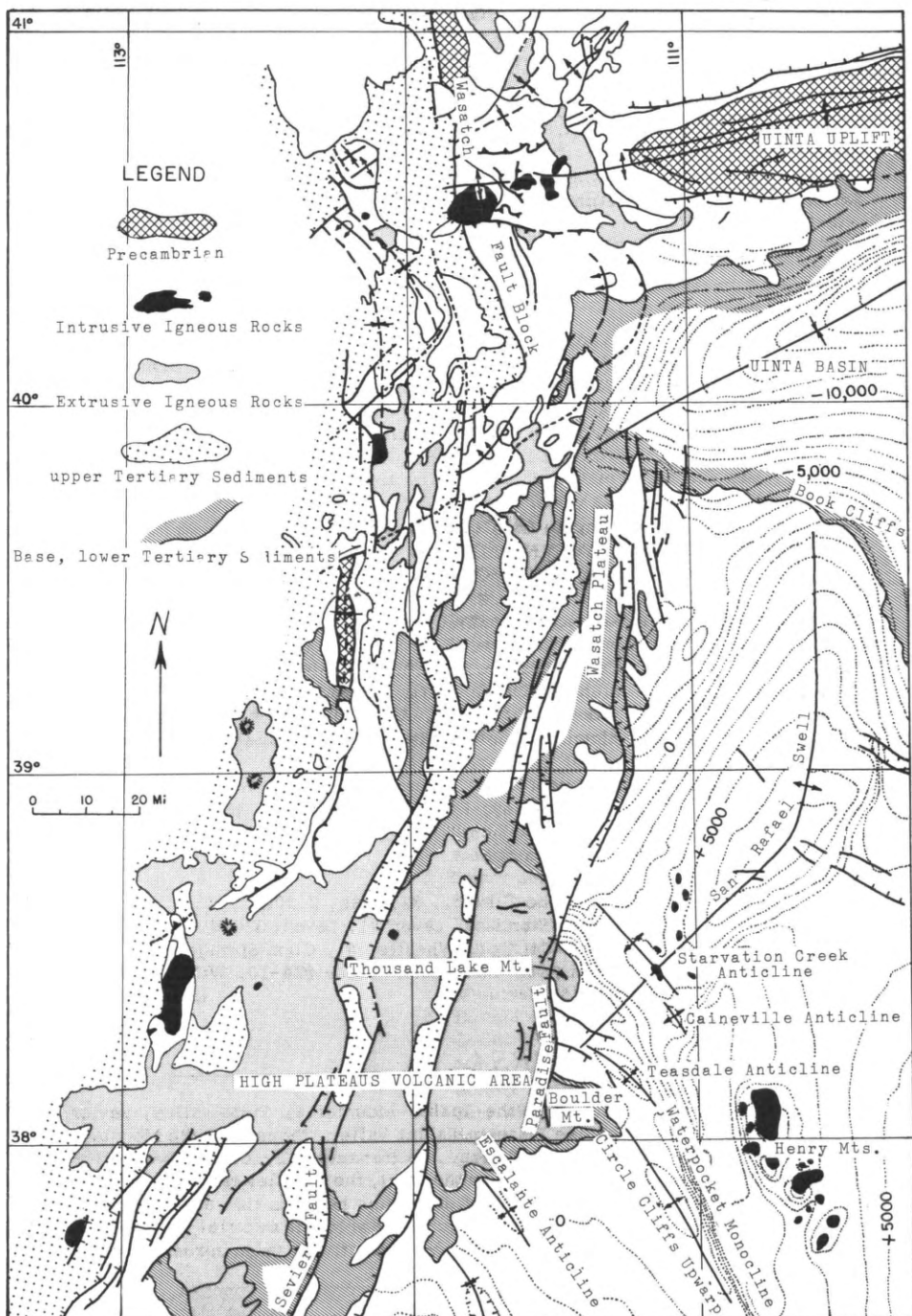


Figure 105. Geologic map of Transition Area.

The younger tectonic elements trend slightly east of north. Normal fault zones and faulted monoclines, and a number of northwest-trending Laramide asymmetrical folds in the southeastern part of the area (Figure 105) are exposed. The Hurricane Fault zone extends northeasterly along the western margin of the area; the Tushar and Sevier faults border the Sevier Valley graben and smaller fault zones are believed to border Grass Valley, which may also be a graben-type valley or perhaps may owe part of its development to the collapse of a salt anticline. The Paradise fault zone extends northward along the western margin of Thousand Lake Mountain and to the graben and horst structure of the Wasatch Plateau (Figure 105).

The stratigraphy and structure below the volcanics are known only from the sedimentary rocks exposed at the margins of the volcanic field and from several windows, such as the window near the north central part of the volcanic field. Richard R. Kennedy (1962) (personal communication) has described the following stratigraphic section in this area.

Sec. 11, T-28-S, R-4-W Piute County, Utah			
Formation	Lithology	Age	Thick- ness (ft)
Sevier River Formation	Silts, sands, gravels	Tertiary-Quaternary	300
Tushar Conglomerate	Limestone, conglomer.	Cretaceous	65
Winsor (probably includes equivalents of the Curtis, Entrada & Carmel fms.)	Limestone, sandstone	Jurassic	610
Navajo (may include Win- gate & Kayenta fms.)	Ortho-quartzite	Triassic-Jurassic	1722
Chinle	Sandstone, shale	Triassic	240
Shinarump	Shales, conglomerate	Triassic	94
Moenkopi	Shales, sands., limes.	early Triassic	1227
Kaibab	Limestone, dolomite	Guadalupian	348
Toroweap	Limestone, dolomite, quartzite	Leonardian	306
Oquirrh (or Talisman)	Cross-bedded, ortho- quartzite	Desmoinesian (?)	580
Callville limestone (exposed in PTH mine tunnel)	Limestone with minor sand and shale; lower part is gyp- siferous.	Morowan-Desmoin- esian (?)	692
TOTAL THICKNESS			6185

In addition to the above measured section, several hundred feet of the Flagstaff formation is exposed in the extreme southeast corner of Piute County.

Kennedy suggests that the following units have oil and gas potential.

1. Winsor formation (probably includes equivalents of the Curtis, Entrada, and Carmel formations).
2. Moenkopi formation (Virgin limestone member).
3. Kaibab limestone.
4. Toroweap formation.
5. Oquirrh (or Talisman) formation
6. Callville limestone.

A limited amount of evidence indicates that the older tectonic trends are east-west and northwest-southeast. B. S. Butler (1920) suggested (p. 111) that an arch or uplift extends eastward from Beaver through the volcanic field. It is suggested that the northern border of this arch strikes eastward along a line about five miles north of Marysville and may join the westward extension of the Starvation Creek and Thousand Lake Mountain structures exposed at the eastern border of the volcanic field. Inferred structural contours indicating a 3,000 foot rise in the Chinle formation (Baker, 1935) extend due west from the Starvation Creek anticline and along the northern margin of the Thousand Lake Mountain anticline. Stratigraphic evidence in the area of Marysville (Kennedy, 1962) suggests that the northern part of the east-west arch was probably defined in Late Cretaceous time. Immediately south, the Laramide and earlier tectonic elements strike northwest. The Thousand Lake Mountain, Starvation Creek, Cainville, Escalante and Teasdale structures are illustrative of this trend (Figure 105).

Considering the attitudes of the larger tectonic elements of the area and those adjoining the above described structures, it is interesting to note that the Water-pocket monocline and Circle Cliffs upwarp trend about north 20 west, and to the north the San Rafael trend is about north 40 east. At the area of juncture of these two major elements a third major element extends westward under the volcanics. This westward-trending zone may mark the northern border of the Beaver Arch (presumably of Laramide age) or the third element of a tri radial system (Christiansen, 1963) centering near the Starvation Creek Anticline.

Summary of drilling in the Southern Volcanic area:

<u>Location</u>	<u>Company</u>	<u>Total Depth</u>
Wayne County		
20-29S-5E C NE NW	Parry Oil Co., Federal #1, Teasdale, 523'.	
11-28S-4E C SW NW	Texaco Inc., Thousand Lake #1, Thousand Lake, 6905'	
30-29S-5E NW SE		Mississippian
23-27S-4E	Argo Oil Co., Hickman #1, Wildcat, 3768'.	
	Shumway Oil, Government #1 - 23, Thousand Lakes Mountain, 1917'.	

CITED REFERENCES

- Baker, A. A., 1935, Geologic Structure of Southeastern Utah: Am. Assoc. Petroleum Geologists Bull., v. 19, no. 10, p. 1472-1507.
- Butler, B. S., 1920, Ore Deposits of Utah: U.S. Geol. Survey Prof. Paper 111.
- Christiansen, F. W., 1963, Polygonal Fracture and Fold Systems in the Salt Crust near Wendover, Utah. Science
- Kennedy, Richard R., 1962, unpublished thesis.
- Spieker, E. M., 1949, The transition between the Colorado Plateaus and the Great Basin in central Utah: Utah Geol. Soc. Guidebook, no. 4.

- D - THE HIGH PLATEAUS

INDEX

<u>Paper</u>		<u>Page</u>
30	GAS FIELDS OF THE WASATCH PLATEAU, by Paul T. Walton	341
	Introduction	341
	History	341
	Stratigraphy	343
	Structure	344
	Gas Fields	344
	Producing Formations	349
	Future Gas Possibilities	352
	Cited References	352
31	GEOLOGY AND OIL AND GAS POSSIBILITIES OF EAST-CENTRAL UTAH, by Stanford R. Mahoney and Robert P. Kunkel	353
	Introduction	353
	General Geology	353
	Major Structural Features	357
	Stratigraphy	358
	Summary of Oil and Gas Possibilities	365
	Probable Future Developments	379
	Cited References	380
32	THE KAIPAROWITS REGION AND ADJACENT AREAS, by Edgar B. Heylman	381
	Stratigraphy	381
	Structure	382
	Oil and Gas Possibilities	383
	Cited References	384
33	PENNSYLVANIAN PALEOTECTONICS OF COLORADO PLATEAU, by Richard W. Fetzner	385
	ABSTRACT	385
34	BASEMENT ROCKS AND RELATIONSHIP TO OVERLYING SEDIMENTS OF THE PARADOX BASIN, by W. Don Quigley	387
	Introduction	387
	Description of the Basement Rocks	387
	Tectonic History of Basin Rocks	392
	Basement Highs and Lower Paleozoic Structures	397
	Geophysical Methods	399
	Summary	402
	Cited References	403

<u>Paper</u>		<u>Page</u>
35	DESERT CREEK ZONE, SOUTHEAST SAN JUAN COUNTY, UTAH, by Kenneth E. Carter	405
	Introduction	405
	Resumé of Development -- Desert Creek Zone	405
	Stratigraphy	407
	Evaporite Facies	409
	Carbonate Facies	409
	Greater Aneth Area	410
	Other Producing Fields	411
	Exploration Problems	411
	Cited References	411
36	OIL AND GAS POSSIBILITIES OF THE ISMAY ZONE, by William C. Hafeman	413
	Introduction	413
	Area and Scope of Study	413
	Lower Ismay Zone	413
	Lower Ismay - Upper Phase Deposits	417
	Age Relationships between "Trough" Evaporites and Shelf Carbonates	423
	Upper Ismay Zone	424
	Upper Ismay Carbonate Phases	425
	Upper Ismay Cross Section	427
	Flaggy Deposits at End of Ismay Time	427
37	GEOLOGY OF THE LISBON OIL AND GAS FIELD, SAN JUAN COUNTY, UTAH, by Robert P. Kunkel and Robert B. Schick	429
	Introduction	429
	Geologic History of the Region	429
	Stratigraphy	431
	Structure	435
	Oil and Gas Development	435
	History of Exploration and Drilling	441
	Economics	441
	Future Potential	443
	Cited References	446
38	OIL AND GAS OCCURRENCES IN THE PROPOSED CANYONLANDS NATIONAL PARK AREA OF SOUTHEASTERN UTAH, by Milan S. Papulak	447
	Introduction and Location	447
	Stratigraphy	451
	Structure	453
	Drilling Highlights	455
	Summary and Conclusions	463
	Cited References	467
39	MEXICAN HAT OIL FIELD, by Sherman A. Wengerd	469
	Introduction	469
	Stratigraphy	471
	Structure	473
	Oil Development	475
	Conclusions	481
	Cited References	482
40	OIL AND GAS OBJECTIVES WORTHY OF EXPLORATION IN SAN JUAN COUNTY, by Dorsey Hager	483
41	PARADOX BASIN SALT DISCONFORMITIES (AND THEIR RELATIONSHIP TO OIL PRODUCTION) by John E. Welsh	487
	Theories of Salt Deposition	487
	Lithofacies Interpretation	491
	Directions for Exploration	493
	Cited References	494

Paper 30 GAS FIELDS OF THE WASATCH PLATEAU

by Paul T. Walton¹

INTRODUCTION

During the period 1952 to 1954, three hydrocarbon gas fields were discovered on the Wasatch Plateau. A CO₂ field had previously been found there in 1947. One important field was developed at Clear Creek, and small production was discovered on the Flat Canyon, Joes Valley, and Gordon Creek structures.

The Wasatch Plateau extends from Soldier Summit south to Salina Canyon, approximately seventy-five miles, and from the Book Cliffs on the east to the Sanpete-Sevier valley on the west, a width of nearly twenty-five miles. For the most part, the surface formations are low-dipping Upper Cretaceous and Paleocene strata which have a structural position of as much as 6,000 feet above the synclinal Sanpete-Sevier valley to the west. Eocene strata are exposed around the margins of the Plateau.

The Wasatch Plateau, basically a north-south trending monocline or terrace, on its north end, consists of a broad uplift with two major lines of folding that plunge northward into the Uinta Basin. The Plateau's faulted western side dips strongly into the Sanpete-Sevier valley; its east side is bounded by the San Rafael Swell, a large mountain-type anticline having a northeast-southwest axis. The axes of folds on the Plateau parallel the San Rafael trend and are considered to be marginal bands of folding to the Swell.

Erosion subsequent to the monoclinical uplift has been controlled to a great extent by graben fault systems, but elsewhere a dendritic-type drainage pattern has developed the region into a youthful, highly mountainous terrain, difficult of access, with topographic relief frequently in excess of 3,000 feet.

HISTORY

Initial drilling on the Wasatch Plateau was done by the Pacific Western Oil Corporation at its No. 1 Gordon Creek Unit well. Commenced in 1946, this well was drilled to a total depth of 12,146 feet, bottoming in the Coconino sandstone. Later it was plugged back to 10,980 feet and completed as a CO₂ gas well in the Sinbad limestone. Open flow was 8,500,000 cubic feet of gas per day.

In 1951, Byrd-Frost, Inc., on a farmout from Morgan-Walton Oil and Gas, Inc., commenced drilling the initial well on the Clear Creek structure. This well was completed at a total depth of 5,260 feet in the basal member of the Ferron sandstone, for an initial open flow of 9,000,000 cubic feet of gas per day. Subsequently, sixteen productive wells and three dry holes have been drilled on Clear Creek. The field was unitized in 1957.

After Three States Natural Gas Company acquired the assets of Byrd-Frost in 1952, it drilled the Northeast Scofield and Flat Canyon structures. Gas was discovered in the Ferron and Dakota at the latter area. The discovery well was

1. Consulting geologist and independent operator (partner in WALTON KEARNS).

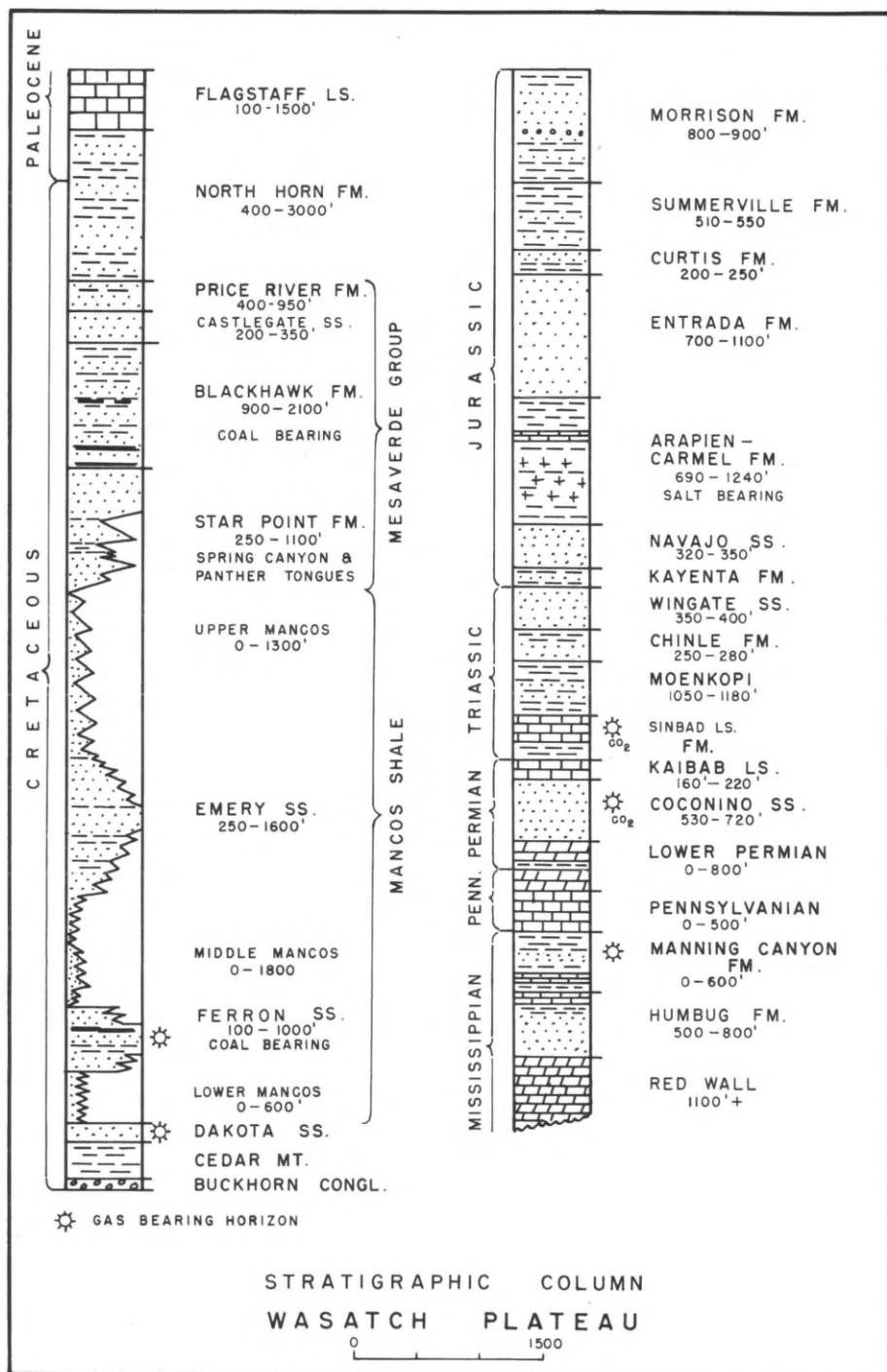


Figure 106.

completed in 1953 at a total depth of 7,038 feet in the Dakota sandstone which, after shooting with sixty quarts of nitroglycerine, produced initially 6,500,000 cubic feet of gas per day open flow. Three additional wells have since been completed; one, Unit No. 4, being a dry hole.

Pacific Western drilled three additional wells during 1952 and 1953 on the Gordon Creek structure, and one of them, Unit No. 3, resulted in the discovery of petroleum gas in the Ferron. This well was drilled to a total depth of 4,308 feet and was completed with an initial open flow of 1,500,000 cubic feet of gas per day. All other wells found water in the Ferron. In 1956 Skelly Oil drilled the No. 2 Bryner well to a total depth of 12,293 feet, bottoming in rocks of Pennsylvanian age. This well was plugged back to the Sinbad and completed as a CO₂ well.

In 1955 Three States completed the discovery well on the Joes Valley field at a total depth of 7,262 feet in the Ferron sandstone with an initial potential of 7,500,000 cubic feet of gas per day open flow. Following unitization, No. 2 and No. 3 Unit wells were completed in the Ferron. Subsequently, both were deepened to the Dakota, which proved productive of gas.

In 1957 the English Oil and American Petrofina companies drilled the discovery well in the Ferron field. The discovery well was completed in the Ferron sandstone at a depth of 720 feet for an initial open flow of 4,700,000 cubic feet of gas per day.

In 1958 Shell Oil Company drilled its No. 1 North Springs Unit well about twelve miles southeast of Gordon Creek, just east of the Wasatch Plateau. This well found 1.8 million cubic feet of methane gas per day in the Mississippian Manning Canyon, the first discovery of petroleum gas below the Cretaceous strata in the region.

Development at Clear Creek resulted in the building by Utah Natural Gas Company of an eighteen-inch line from the field to Orem, where gas is sold to Mountain Fuel Supply Company for distribution. At the present time, an average of 35,000,000 cubic feet of gas per day is being taken altogether from the Clear Creek, Joes Valley, and Flat Canyon fields.

STRATIGRAPHY

Upper Cretaceous to Eocene strata are exposed on the surface of the Wasatch Plateau. Beds ranging in age from middle Upper Cretaceous to Pennsylvanian have been penetrated by the No. 1 Unit well on the Gordon Creek structure. Shell's North Springs No. 1 Unit well located twelve miles southeast of Gordon Creek penetrated Middle Cretaceous to Cambrian strata. The distribution of the surface formations and their descriptions for most of the Wasatch Plateau and its west margin are shown on two maps by Spieker (1931-1949). The writer (1955) has described the surface and subsurface strata.

The stratigraphic column (Figure 106) which follows should suffice for the purpose of this paper.

STRUCTURE

Structure Map

The structure map (Figure 107) constructed from data obtained by surface and photogeologic mapping, augments well information. The structure contours are based on the Ferron sandstone.

The most striking features of the regional structure are the anticlinal trends parallel to the San Rafael Swell uplift. One of these, a major anticlinal fold, is located on an axis that trends from Soldier Summit southwesterly through Clear Creek to the South Joes Valley anticline, a distance of forty-five miles. Another important fold is the axis connecting the Flat Canyon and Gordon Creek anticlines, a distance of thirty-eight miles. Major graben fault zones, the Pleasant Valley and the Joes Valley rifts, apparently intersected these two anticlinal trends after the lines of folding had been established, for certain fault blocks in these grabens are merely faulted segments of the original folds.

One of the most spectacular topographic features in the northern Wasatch Plateau is the Joes Valley graben. Opposite the Straight Canyon syncline, the throw on the faults bounding this graben is over 3,000 feet. The North Joes Valley structure is closed on the east by the shear zone of this large graben. On its south end the Joes Valley graben describes a gentle curve toward the west and, together with some regional northwest-trending nosing, forms a large structural closure known as the Emery structure.

The most important fault zone, economically, in the area is the Pleasant Valley graben, against which the Clear Creek gas field is formed. This zone is parallel to the Joes Valley graben and can be traced for thirty-eight miles from north to south. Numerous splinters occur along its edge, and the maximum throw of the boundary fault appears to be opposite the highest point on the Clear Creek structure.

The graben along the axis of the Gordon Creek anticline may be a keystone fault formed by plastic flow in the underlying Arapien salt series, which allowed the crestal block to fail in tension and drop to its present position.

GAS FIELDS

Clear Creek

The productive portion of the Clear Creek structure is at present confined to the large fault segment lying west of the Pleasant Valley graben. This fault segment is the highest point structurally in the northern Wasatch Plateau. The total structural closure within this one fault segment, which includes the Flat Canyon anticline, is at least 2,100 feet.

Clear Creek was initially tested because it is a large structural closure, and gas was discovered in the Ferron sandstone solely on the basis of this structural theory. The accumulation is probably principally determined by structural closure; however, the Ferron appears to be cleaner and better sorted at Clear Creek than elsewhere in the area. Also, the Ferron is highly fractured at Clear Creek, and the field's production history to date indicates it is in part a fracture reservoir. Pressure surveys indicate good intercommunication between the wells of the field, probably due to the large number of faults in the area.

True structural traps frequently have more than one pay horizon. The Dakota and Lower Cretaceous sands have been tested on the top of Clear Creek with negative results; however, flank tests of these sands have not been made.

Flat Canyon

The Flat Canyon anticline was drilled following Clear Creek's discovery. It is a closed surface structure. In the initial well commercial quantities of gas were found in the Dakota, and a small volume was recovered from the Ferron. The productive portion of the Flat Canyon anticline is confined at present to that portion located immediately east of the Joes Valley graben. Little more than 150 feet of closure can be mapped in the Castlegate sandstone on the surface, but the three wells drilled on this feature indicate it has more than 250 feet of closure in the Ferron (Figure 107).

The trapping of gas in the Ferron and Dakota sandstones at Flat Canyon seems purely structural.

Gordon Creek

Of all of the northern Wasatchfolds, the symmetry of the Gordon Creek anticline has been least damaged by graben faulting. This anticline has at least 500 feet of surface closure in the Star Point and Emery beds, and apparently maintains much of this structural relief at depth, for 560 feet of continuous CO₂ gas saturation was found in the Coconino sandstone in the Unit No. 1 well.

Gordon Creek's great size and closure make it an outstanding structural trap. It was drilled primarily to test the Permian and Pennsylvanian strata. In its initial well, the Jurassic and Triassic formations were found to have thickened nearly 4,000 feet over their measured thicknesses in the northern San Rafael Swell area, thus precluding a test of the Pennsylvanian strata at that time because of the great depths and expense involved. While three other wells have been drilled to the Ferron, only one of these, Unit No. 3, has found petroleum gas in the Ferron.

The gas accumulations in the Ferron, Sinbad, and Coconino appear to be due to structural closure.

North Joes Valley

The North Joes Valley structure has 900 feet of independent closure against the Joes Valley fault zone. The fault segment in which the North and South Joes Valley structures are located has at least 1,600 feet of surface closure.

Three wells have been completed on this structure. The initial well found gas in the Ferron. Another proved productive from the Dakota. The third was a dry hole. The discovery well has since been deepened to the Dakota. Both productive formations make large quantities of water with the gas.

The accumulation of gas in the Ferron and Dakota sandstones at North Joes Valley appears to be related solely to structural closure.

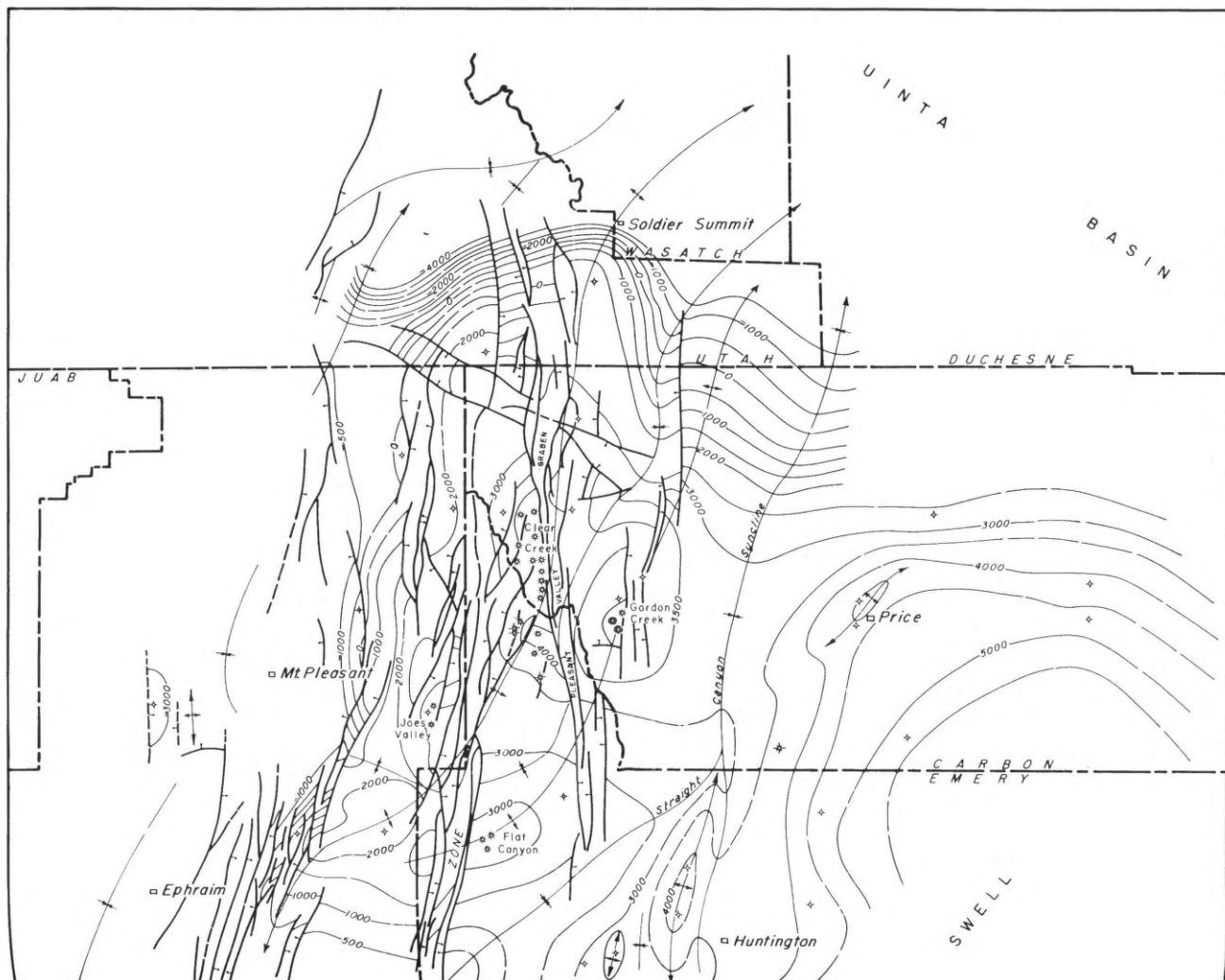
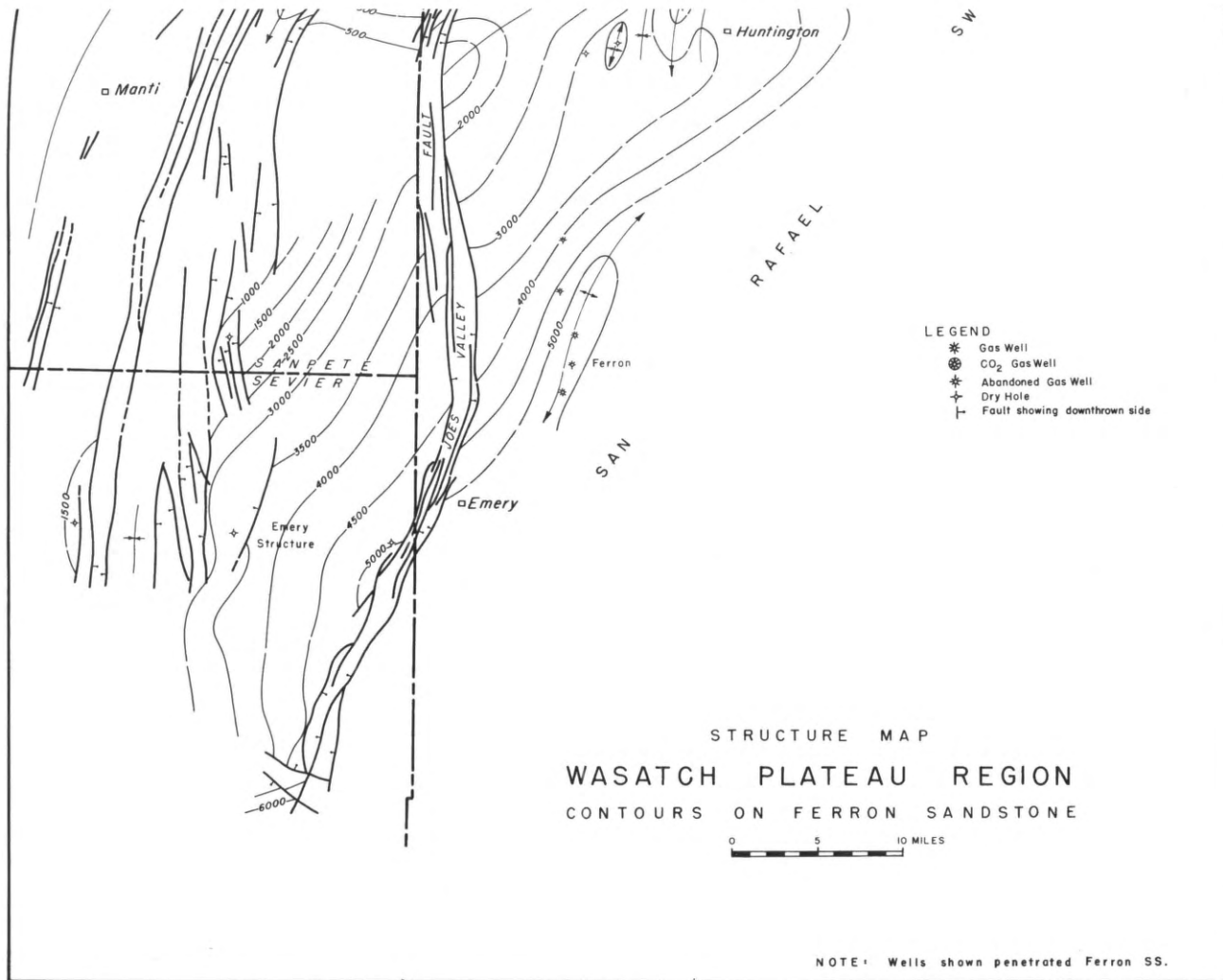
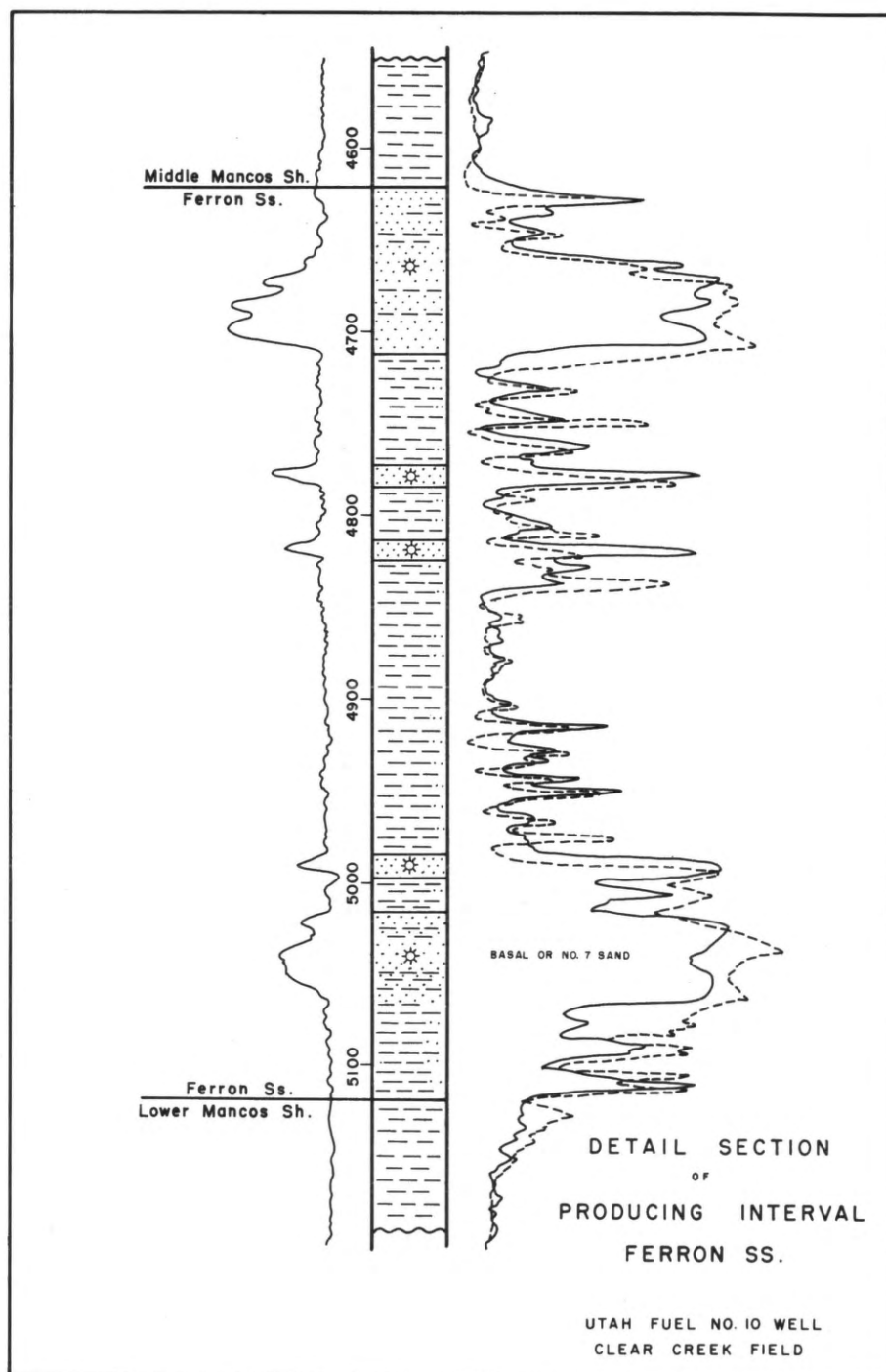


Figure 107.





Ferron

The Ferron field is located on a northeast-trending anticline with two areas of closure. The producing formation is the Ferron sandstone, and the accumulation appears to be controlled principally by structure.

PRODUCING FORMATIONS

Ferron Sandstone

Cores and electric and radioactive logs furnish the bulk of the data on the physical characteristics of the Ferron as a producing formation.

At Clear Creek the Ferron appears hard and tight and is frequently cut by vertical and 45° fractures. Fracturing seems important in the physics of gas production and unquestionably enhances favorable reservoir characteristics by providing additional porosity and permeability to aid the flow of gas from the reservoir into the wells. Fracturing is probably materially augmented because of faulting near the wells, or it may be induced by shooting the wells with nitroglycerine explosives. Fracturing with sand-oil and sand-water emulsions has been successful recently in several of the wells where workovers were necessary to shut off bottom hole water.

For convenience in the completion of the wells at Clear Creek, seven zones of sand development were recognized from drilling breaks and electric and radioactive logs. These zones appear interconnected, for gas analyses and pressures from wells producing only from the shallow zones are identical with those producing from the basal or No. 7 sand only (Figure 108).

An isopach (Figure 109) of the net sandstone thickness of the Ferron indicates a local thickening or "build up" in the vicinity of Clear Creek. This thickening is believed to be related to early movement along the Clear Creek uplift during Ferron deposition.

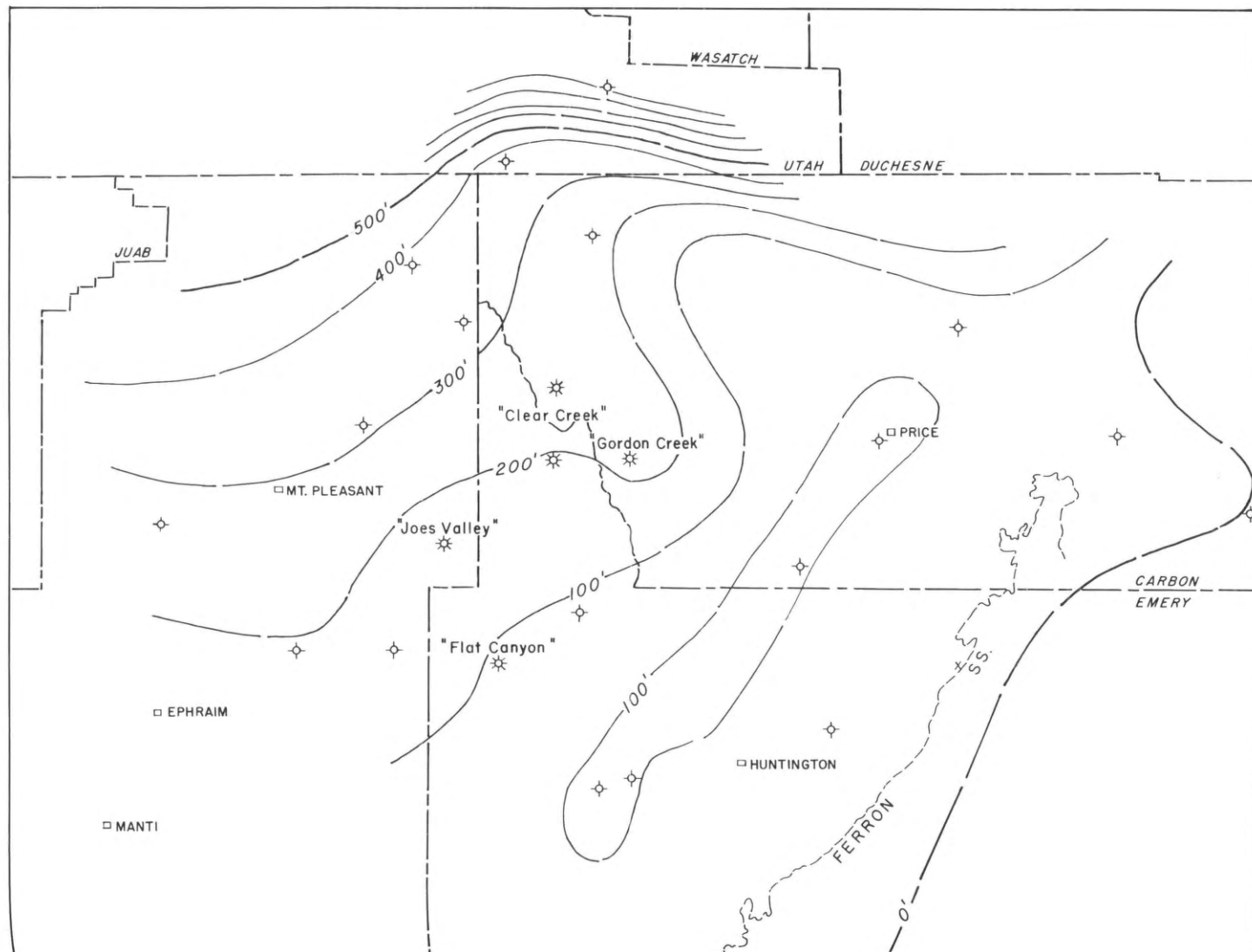
The Ferron sandstone in the south end of the Wasatch Plateau appears to be a deltaic deposit with its origin to the southwest. The Ferron field is located near an apparent channel deposit of sand emanating from this delta.

At Joes Valley, Flat Canyon, and Gordon Creek, the Ferron is less porous and permeable than at Clear Creek and does not appear to be as well fractured. Reservoir capacity at these three fields is therefore much less.

Dakota Sandstone

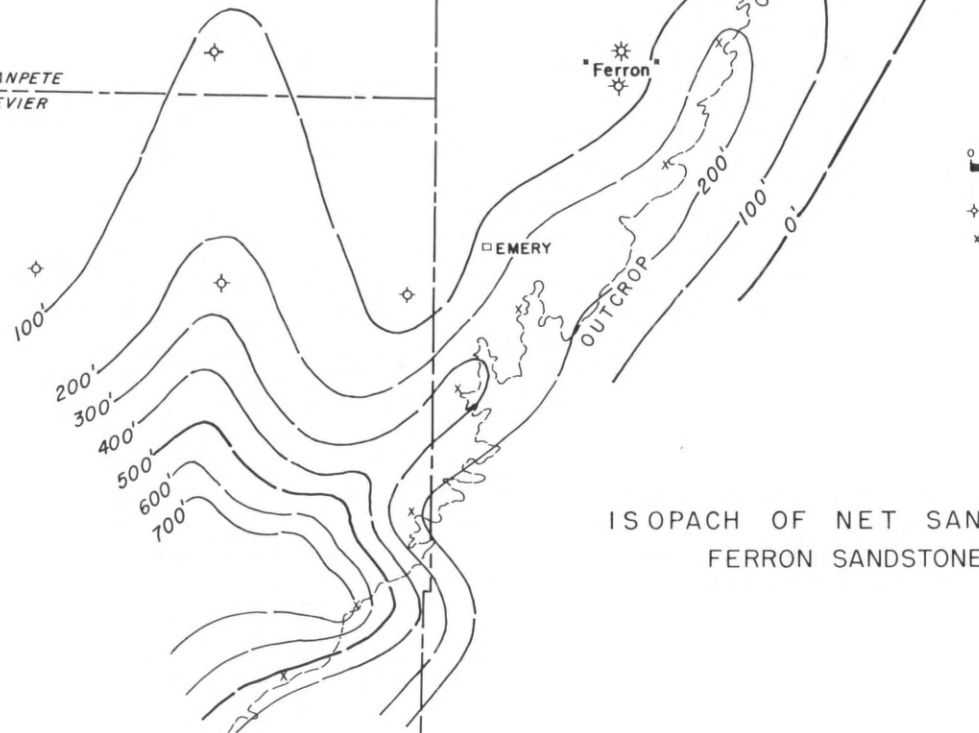
At Flat Canyon the Dakota sandstone was drilled with cable tools, and, since no cores were taken, very little of its physical character can be ascertained. The forty-four feet penetrated in the discovery well were hard and relatively impermeable, as the well flowed naturally only 4,500,000 cubic feet of gas per day open flow through the casing. Upon being shot with sixty quarts of nitroglycerine, the flow increased to 6,500,000 cubic feet of gas per day. Considerable amounts of water are currently being produced from the Dakota at Flat Canyon. The Dakota contained water at Gordon Creek, but is apparently without fluid of any kind on the crest of Clear Creek.

At Joes Valley the Dakota also is hard and tight, and reservoir capacity appears low. Considerable water is produced with the gas.



□ MANTI

SANPETE
SEVIER



0 5 10 MILES

✧ WELL DATA
x SURFACE DATA

ISOPACH OF NET SANDSTONE THICKNESS
FERRON SANDSTONE FORMATION

Sinbad Limestone at Gordon Creek

The 108-foot-thick, hard, non-porous Sinbad limestone was the zone in which the Unit No. 1 well was completed as a CO₂ producer with an initial natural open-flow potential of 8,500,000 cubic feet of gas per day. Unconfirmed reports indicate that while being tested this producing formation failed to maintain its initial productivity because of the apparent small reservoir capacity. No sustained production has ever been taken from this well since it was initially completed and tested; therefore, its producing characteristics are unknown.

Coconino Sandstone at Gordon Creek

A drill-stem test in the top 560 feet of the Coconino sandstone in the Unit No. 1 well revealed an initial flow of 8,880,000 cubic feet of CO₂ gas per day with no water. Due to a fishing job the hole was lost, and the well was completed in the Sinbad limestone instead. Diamond coring of almost the whole Coconino section revealed a remarkably uniform, porous, and permeable sandstone into which some secondary anhydrite had been deposited in a few places. Considering the size of the Gordon Creek structure and the large gas column in the Coconino, an immense reserve was estimated in the reservoir. However, the Skelly No. 2 Bryner well, drilled one and one-half miles to the south, found the Coconino water bearing. An explanation for this condition is not yet available.

FUTURE GAS POSSIBILITIES

Future possibilities for finding gas and/or oil may be grouped into two classifications: (1) deeper drilling on known structures, either productive or dry, in the shallow zones, and (2) initial drilling of untested structures.

Under the first classification, certainly Pennsylvanian, Mississippian, or deeper tests on the already productive Clear Creek, Gordon Creek, Joes Valley, Flat Canyon, and Ferron fields would have much to recommend them. Likewise, a Mississippian or deeper test on the Emery structure is justified, and one is at present drilling on this structure.

Under the second classification, it is apparent from the Structure Map (Figure 107) that there must be numerous fault traps which are as yet undrilled. The horsts in the Joes Valley graben and the segment of the Flat Canyon structure lying on the west side of the same graben are examples of structural traps which may offer future gas possibilities for the Wasatch Plateau.

CITED REFERENCES

- Spieker, Edmund M., 1931, The Wasatch Coal Field, Utah: U.S. Geol. Survey Bull. 819.
- _____, 1946, Late Mesozoic and Early Cenozoic History of Central Utah: U.S. Geol. Survey Prof. Paper 205-D.
- _____, 1949, The Transition between the Colorado Plateau and the Great Basin in Central Utah: in Utah Geol. Society, Guidebook No. 4.
- Walton, P. T., 1955, Wasatch Plateau Gas Fields, Utah: Am. Assoc. Petroleum Geologists Bull., v. 39, no. 4.

Paper 31 GEOLOGY AND OIL AND GAS POSSIBILITIES OF EAST- CENTRAL UTAH

by Stanford R. Mahoney¹ and Robert P. Kunkel²

INTRODUCTION

The area discussed extends eastward from the Wasatch Plateau to the Utah-Colorado boundary, and southward from the Uinta Basin to the south boundary of T-29-S S.L.B. & M., some 18 miles south of the Grand County-San Juan County line. Included are parts of Carbon, Emery, Wayne, Grand, and San Juan Counties. The area embraces the San Rafael Swell, the northern portions of the Paradox Basin, and the Uncompahgre Highland, major structural, stratigraphic, and physiographic subdivisions of the Colorado Plateau province (Figure 110).

Five cross-sections have been constructed, principally from well data supplemented by surface measured sections. The lines of cross-sections and the major structural features are shown on Figure 111 and 112). Oil and gas fields in the area are shown on Figure 1. The writers have drawn extensively on their experience, and, in addition, from the geological reports of the U.S. Geological Survey, principally by A.A. Baker, C. H. Dane, E. M. Spieker, E. T. McKnight, and D. J. Fisher. Other geological summaries dealing with the area have been published in bulletins of the Am. Assoc. Petroleum Geologists and in guidebooks of local geological societies in Utah and Colorado.

GENERAL GEOLOGY

Geologic History

The Colorado Plateau craton was exposed and subjected to moderate erosion until Middle and Upper Cambrian time when sedimentary rocks were deposited in a transgressing sea whose shoreline migrated eastward from the Cordilleran geosyncline to the vicinity of the Colorado-Utah boundary, and eventually into central Colorado. A gentle uplift of the Colorado Plateau began in the Ordovician period and persisted until Middle Devonian time, when southward tilting allowed the sea to advance toward the north. Ordovician and Silurian rocks are absent or only locally developed. Upper Devonian rocks are believed to underlie most of the region. These grade upward into Mississippian carbonates which were deposited on a stable shelf in shallow, warm seas that spread over much of western America from the Arctic to Mexico. Toward the end of the Mississippian, uplift, accompanied by some erosion, occurred in the north and west parts of east-central Utah.

In Late Mississippian and Early Pennsylvanian time, black shales and limestones were deposited in western and north-central Utah. The first major orogeny to affect this region began along what is now the Uncompahgre Highland, complemented by subsidence of the paralleling Paradox Basin. Vast quantities of

1. Consulting Geologist, Salt Lake City, Utah.

2. Consulting Geologist and Associate Editor of *Petrogram*, Salt Lake City, Utah.

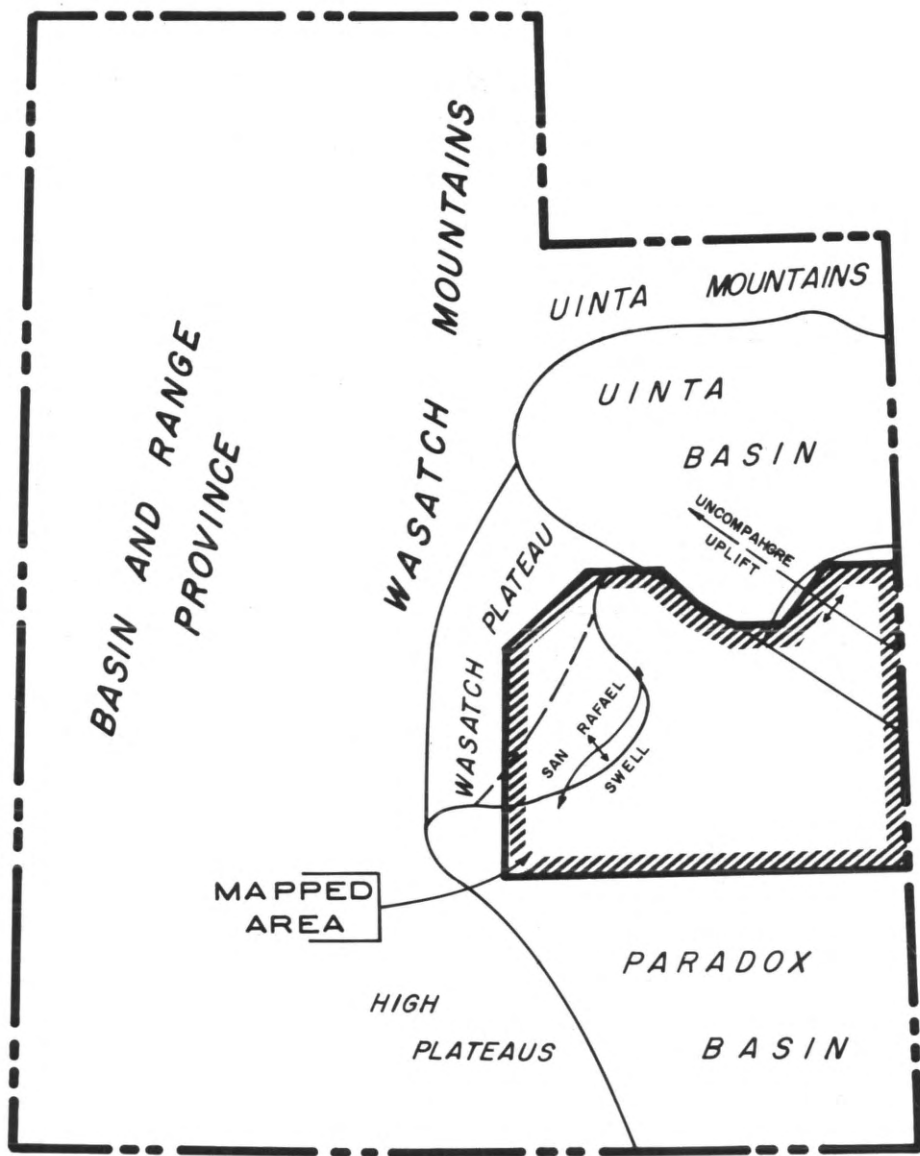


Figure 110. Index map of east central Utah, showing tectonic elements and discussion area.

coarse arkosic material were shed westward from the rising highland. This clastic material wedged abruptly into thick marine carbonate rocks and black shales which accumulated between periods of prolonged evaporite deposition.

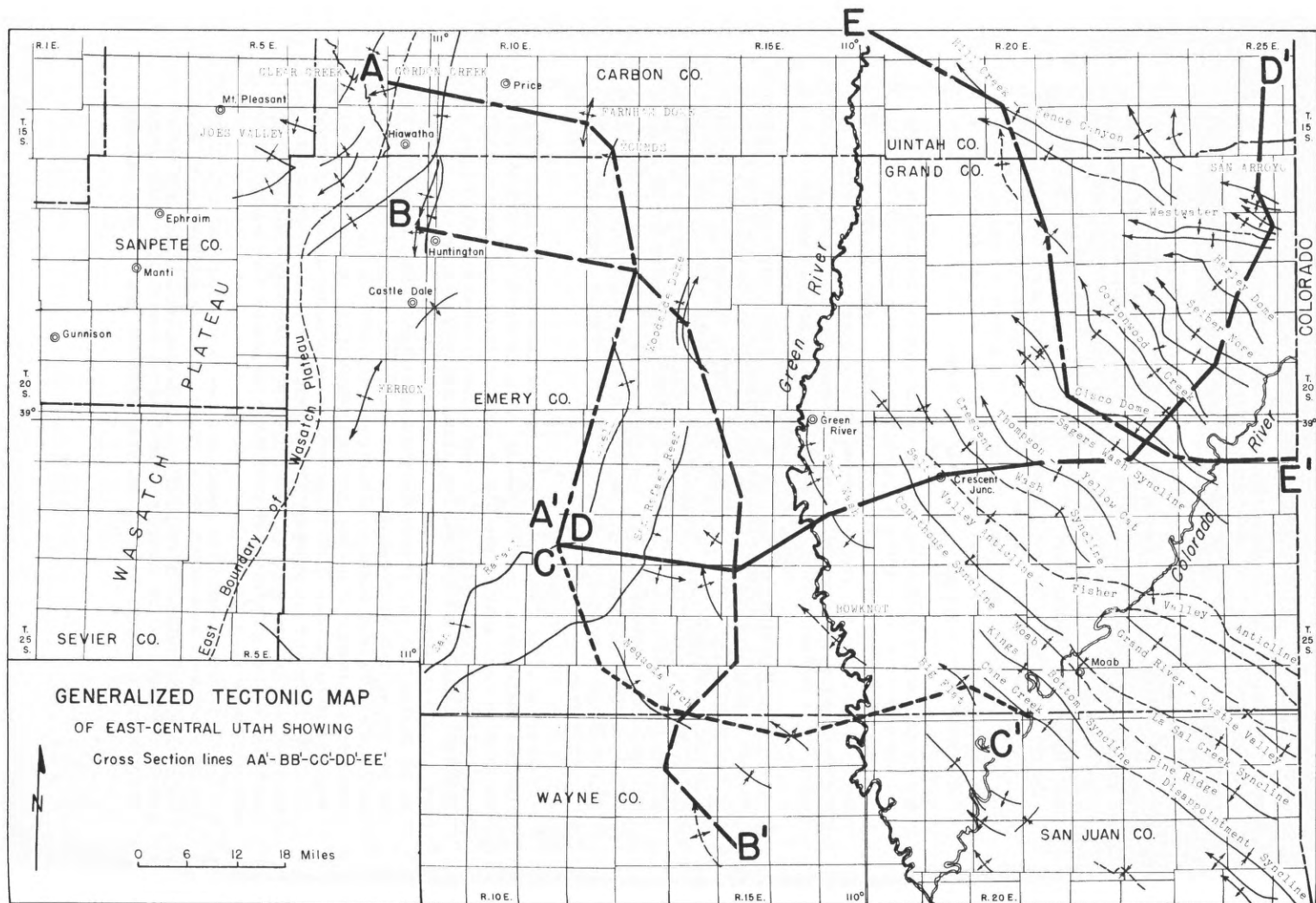
The change from marine to continental environment in the Paradox Basin is reflected in the carbonates of Wolfcampian (Permian) age. Intermittent erosional intervals were interspersed with marine invasions and accompanying carbonate deposition (Wolfcampian). Sands on the west and north interfingered with red arkosic continental sedimentary rocks derived principally from the Uncompahgre. Periodic uplift of the Uncompahgre Highland, and compressive stresses acting from the southwest produced a series of northwest-trending structures in the Paradox Basin. Plastic flowage of thick evaporites and black shales of the Paradox formation was induced by these stresses and produced numerous salt domes, salt plugs, and salt anticlines. The growth of some of the evaporite structures continued until Late Jurassic time, and was accompanied by a persistent westward tilting of the Colorado Plateau.

Early in the Triassic Period, red-bed floodplain deposits spread over the Plateau from uplands in Colorado and New Mexico, interfingering with predominantly marine sands, siltstones, and limestones, being deposited in the western geosyncline and adjacent areas. In Late Triassic, non-marine sedimentary rocks first began to collect upon the exposed Precambrian rocks on the surface of the now quiescent and deeply eroded Uncompahgre Highland.

Westward tilting of the Colorado Plateau continued into Jurassic time. A unique and widespread dune sand deposition began in Late Triassic time. Oscillating shallow seas deposited thin marine and estuary sedimentary units which interfingered with, or were interbedded with, the thick sands during several eastward advances of the Late Triassic and Jurassic seas. With the final retreat of the Jurassic sea, widespread playa, floodplain, and lacustrine conditions developed. Muds, limestones, sandstones, and conglomerates of the Morrison formation accumulated. Abundant volcanic debris in the Morrison is probably related to volcanism associated with the Nevadan orogeny of western Utah and Nevada.

The destruction of the Cordilleran geosyncline by these orogenic forces transformed the western area from a depositional basin persisting into Late Jurassic time to an actively positive area which supplied clastic sediments eastward across the Colorado Plateau as that area began to subside beneath the encroaching Cretaceous sea. The coarse clastics of the Cedar Mountain, Buckhorn, and Dakota units reflect this event. The thick marine Mancos shale section of eastern Utah and western Colorado intertongues and grades westward into sandstones and conglomerates of the Mesaverde group of the Wasatch Mountains and Wasatch Plateau, reflecting periodic uplifts of the orogenic belt along the eastern margin of the old Cordilleran geosyncline. In later Cretaceous time, the coarser clastics of the Mesaverde group extended eastward over the Colorado Plateau and are exposed in the spectacular escarpment of the Book Cliffs. Swampy coastal-plain conditions in a humid temperate climate resulted in extensive coal deposits of the Wasatch Plateau of eastern Utah and the Mesaverde Plateau of western Colorado.

Tertiary continental sedimentary rocks, similar to those exposed in the Roan Cliffs and found beneath the Uinta Basin, were probably deposited over most of east-central Utah, but are now absent south of the Roan Cliffs. These rocks were principally derived from the active thrust-fault belts of the Wasatch



Mountains. The region was elevated several thousand feet above sea level in Late Tertiary time, causing the rejuvenation of many pre-existing structures and the development of new ones. Salt in many of the evaporite structures in the Paradox Basin was extensively leached by ground water, and numerous complex slump and collapse features developed. Rapid erosion, subsequent to this major uplift, has removed all the Tertiary and many of the other sediments from the region and in some places has exposed Precambrian rocks at the surface.

MAJOR STRUCTURAL FEATURES

San Rafael Swell

The San Rafael Swell is a large northeast-trending closed anticlinal feature located principally in Emery County. The absence of Pennsylvanian rocks on part of the structure, and in bordering areas, indicates that this region was tectonically positive, or at least above sea level, during or immediately following Pennsylvanian time. If sediments were deposited here during Des Moines, Missouri, and Virgil (Pennsylvanian) time, they were removed prior to Wolfcampian (Early Permian) deposition. Herman and Sharps (1956) have named this ancient high the "Emery Uplift." Sedimentary rocks younger than Jurassic have been removed from the crest by post-Laramide erosion.

Uncompahgre Highland

The Uncompahgre Highland is a major northwesterly-plunging anticline, with a structural history dating back to Late Mississippian or Early Pennsylvanian time. This structure plunges under the Book and Roan Cliffs on the north and rises on the southeast to form the high mesas in southwestern Colorado. Uplift of this element, its denudation and contribution of sediments to the Paradox Basin on the west, its eventual burial under Upper Triassic sediments, and its rejuvenation in Late Cretaceous or Early Tertiary time (Laramide), strongly influences the geologic history of the region. Several important gas fields have accumulated in Jurassic, Cretaceous, and Tertiary rocks related to this feature.

Paradox Basin

The northern extension of the Paradox Evaporite Basin is one of the most complex and interesting geological features of Utah. It is separated abruptly from the Uncompahgre Highland on the northeast by a large, subsurface fault (Section D-D'). Eastward tilting against the fault produced an asymmetrical, subsiding basin. Thick deposits of Pennsylvanian carbonate, clastic and evaporite sedimentary rocks, and dominantly clastic Permian sediments filled the basin. Maximum thicknesses are found near the fault, where arkosic rocks derived from the highland accumulated. Numerous evaporite plugs and linear intrusions formed in Late Pennsylvanian and in post-Pennsylvanian time by flowage of evaporite deposits of the Paradox formation, into overlying rocks along northwest-southeast structural trends, principally in the deeper parts of the basin.

Arms of the Paradox sea extended northward along the east side of the San Rafael Swell and westward across the south plunge of the Swell in the vicinity of Cainville (Wengerd, 1958, and Wengerd and Matheny, 1958). A possible sea connection to the Oquirrh Basin on the northwest in the vicinity of Farnham dome is indicated in deep wells. Although it has been suggested that these structurally low extensions may have been points of supply for cyclic recharge of fresh sea water into the subsiding Paradox evaporite basin, most evidence indicates that

the main connection of the embayment with normal marine conditions lay to the southeast (Herman and Sharps, 1956). Evaporite deposition continued longer in the northern end of the basin where thick salt, anhydrite, and potash deposition persisted beyond the time when normal marine conditions were restored in the southern part of the basin.

Rapid changes in the Pennsylvanian rocks, from fine clastics and evaporites to shelf carbonates, occur along the margins of the northern Paradox Basin. This transition results largely from a sedimentary wedgeout of the Paradox evaporite and black shale facies against the fringing positive or shelf areas. The wedgeout on the west is much less abrupt than on the northeast, where the carbonate-evaporite facies grades into a thick arkosic facies which is sharply terminated against the basin-flanking Uncompahgre fault. The fault has maximum displacement probably in excess of 15,000 feet.

During 1961, Richfield Oil Company drilled No. 1 Onion Creek Unit in NE SW Sec. 31, T-23-S, R-24-E to 13,922 feet and was still in the Paradox member at total depth. Late in 1962, Phillips Petroleum Company was drilling a Devonian test three miles southwest on the same project.

STRATIGRAPHY

Precambrian

Foliated schists and gneisses, lesser granite, granite gneiss, and granite pegmatites have been penetrated in wells on the San Rafael Swell.

Cambrian Period

Very few wells have penetrated the Cambrian in the northern Paradox Basin. The Cambrian in the northern San Rafael Swell area consists of a lower quartzite, a middle shale, and an upper carbonate unit. Cambrian sediments are not known over the site of the Uncompahgre Highland. The lower units of the Cambrian wedge out eastward across the Paradox Basin from the San Rafael Swell as they do in areas to the north and south in the widespread Cambrian overlap on the Colorado Plateau craton.

Ordovician and Silurian Periods

Rocks of Ordovician and Silurian age have not been definitely identified in the San Rafael Swell and Paradox Basin.

Devonian Period

Several hundred feet of Devonian rocks have been identified in wells in the Paradox Basin, and oil production has been established in the Lisbon field from two of the units (Ouray limestone and McCracken sandstone). Devonian sediments, including the glauconitic shale, siltstone, sandstone, and limestone sequence of the Elbert formation and the overlying Ouray limestone, have also been identified in wells in the San Rafael Swell and in the northern Paradox Basin.

Mississippian Period

Mississippian rocks are regionally thin over the Colorado Plateau. Basal Mississippian rocks in wells drilled in central Utah are limestones and dolomites, and are generally referred to as the Madison and Deseret limestones. In the Paradox Basin, the terminology generally used is Leadville (Deseret?) for the dominantly limestone upper unit of the Mississippian sequence and Madison for the lower unit which is mostly dolomite.

The Mississippian formations of the Oquirrh Basin extend into the northeastern part of the area. The Deseret is overlain by the Humbug formation, composed of poorly-sorted sandstone interbedded with argillaceous limestone, and the Manning Canyon formation, which consists of interbedded dark carbonaceous shale, fine-grained sandstone and black argillaceous limestone. This section wedges out southward on the north plunge of the San Rafael Swell and south-eastward under the Paradox Basin (sections A-A' and B-B'). The Mississippian-Pennsylvanian boundary occurs in the upper part of the Manning Canyon shale.

In Late Mississippian time a general uplift resulted in widespread solution, mechanical weathering, and erosion of the Mississippian carbonate rocks. Porosity developed near the erosion surface and in thin zones beneath it, and often in a zone 100 to 200 feet below the top. Shows of live oil and flammable and non-flammable gas have been encountered in Mississippian rocks in several wells, and commercial oil has been discovered in Mississippian rocks at Big Flat, Salt Wash, and on Lisbon anticline. Intensive exploration should result in the discovery of additional areas where porous or fractured limestones and dolomitized sections form stratigraphic traps, or have been folded into structural traps, with resulting commercial oil and gas production.

Pennsylvanian and Permian Periods

SYSTEM	SERIES	GROUP
Permian	Leonard Wolfcamp	Cutler
Pennsylvanian	Virgil Missouri Des Moines Atoka Morrow	Hermosa

Wengerd (1958) and Wengerd and Matheny (1958) suggested several revisions of Pennsylvanian terminology and stratigraphic subdivisions. Their suggestions are here followed.

The Molas formation, a presumed regolith formed on the Mississippian erosion surface, when the Uncompahgre Highland began to rise, forms the base of the Pennsylvanian sequence. The Molas is a widespread unit composed of varicolored silty and waxy shales and thin beds of limestone and sandstone. Sedimentary rocks between the Molas formation and the Cutler formation are placed in the Hermosa group, which as thus defined, is subdivided, in ascending order, into the Pinkerton Trail formation, the Paradox formation, and the Honaker Trail formation. The Pinkerton Trail is a dark gray, fine to medium-crystalline fossiliferous limestone interbedded with silty shale.

The Paradox formation is divisible into three members where the salt section is present. The lower member is composed of interbedded shales, siltstones, anhydrite, and dolomite or limestone. The middle, or evaporite, member consists of cyclic interbeds of organic black shales, dolomite, anhydrite, gypsum, and salt. The evaporites wedge out toward the marginal shelf areas. The upper member, a biostromal limestone or dolomite, has been subdivided into an upper (Ismay) zone and a lower (Desert Creek zone) in areas where productive in the southern part of the Paradox Basin.

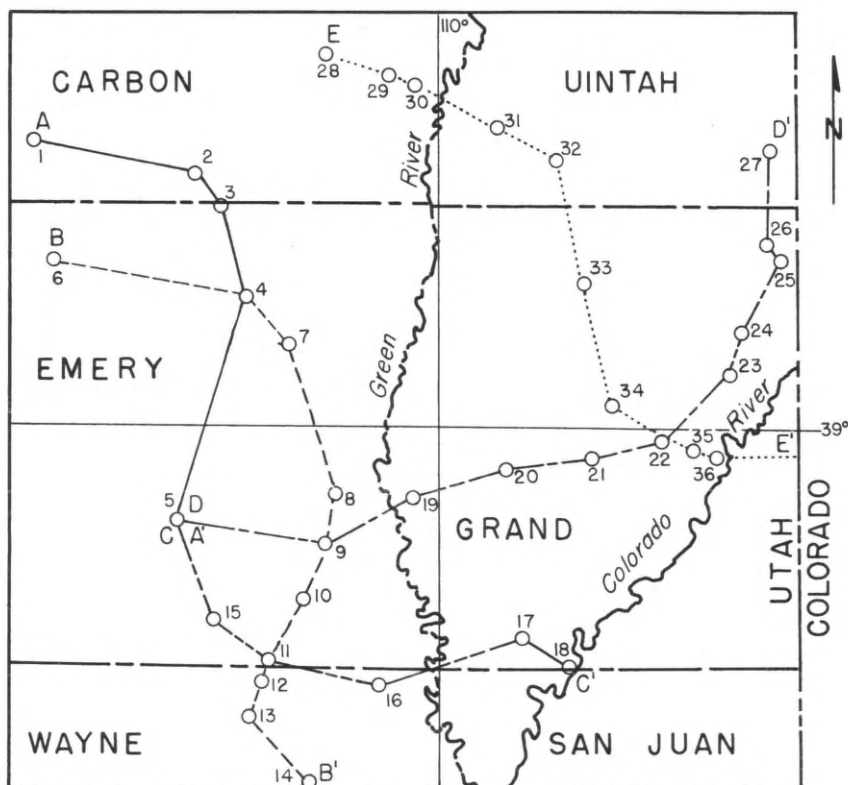


Figure 112. Cross Section Index Map.

The Honaker Trail formation, composed of cherty limestone and dolomite, shale, siltstone, and sandstone, includes carbonate sediments of both Pennsylvanian and Permian age. It grades northwest into the Oquirrh formation of the Cordilleran geosyncline, and eastward into a coarse clastic arkosic facies near the Uncompahgre Highland. Clean, well-sorted, fine-grained, orthoquartzose sandstones occur in the Honaker Trail equivalents southeast of the San Rafael Swell. Several good shows of oil have been encountered in these sands, but no production has been established.

In Late Pennsylvanian time prior to the deposition of Wolfcampian (Permian) sediments (Herman and Sharps, 1956), most of the Paradox Salt Embayment was being eroded after a period of Pennsylvanian folding and faulting. In the center of the embayment, Virgil sediments are overlain by Wolfcampian strata. Toward the west, strata of Wolfcampian age rest on progressively older Pennsylvanian rocks, and in the San Rafael Swell on rocks of Mississippian age.

At the top of the Honaker Trail formation, interbedded and intertonguing fossiliferous marine limestones, reddish siltstones, and red calcareous sandstones are Late Pennsylvanian in age near Moab (Henbest, 1948), but similar rocks are Wolfcampian (Permian) in age farther west. The exact relationship between these unassigned facies, formerly referred to as "Rico", and the Wolfcampian carbonates that are included in the Honaker Trail formation is still not clearly understood. Presumably, they intertongue westward.

Cutler stratigraphy in the Paradox Basin is characterized by interfingering light-colored sandstones and red beds, which were derived from source areas in opposite directions. Tongues of coarse arkosic sandstones, siltstones, and shales, up to 8,000 feet in thickness, extend westward into the basin from the Uncompahgre uplift. Individual units thin rapidly and decrease in grain size in a westward direction and change to predominantly siltstone and shale red-bed deposits. These units wedge out between light-colored sandstone tongues of the Permian "Coconino" and White Rim that extend eastward into the Paradox Basin and persist to some degree nearly as far as the Utah-Colorado boundary. Some red-bed tongues project westward to the San Rafael Swell. Where sandstone and red beds interfinger in nearly equal proportions, the sequence is usually named the Cutler formation, and individual units are designated as members or tongues.

The "Coconino sandstone", well exposed on the San Rafael Swell, is a white to light-gray, generally fine-grained, rounded to subangular quartz sandstone. It is massive and cross-bedded, and is very similar lithologically to other sandstone tongues of the Cutler and Toroweap formations and to the type Coconino sandstone of the Grand Canyon area. According to McKee (1954), the type Coconino thins rapidly northward from the Grand Canyon and wedges out a few miles north of the Utah-Arizona boundary. The "Coconino" of the San Rafael Swell may include some Coconino equivalents not necessarily continuous with the Grand Canyon type locality, but also includes parts of the Toroweap sandstone and the White Rim and Cedar Mesa sandstone members of the Cutler formation, which are widespread throughout southeastern Utah.

Above the "Coconino" is the white or light gray to brown, sandy, dolomitic, cherty Kaibab limestone, present along the western part of the Paradox Basin and extending only a few miles east from the San Rafael Swell. The limestone was deposited in a sea that transgressed north or northeast from its principal area of development in southwestern Utah and northwestern Arizona. The Kaibab in the vicinity of the San Rafael Swell is correlative with only the top part of the type Kaibab in Kane County, Utah (McKee, 1938). The lower units are not represented.

Triassic Period

The Moenkopi and Chinle formations are present throughout the San Rafael Swell and Paradox Basin except where local unconformities are present. The Chinle lies directly on Precambrian or granite wash of unknown age, over most of the northern part of the Uncompahgre Highland. The upper part of the Moenkopi may be present at some localities on the Uncompahgre.

The Moenkopi formation consists principally of thin-bedded reddish siltstones, with a middle marine limestone unit (Sinbad) in the San Rafael Swell and westward. The marine unit wedges out and interfingers with red-bed siltstones along the east edge of the San Rafael Swell. A dolomitic zone, which may represent the Sinbad interval, has been detected in several wells as far east as the Salt Valley anticline. Thickness of the Moenkopi in the Farnham dome area is approximately 543 feet. The Cities Service No. 1 Government well at Grassy Trails (NW NW Sec. 1, T-16-S, R-12-E) and the El Paso No. 1 Pack Saddle well (SE NE Sec. 12, T-18-S, R-12-E), drilled southeast of Farnham dome, encountered the eastern wedge edge of the marine facies of the Moenkopi. Petroliferous beds of calcareous siltstone and limestone interfinger with reddish siltstones in these wells. Cities Service No. 1 Government was completed in September 1961 as an oil discovery (84.5 barrels of oil per day) in the Moenkopi.

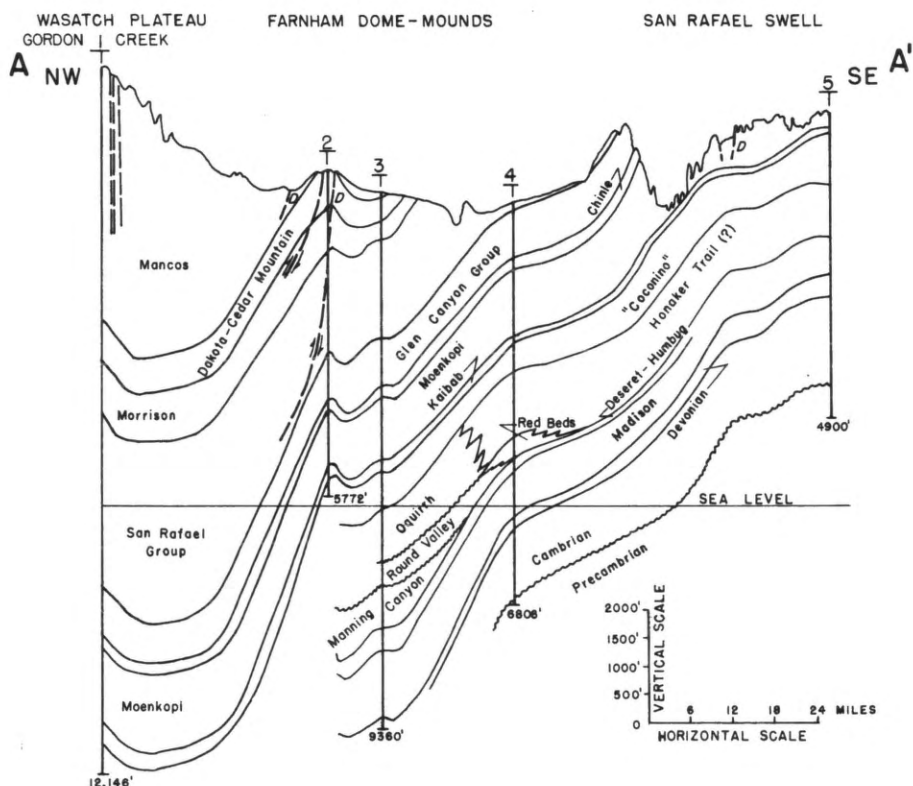


Figure 113. Cross Section A-A'

Rocks in the San Rafael Swell and east-central Utah, formerly called Shinarump, are now generally mapped as the Moss Back sandstone member of the Chinle formation (Stewart and Smith, 1954). The Shinarump may occur in patchy remnants in a few localities, but is generally well developed in areas farther south near the Colorado River and southward into Arizona.

The Chinle formation consists of several hundred feet of varicolored shales with interbedded minor sandstones of fluvial origin. Considerable bentonite, glass shards, and other volcanic material is present. Locally, the sandstone members of the Chinle formation are petroliferous.

Jurassic and Triassic (?) Periods

Jurassic rocks include the Glen Canyon and San Rafael groups, and the Morrison formation (Stokes, 1962). Natural gas is currently being produced from sandstones of the Entrada and Morrison in numerous small fields between Cisco and the Colorado-Utah boundary. Oil is produced from Morrison sands at Bar-X, Seiber nose, and Cisco Townsite, and in Sec. 8, T-20-S, R-24-E.

Cretaceous Period

Cretaceous rocks exhibit a striking west-to-east facies change, which reflects the eastward transition from continental sediments in central Utah into the dominantly marine rocks of eastern Utah and western Colorado. Most of the Cretaceous sediments were derived from the Nevadan thrust fault and fold belt of western Utah. Thick conglomerate and sandstone units, with interbedded continental shales, siltstones, and mudstones, grade eastward to the gray marine shales of the Mancos. Sandstone units which persist to the east transgress time boundaries upward and represent deposits of a strand line progressively retreating eastward across east-central Utah. Oscillations of the Cretaceous sea over the Wasatch Plateau and through the Book Cliffs area into Colorado have produced a complex assemblage of coarse and fine clastic sedimentary rocks. A final regression in Late Cretaceous time is indicated by the coal-bearing sandstone units in the Book Cliffs area which persist eastward into Colorado, and grade stratigraphically upward into continental sediments of Latest Cretaceous and Tertiary age. Burger (Paper 12) gives a detailed discussion of the geology of the Utah Cretaceous deposits.

Stratigraphic traps formed by porosity and permeability variations, wedgeouts of lenticular sands, and structural traps in the Ferron and other Cretaceous sandstone lenses have been explored for natural gas and possible oil accumulation in the Wasatch Plateau and eastward through Grand County into western Colorado. Eastward wedging of some of these units and sands of the Mesa-verde in the Book Cliffs and east-central Utah offer many possibilities for discovery of oil and gas.

Tertiary Period

Tertiary beds are present only north of the Book Cliffs in the area under discussion. They form the Roan Cliffs, a second major escarpment above and paralleling the Book Cliffs, and dip into the Uinta Basin toward the north. South of this escarpment Tertiary rocks are not known. Hardy (Paper 13) gives a detailed discussion of the Tertiary rocks of Utah. Active exploration has resulted in the discovery of several oil and gas fields along the southern and eastern margins of the Uinta Basin.

A large accumulation of bituminous residue, principally in the Wasatch, but extending into the Green River formation, contains in excess of 700,000,000 barrels of bitumen in a single deposit near Sunnyside, Utah (T-14-S, R-14-E). Bitumen occurs in sandstone lenses surrounded by impervious shales, the occurrence appearing to be an outstanding example of a stratigraphic trap reservoir exposed to the surface by erosion. Numerous exposures of bituminous sandstone can be observed along the Roan Cliffs from their juncture with the northern Wasatch Plateau, eastward to the Colorado-Utah boundary. Production of gas at Peter's Point and oil at Jack's Canyon has been developed in similar lenticular sandstones.

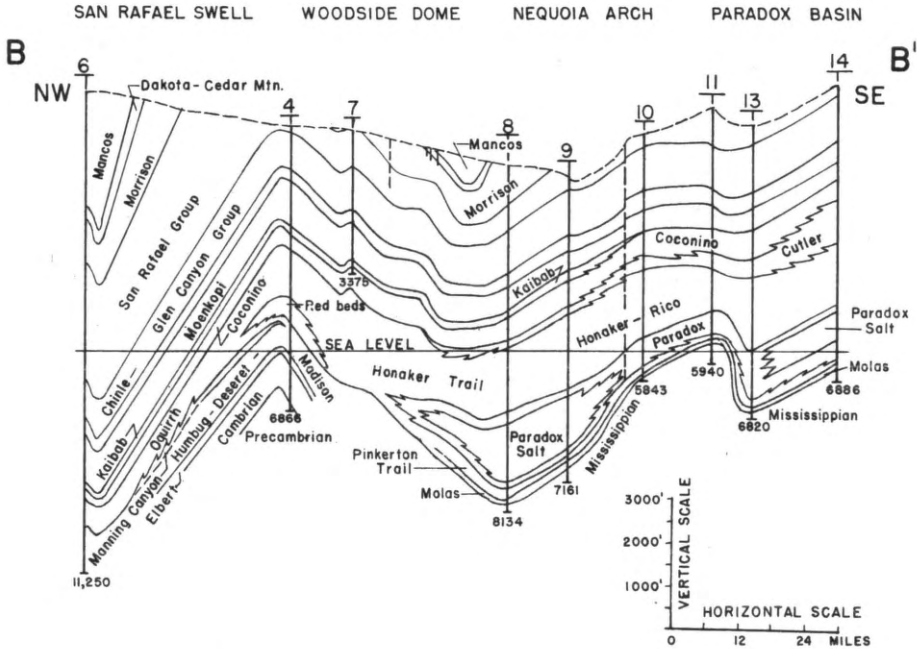


Figure 114. Cross Section B-B'

SUMMARY OF OIL AND GAS POSSIBILITIES

Brief History of Exploration

The first attempt to explore for oil and gas in Utah was in the area covered by this paper. In 1891 Simon Bamberger drilled to a depth of 1,000 feet, a few miles south of Green River in T-21-S, R-16-E. His well bottomed in the Morrison with no "shows" reported. Since then, a total of nearly 500 wells have been drilled in east-central Utah. Most of the early tests were confined to shallow exploration of Mesozoic rocks and Pennsylvanian sediments in the cores of the salt anticlines. Important commercial discoveries have been made in numerous fields on the Uncompahgre Highland and southern Uinta Basin, especially since 1955. Recent discoveries have been made in the northern Paradox Basin, at Big Flat, Lisbon, and Salt Wash. These recent discoveries have lead to an upsurge of drilling activity in the Paradox and Uinta Basins and on the north plunge of the Uncompahgre Highland in eastern Grand County.

Suggested Exploration Guides

1. Zones of porosity and some oil shows have been encountered in the few wells penetrating the marine Devonian strata.

2. Secondary porosity zones developed as a result of widespread erosion of Mississippian carbonates prior to Pennsylvanian deposition, and persistent zones of vuggy and intergranular porosity occur in dolomites and limestones in the upper several hundred feet of the Mississippian. The Pure Oil Company's discoveries at Big Flat and Lisbon and Pan American's Salt Wash discovery demonstrate the potential of Mississippian rocks in east-central Utah. Shell Oil Company tested gas at the rate of 1,820,000 cubic feet per day from the Manning Canyon formation at their No. 1 North Springs Unit well in Sec. 27, T-15-S, R-9-E, during 1958. Dead oil staining at Moonshine Wash (T-25-S, R-1-S and -16-E) and other localities in flushed vuggy porosity zones further indicates the productive potential of rocks of Mississippian age.

3. Lateral facies changes in Pennsylvanian and Permian rocks on the marginal western shelf of the Paradox Basin may have created hydrocarbon traps-- the widely distributed porous carbonates of the Paradox formation intertongue with black shales to form a favorable combination of source and reservoir rocks. Extremely rapid changes which often contain zones of favorable porosity occur within the Paradox formation where it changes from the basinal and evaporite facies to the marginal shelf facies. Stratigraphic-trap possibilities are good in these marginal areas which exist along the south and east flanks of the San Rafael Swell, the north and south flanks of the Nequioia Arch, and probably in the northern part of the Paradox Basin. Recently two oil wells have been successfully complete in a fractured clastic zone within the salt facies of the Paradox formation at Big Flat. During late 1958, Tennessee Gas Transmission Company drilled 110 feet of oil-stained porous biohermal reef material in Sec. 4, T-31-S, R-12-E, in the lower Paradox. Water saturation was too high for oil production. Offset wells were all dry holes.

Good shows of oil were also noted in sandstones in the Honaker Trail (upper Hermosa) formation in a well drilled by Paradox Production Company in T-30-S, R-13-E during 1957. The Kaibab limestone and "Coconino" sandstone are sometimes saturated with dead oil when encountered in wells in east-central Utah. Live oil was recovered from "Coconino" sandstone in a well drilled by Tennessee

Table XVIII. Discovery and Production information relating to Oil and Gas Fields in East-Central Utah. (prepared from Petrogram)

FIELD	LOCATION	DISCOVERY DATE	DISCOVERY WELL	NO. OF WELLS Producing Produ- ing ciple		PROD. HORIZON (S)	AVER. PROD. DEPTH	DEEPEST FM. DRILLED	1961 PRODUCTION Oil-BBLS Gas-MCF	
BAR-X AND STATELINE	17S-25, 26E	8-8-48	STANOLIND # 1 (17S-25E, 12 SESE)	9	13	Cret. Dakota and Buckhorn, Jur. Salt Wash & Entrada	3000 3500	Precambrian Granite	0	1,167,330
BIG FLAT	26S-19E	11-1-57	PURE # 1 Unit (26S-19E, 14 SWSE)	2	4	Mississippian	7700	Cambrian	23,838	18,399
CISCO DOME (Shut-in gas)	19,20S-21, 22E	4-13-25	UTOCO # 2 (20S-22E, 30 NWSW)	0	16	Cret. Dakota, Cedar Mt., Jur. Morrison	2100 2300	Precambrian	0	0
CISCO SPRINGS (Shut-in gas)	20S-23E	1955	THREE STATES, ET AL # 1	0	1	Jur. Morrison	1775	Jur. Entrada	0	0
N. CISCO SPR- INGS (Shut-in gas)	19S-23E	1955	INTERNAT'L DRLG. # 1 Linney (19S-23E, 20 NWSW)	0	1	Cret. Dakota	2820	Cret. Dakota	0	0
CISCO TOWNSITE	21S-23E	4-1-54	D&N MINING #2 Murray (21S-23E, 24 NWNE)	0	1	Jur. Morrison	500	Jur. Morrison	145	0
CLEAR CREEK	13-15S-6,7E	11-1-51	BYRD FROST # 1 (14S-7E, 5 NWSE)	10	15	Cret. Ferron	4700	Jur. Morrison	0	9,413,620
CRESCENT JUNCTION (Abandoned oil)	22S-19E	6-22-43	AMER. POTASH # 1 (22S-19E, 16 NWNE)	0	2 (abd.)	Jur. Morrison	1600	Jur. Morrison	0	0
DANISH WASH (Shut-in gas)	19S-24E	6-6-55	SMITH MOORE, ET AL #1 Govt. (19S-24E, 31 SENE)	0	2	Cret. Dakota	1965'	Jur. Morrison	0	0
FARNHAM DOME	14, 15S-11, 12E	1921	UTAH OIL REF. # 1 (15S-11E, 12S $\frac{1}{2}$)	1	1	Jur. Navajo	3000	Devonian (?)	0	78,136 (CO ₂)
FENCE CANYON (Shut-in gas)	15,15 $\frac{1}{2}$ S-22,23E	4-19-60	TEXACO # 1 Unit (15S-22E, 36 NESE)	0	3	Cret. Dakota Cret. Buckhorn Jur. Morrison Cret. Ferron	8560 8175 8450 810	Precambrian	0	0
FERRON (Shut-in gas)	20,21S-7E	6-23-57	AMER. PETROFINA #1-22 (20S-7E, 22 NESW)	0	3	Cret. Ferron	810	Cret. Dakota	0	0
FLAT CANYON	16S-6E	1953	THREE STATES #1 Kearns (16S-6E, 27 NWNE)	3	3	Cret. Ferron Cret. Dakota	5900 7020	Cret. Dakota	0	193,084
GORDON CREEK (Shut-in, mostly CO ₂)	14S-7,8E	5-10-48	PACIFIC WESTERN # 1 (14S-7E, 24 SENE)	0	3	Cret. Ferron Triassic Sinbad	3500 10,900	Penn. Hermosa	0	0
GRASSY TRAIL UNIT	15,16S-12, 13E	9-21-61	CITIES SERVICE # 1 Govt. (16S-12E, 1 NENW)	1	1	Triassic Moenkopi	3900	Mississippian	5851	0

HARLEY DOME (Shut-in gas and helium)	18,19S-25E	5-3-26	FALLGREN, ET AL # 1 (19S-25E, 4 SENE)	0	4	Jur. Morrison and Entrada	1000	Jur. Entrada	0	0
JOE'S VALLEY (Shut-in gas)	15S-6E	9-11-56	THREE STATES # 3 (15S-6E, 20 SWNW)	0	2	Cret. Perron Cret. Dakota	7000 7700	Cret. Dakota	0	13,609
LAST CHANCE (Abandoned gas)	26S-6,7E	12-16-34	RAMSEY PETR. # 1-X (26S-7E, 18 NWSW)	0	2(Abd.)	Triassic Moenkopi	2625	Permian Coconino	0	0
PETERS POINT (Incl. Jacks Canyon - shut- in oil and gas)	12, 13S-16,17E	1954	EL PASO # 3 Unit (13S-17E 8 SWSE)	0	6	Tert. Green River	3000	Cret. Mesaverde	0	0
SALT WASH	23S-17E	5-28-61	PAN AM # 1 Salt Wash (23S-17E, 15 NWSW)	1	1	Tert. Wasatch 4800	8700	Cambrian Lynch	1,236	9,350
SAN ARROYO (Shut-in gas)	16S-25,26E	10-9-55	SINCLAIR # 1 Govt. (16S-25E, 26 SENW)	0	6	Jur. Entrada 5250	4500	Precambrian	0	0
SEIBER NOSE	19,20S-24E	2-17-55	CARTER # 1 Larson- State (20S-24E, 2 NENW)	0	1	Jur. Morrison 1435	5250	Jur. Morrison	508	0
STONE CABIN (Shut-in gas)	12S-14E	1958	GREAT LAKE NAT. # 1 (12S-14E, 13 SWNE)	0	2	Tert. Wasatch	5200	Cret. Mancos	0	0
UNNAMED (Horse Point Unit, Sl gas)	16S-23E	12-11-61	TIDEWATER # 1-X Unit (16S-23,14 NWNE)	0	1	Cret. Dakota	8050	Jur. Salt Wash	0	0
UNNAMED (East Canyon Unit, Sl gas)	16S-24E	1-16-62	R.C. UNDERWOOD # 1 (16S-24E, 13 SENE)	0	2	Cret. Cedar Mtn., Jur. Morrison	5895 6136	Jur. Morrison	0	0
UNNAMED (Diamond Ridge Unit, shut-in gas)	16,17S-22,23E	2-2-60	SUNRAY #2 Unit (17S-22E, 23 NENE)	0	2	Cret. Dakota	7270	Jur. Salt Wash	0	0
UNNAMED (Bryson Can. Unit, Sl gas)	17S-24E	10-6-60	TREND OIL # 1 Unit (17S-24E, 10 SESW)	0	4	Cret. Castlegate 660	660	Jur. Entrada	0	0
UNNAMED (Book Cliffs Unit, Sl gas)	18S-22E	6-13-61	GREAT YELLOWSTONE # 1 (18S-22E, 32 SESE)	0	1	Cret. Dakota 4330 Jur. Morrison 4560 Cret. Dakota 5210	4330 4560 5210	Jur. Salt Wash	0	0
UNNAMED	20S-24E	1-20-61	PUMPELLY # 1 Fee (20S-24E, 8 NENE)	2	2	Jur. Brushy Basin	1585	Jur. Brushy Basin	9,159	0
WESTWATER	17S-23,24E	11-6-57	OIL, INC. # 18-C-2 Fed. (17S-24E, 18 SENE)	9	9	Cret. Castlegate 900 Cret. Dakota 4400 Jur. Morrison 5200 Jur. Entrada 5700 Permian Coconono 3120	900 4400 5200 5700 3120	Jur. Entrada	0	2,354,094
WOODSIDE (Shut -in CO ₂ and Helium)	18,19S-13,14E	2-7-24	UTAH OIL # 1 (19S-13E,12 SWSE)	0	1	Permian Coconono	3120	Permian	0	0

Gas Transmission Company at Sorrel Butte in T-29-S, R-12-E late in 1958. Attempts to produce the oil commercially failed.

4. The marine calcareous Sinbad member of the Moenkopi formation in the San Rafael Swell and the Nequoia Arch is oil saturated in most wells. In August 1958 Superior Oil Company recovered live oil from the Moenkopi at Iron Wash in T-24-S, R-13-E, but failed to complete a commercial well because of low pressures and permeability. Cities Service recently completed several oil wells just north of the San Rafael Swell in the Grassy Trail unit. Equity Oil Company also has encountered good shows of oil in the Moenkopi. More favorable porosity and permeability may be present within this widespread petroliferous unit.

5. Petroliferous sandstone facies of the Chinle fromation may contain oil, notably in the Nequoia Arch region and on the east flank of the San Rafael Swell. Shows of oil are common in these units when drilled and numerous saturated outcrops have been mapped.

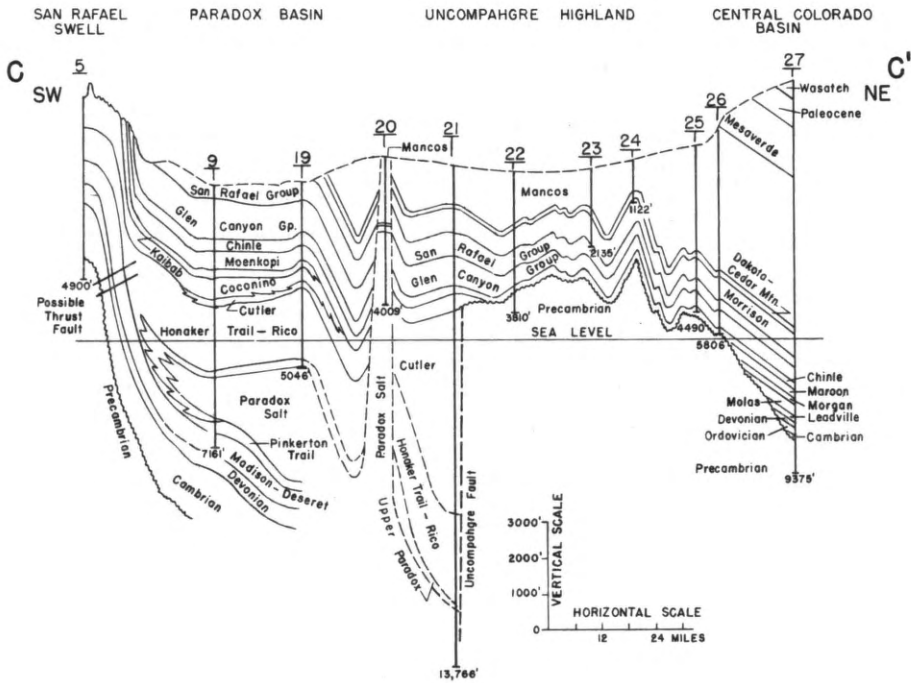


Figure 115. Cross Section C-C'

6. Gas accumulations are possible in sandstones of the Glen Canyon group around the north end of the Uncompahgre, as at Garmesa field in western Colorado, a few miles east of the Bar-X area. Nonflammable carbon dioxide gas is produced from this rock sequence at Farnham dome.

7. Gas occurs in the Entrada sandstone in the gentle folded belt around the Uncompahgre. Excellent porosity and permeability is characteristic. Entrada gas discoveries on the Bar-X, Westwater, and San Arroyo Wash structures and vicinity are low in heat value because of contained carbon dioxide, but volumes are large.

8. Lenticular sandstone beds within the Morrison, Burro Canyon-Cedar Mountain formations, and the Dakota sandstone produce gas and oil in numerous small fields in the Bar-X area.

9. Lenticular units of the Cretaceous Ferron sandstone produce gas at Clear Creek, Flat Canyon, and other fields of the Wasatch Plateau and may contain commercial gas in other areas, principally west of Farnham Dome and the San Rafael Swell.

10. Lenticular sandstone units in the Mesaverde group have yielded gas and oil in western Colorado, and gas north of the Book Cliffs in recently developed fields of the southeastern Uinta Basin.

11. Substantial production of oil and gas has been developed in the sandy facies in the Wasatch group and Green River formation north of the Book Cliffs, in the Uinta and Piceance Creek Basins. The bituminous sandstone deposits of the Sunnyside area, in T-13 and 14-S, R-13 and 14-E, are contained in these rock units. Many millions of barrels of oil residue are present.

In summary, the following formations produce oil or gas in east-central Utah:

Tertiary	Green River Wasatch
Cretaceous	Mesaverde Ferron Dakota Buckhorn Cedar Mountain
Jurassic	Morrison Entrada Navajo (carbon dioxide)
Triassic	Moenkopi (Sinbad member)
Permian	Coconino (carbon dioxide)
Mississippian	Undifferentiated

Summary of Individual Areas

San Rafael Swell: Permian "Coconino" and Kaibab formations and a small outcrop of Permian Wolfcamp strata are exposed in the core of the San Rafael Swell. A Mississippian outcrop has been reported at one locality. Many outcrops of the "Coconino" and Kaibab formations and sandstones and limestones of the overlying Moenkopi and Chinle formations are saturated with oil. Rocks of Pennsylvanian age are absent in wells drilled on top of the San Rafael Swell.

The surface structure of the swell is a broad dome with an axis trending slightly east of north. The major structural development probably was during the Late Cretaceous-Early Tertiary Laramide disturbances, though the region around and including parts of the swell (Emery uplift) appears to have been a mildly positive element during much of Pennsylvanian time.

The east flank is sharply defined by the so-called San Rafael "reef." Steeply dipping beds, in places exceeding 80 degrees, from a spectacular hogback, mostly in sandstones of the Glen Canyon group. Dips a short distance east

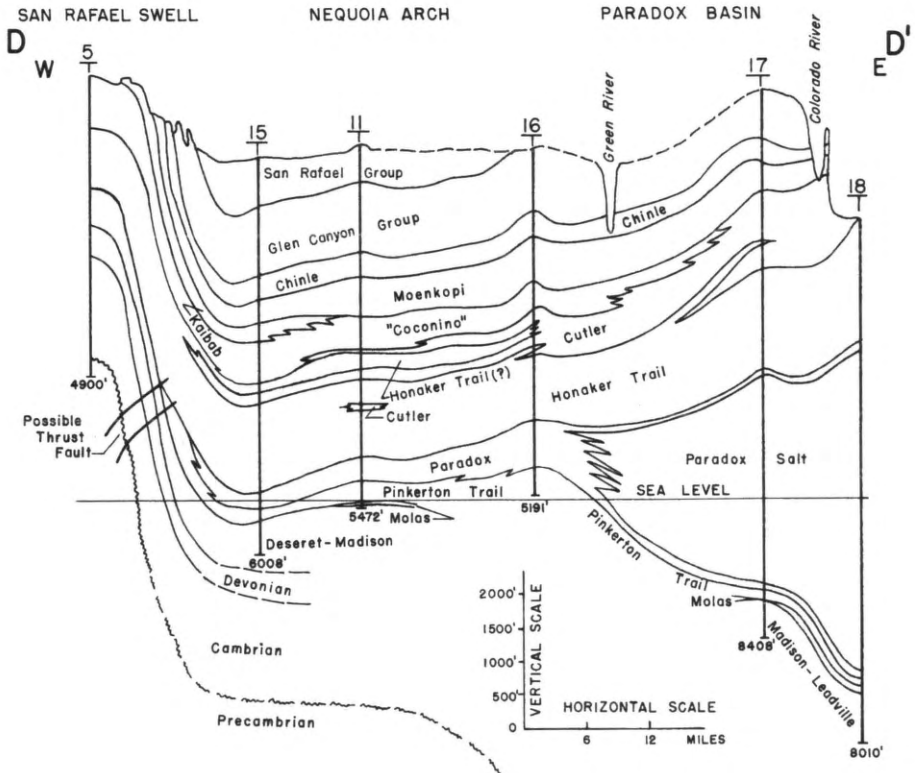


Figure 116. Cross Section D-D'

and west of the "Reef" are moderate to nearly horizontal. The steep east flank may have been formed by strong compressive stresses, with possible thrust faulting at depth. The discovery of high-angle thrust faulting at Farnham dome, on the north nose of the swell, and possibly at Huntington dome on the west, suggests that such compressive stresses were more prevalent in the shelf area than formerly believed. Furthermore, some workers believe that magnetic, seismic, and gravity profiles crossing the east flank of the swell strongly indicate thrust faulting.

The structural history which is emerging from recent studies of the San Rafael Swell area includes the discovery of a pre-Laramide cross fold or positive area of major importance. Mississippian and Pennsylvanian sediments thicken northward from the crest of the swell, where rocks of Pennsylvanian age are absent, into the Farnham dome area. A similar thinning is noted southwestward from Farnham Dome toward the Huntington dome. It appears, therefore, that the northwesterly-trending folds which flank the Paradox Basin in the Nequio Arch region may continue through the San Rafael Swell, at least as far west as the Huntington dome area. If the above suggested interpretations are found to be valid, the subsurface structure of the San Rafael Swell may be considerably more complex than indicated by the surface. Numerous stratigraphic and structural traps for oil and gas should be present surrounding the old San Rafael positive area, particularly in rocks of Pennsylvanian age. Therefore, a consideration of the petroleum possibilities of subsidiary structures related to the San Rafael Swell is of importance.

Woodside Anticline: The Woodside anticline is an asymmetrical structure on the east flank of the north-plunging nose of the San Rafael Swell in T-19-S, R-13-E. Surface closure is approximately 800 feet. The first of two wells (Burns No. 1 drilled in 1899) bottomed in the Navajo sandstone at 1,490 feet, with a show of oil reported in the Curtis or Entrada at 1,100 feet. The Utah Oil Refining Company No. 1 Fitzhugh, completed February 7, 1924, bottomed in the "Coconino" sandstone, and produced helium-rich gas from that formation at the rate of 6 to 10 million cubic feet per day. On March 21, 1924, the area was set aside as a helium reserve by the U.S. Government. Deeper formations with good oil and gas possibilities include all members of the Hermosa group and the carbonate rocks of the Mississippian and Devonian. Production rights to these deeper formations were leased to Humble Oil and Refining Company, which recently drilled a dry hole in SE SE Sec. 12, T-19-S, R-13-E.

Farnham Dome: Farnham dome is located on the north-plunging nose of the San Rafael Swell. Geophysical and subsurface studies by Equity Oil Company (Peterson, 1954, personal communication) indicate that minor surface faulting is associated with a major subsurface thrust fault. The surface structure is now known to be a drag-folded portion of the hanging wall of an overthrust fault which has overridden the west flank of a buried structure to the southeast. Earlier interpretations failed to recognize the thrust faulting, and the stratigraphic sequence was not correctly interpreted. Wells drilled on the surface dome pass through the overthrust into the west flank of the buried anticline at depth and encounter the Cedar Mountain formation and Buckhorn conglomerate. Production of carbon dioxide gas, which was once believed to be from the "Coconino" sandstone, is now known to come from a very similar lithologic unit, the Navajo sandstone.

Four wells have been drilled on the surface anticline. Three of them produced carbon dioxide gas from the Navajo sandstone, but have been abandoned. Two

wells were drilled on the sub-thrust anticline. One is producing carbon dioxide and one is a dry Devonian test completed as a carbon dioxide well in the Moenkopi. Non-commercial shows of inflammable gas mixed with carbon dioxide and light oil were encountered in the marine Sinbad member of the Moenkopi formation in most of the wells. Carbon dioxide gas from Farnham dome is piped to a dry ice manufacturing plant in the nearby town of Wellington.

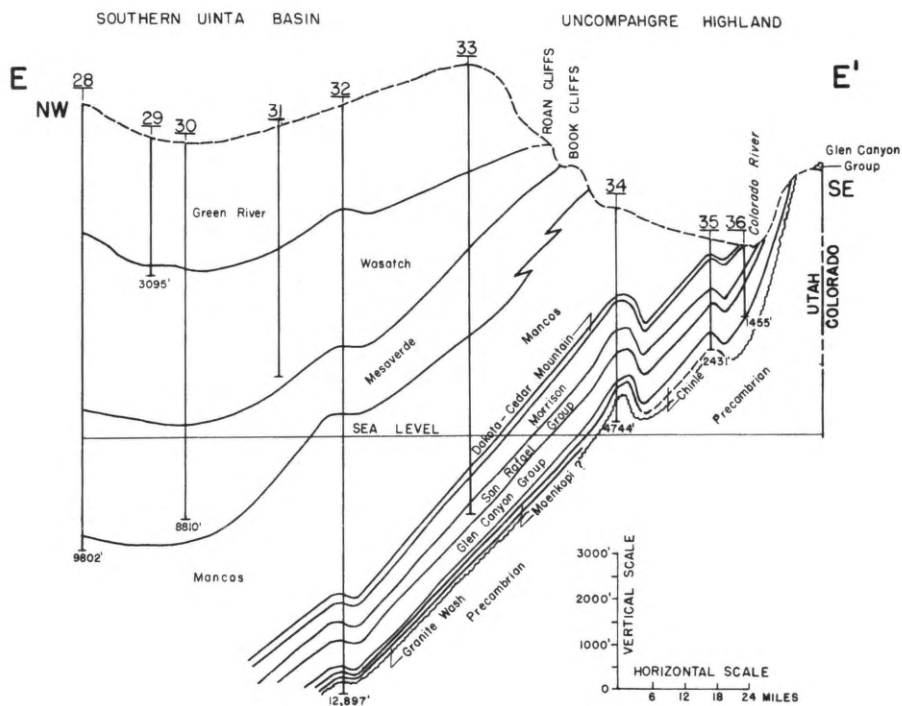


Figure 117. Cross Section E-E'

Mounds Structure: This structure, four miles southeast of Farnham dome, is a faulted anticline discovered by seismic surveys and subsurface well data. Folding occurs beneath an unconformity which appears to separate the Mississippian and Pennsylvanian. Three wells have been drilled. The Equity Oil Company No. 1 Mounds well was drilled to the Cambrian. No encouraging shows of oil or gas were found in the pre-Triassic beds, but the well was temporarily completed as a small gas producer from the marine section of the Triassic Moenkopi formation. The other two wells were drilled to the "Coconino". Encouraging shows of oil and flammable gas were found in the Moenkopi, but attempts to complete the wells as commercial producers failed because of low permeability. All of the wells were eventually plugged and abandoned. Recent successful completions of several oil wells in the Grassy Trail unit, two miles east of Mounds, has revived interest in the Mounds area.

The Farnham dome-Mounds area is within the transitional belt between the Cordilleran geosyncline, including the Oquirrh basin on the northwest, and the Colorado Plateau shelf on the east. A possible intermittent seaway connection may have existed here between the Oquirrh basin and the Paradox basin during part of Pennsylvanian time. Stratigraphic traps may occur in this area as a result of facies changes within the transitional belt.

Nequoia Arch: The Nequoia Arch is a large gentle northwest-plunging surface fold that extends from the Monument upwarp to the San Rafael Swell. Smaller surface folds, such as the Barrier Creek, Blue John, Sweetwater, and Big and Little Flattop anticlines, are superimposed upon the arch.

The Nequoia arch formed a salient out from the Emery "high" into the Paradox Basin during deposition of the Paradox formation. The Paradox thins westward from approximately 5,600 feet at the Cane Creek anticline, near Moab, to about 700 feet on the Nequoia Arch. Thick Paradox sections on the northeast and southwest thin rapidly toward the arch. Thinning takes place principally by shoreward wedgeout of individual beds in the basal Paradox formation in a few miles of overlap on the shelf area. The salt unit wedges out completely. The lithology of the Paradox formation on the Nequoia Arch is predominantly dolomite, limestone, anhydrite, minor sands, and thin black shales which represent the upper Paradox only. The section sharply contrasts with the thick salt, gypsum, anhydrite, and black shales encountered in wells a few miles to the north, south, and east in the Paradox Basin. Sedimentary units in the Paradox formation at this locality suggest a near-shore, shallow water environment, such an environment is often favorable for the development of porous organic barrier of oil and gas have been encountered in a majority of wells drilled through the Paradox formation. Although numerous dry holes have been drilled in the vicinity within the last seven years, it is probable that productive traps formed by folded porous beds, stratigraphic wedgeouts developed by organic "reefs", unconformities, and up-dip terminations or porous beds may yet be discovered in the Nequoia Arch region.

A thick section of porous and permeable sandstone, saturated with dead tarry oil was encountered in the "Coconino" at the Standard Oil Company of California Moonshine Wash No. 1 well in NE SW Sec. 32, T-25-S, R-15-E. This section was tested and yielded a few specks of light-brown oil with the drilling fluid. Several tests of the Paradox and porous Pinkerton Trail rocks yielded fluorescence, a few oil spots, a scum of oil, and minor gas shows. Excellent Mississippian vuggy and intercrystalline porosity containing some dead oil staining, and a trace of live oil was encountered in the same well. A drill stem test of this interval yielded 4,695 feet of salty sulphur water. Casing was set to shut off water. Attempts to acidize perforations and obtain production failed. It is possible that at a higher structural position the zone of vuggy Mississippian porosity encountered in this well might be productive.

The prospect for Moenkopi, "Coconino", Paradox, and Mississippian production appears favorable in the Nequoia Arch area. Although shows were encountered, the Paradox formation has lacked porosity in many wells. This section should be productive if areas of improved porosity and permeability can be found in favorable structural positions.

Table XIX. Supplement to Figures 113 through 117.

	Section A - A'	Section B - B'	Section C - C'	Section D - D'	Section E - E'
CENO. TERTIARY				Wasatch fm.	Green River
				Paleocene beds	Wasatch fm.
				Mesaverde group	Mesaverde group
CRETACEOUS	Mancos shale Ferron mbr.	Mancos shale Ferron mbr.	Mancos shale Ferron mbr.	Mancos shale Ferron mbr.	Mancos shale
	Dakota sandstone	Dakota sandstone	Dakota sandstone	Dakota sandstone	Dakota-Cedar Mtn.
	Cedar Mtn. fm. Buckhorn mbr.	Cedar Mtn. fm.	Cedar Mtn. fm.	Cedar Mtn. fm.	
	Morrison fm. Brushy Basin mbr. Salt Wash mbr.	Morrison fm. Brushy Basin mbr. Salt Wash mbr.	Morrison fm. Brushy Basin mbr. Salt Wash mbr.	Morrison fm. Brushy Basin mbr. Salt Wash mbr.	Morrison fm. Brushy Basin mbr. Salt Wash mbr.
	Summerville fm.	Summerville fm.	Summerville fm.	Summerville	Summerville fm.
	Curtis fm.	Curtis fm.	Curtis fm.	Curtis fm.	
	Entrada sandstone fm.	Entrada sandstone fm.	Entrada sandstone fm.	Entrada sandstone fm.	Entrada sandstone
	Carmel fm.	Carmel fm.	Carmel fm.	Carmel fm.	Carmel fm.
	Navajo sandstone	Navajo sandstone	Navajo sandstone	Navajo sandstone	Navajo sandstone
MESOZOIC JURASSIC	Kayenta fm.	Kayenta fm.	Kayenta fm.	Kayenta fm.	Kayenta fm.
	Wingate sandstone	Wingate sandstone	Wingate sandstone	Wingate sandstone	Wingate sandstone
	Chinle fm. Mossback mbr.	Chinle fm. Mossback mbr.	Chinle fm. Mossback mbr.	Chinle fm. Mossback mbr.	Chinle fm.
	Moenkopi fm. Sinbad mbr.	Moenkopi fm. Sinbad mbr.	Moenkopi fm. Sinbad mbr.	Moenkopi fm. Sinbad mbr.	Moenkopi fm.
	Kaibab fm.	Kaibab fm.	Kaibab fm.	Kaibab fm.	
	Coconino sandstone	Coconino Cutler	Coconino Cutler	Coconino Cutler	
	Hermosa - Oquirrh fm.	Honaker Trail-Rico fm.	Honaker Trail-Rico fm.	Honaker Trail-Rico fm.	
	Round Valley fm. ?	Paradox Salt	Paradox Salt	Paradox Salt	
		Pinkerton Trail ls.	Pinkerton Trail ls.	Pinkerton Trail ls.	
MESOZOIC TRIASSIC	Manning Canyon fm.	Manning Canyon fm.	Molas fm.	Molas fm.	
	Deseret-Humbug fm.	Humbug-Deseret	Deseret-Madison-	Madison-Leadville	
	Madison limestone	Madison-Leadville ls.	Leadville ls.	limestone	
	Devonian undif.	Devonian-Elbert ?	Devonian	Devonian	
	Cambrian undif.	Cambrian undif.	Cambrian undif.	Cambrian undif.	
	Lynch dolomite	Lynch dolomite	Lynch dolomite	Lynch dolomite	
	Maxfield limestone	Maxfield limestone	Maxfield limestone	Maxfield limestone	
	Ophir fm.	Ophir fm.	Ophir fm.		
	Tintic qtzt.	Tintic qtzt.	Tintic qtzt.	Tintic qtzt.	Granite Wash
	Precambrian	Precambrian	Precambrian	Precambrian	Precambrian
PALEOZOIC					
PC					

Ferron--The Ferron anticline, 6 1/2 miles in length, lies between the Wasatch Plateau and the San Rafael Swell. Gas has accumulated in lenticular Ferron sandstones beneath two distinct closures. The field was discovered in 1957 by American Petrofina and English Oil Company. Gas flowed at the rate of 4,700,000 cubic feet per day from 628 to 758 feet. Two additional gas wells have been completed. Development drilling is continuing.

Last Chance Anticline--In 1934 gas was discovered in several fine-grained lenticular sandstones in Sec. 17, T-26-S, R-7-E, in the lower part of the Moenkopi formation. Initial potential in the discovery well was 21,000,000 cubic feet per day of natural gas (840 B.T.U.). Of the seven additional wells drilled on the anticline, three are capable of producing gas. The field is shut in because of lack of market. Production is probably dependent upon the presence of porous sandstone in a favorable structural position. Two of the wells tested the Paleozoic section. The Paradox formation is missing, although more than 800 feet are present 17 miles south on the Caineville anticline. Stratigraphic traps may possibly be associated with the northward wedgeout of Paradox strata in this vicinity.

Subsidiary Structures of the Uncompahgre Highland: The surface of Grand Valley, from the base of the Book Cliffs southward to the Canyon of the Colorado River is covered with Late Cretaceous marine Mancos shale. The Mancos is underlain by a sequence of dominantly continental strata comprising the Cretaceous Dakota sandstone, the Lower Cretaceous Cedar Mountain formation and Buckhorn conglomerate, and the Upper Jurassic Morrison formation and Entrada sandstone. With the exception of the blanket-type sandstones of the Entrada, these formations consist of porous, lenticular sandstones and conglomerates interbedded with, and often surrounded by, impervious shale. Most of the material is fluvial in origin. Lithology changes abruptly both laterally and vertically. Sand development appears to control oil or gas accumulation more than does structure. Sand lenses of these formations are oil saturated in numerous outcrops along the canyon of the Colorado River, and produce oil and gas in several fields. Studies aimed at delineating areas of maximum porous and permeable sand development should result in the discovery of additional oil and gas reserves. Production from the blanket-type sands of the Entrada is largely confined to structural traps. The typically porous and permeable massive sandstone units of the Glen Canyon group will usually require an anticlinal structure in order to form a trap.

The Triassic Chinle formation rests upon Precambrian crystalline rocks or granite wash over most of the area. Possibly well-sorted granite wash sediments noted in some wells might be potential reservoirs.

Subsidiary structures consist of numerous gentle anticlines and synclines superimposed on the northwestward-plunging anticlinal nose of the Uncompahgre Highland. A brief discussion of developments in some of the local areas of the Uncompahgre Highland follows:

Cisco Dome: Cisco dome is a local closure on a long anticline, which is located on the boundary between the Uncompahgre Highland and the Paradox Basin. Between 1925 and 1929, seventeen wells were drilled on Cisco dome and most produced natural gas from the Dakota and Cedar Mountain formations until about 1936. The gas contained appreciable amounts of distillate and was used for the production of carbon black in a local manufacturing plant. In the early 1930's the U.S. Government halted the exploitation of gas for carbon black. Initial flows

of wells averaged about 4,000,000 cubic feet per day. Very little was done in the field until 1955 when a new development program was initiated. During the period 1955-1959, seven wells were drilled in the field, three of which were completed as gas wells. A large reserve of gas probably remains to be produced in this field.

A plunging anticlinal nose extends northwest from the Cisco dome for a distance of at least six miles. Some very good stratigraphic traps could have formed where lenticular sandstones wedge out up-dip along the axis of the fold.

Cisco Townsite: At least 16 wells have been drilled on a domal structure near and in the townsite of Cisco. Several have produced three to four barrels of oil per day on pump from a sand in the Morrison formation. Initial flows in some wells ranged up to 50 barrels or more per day. Two have yielded gas at the rate of 85,000 to 100,000 cubic feet per day. Production is from lenticular stream channel deposits and declines rapidly. Depths of the wells range from 552 to 2,826 feet. The possibility for important production appears meager. Pressures are very low in most wells. The Morrison outcrop is only a few miles to the south in the valley of the Colorado River.

Cisco Springs-Cottonwood Anticline: Seven wells were drilled on the Cisco Springs-Cottonwood anticline during 1955 and 1956. One yielded 241 feet of green oil from the Dakota formation on a test, but failed to produce oil in commercial quantities. It was later completed as a gas well in the Morrison where 2,800,000 cubic feet per day was gauged after fracturing treatment. Encouraging shows of oil and gas were found in two other wells, and a good show of oil was reported from a fourth well. The three remaining wells were dry. Lenticular sandstones of the Dakota, Cedar Mountain and Morrison formations are the principal objectives. An area of probable closure on the anticline should be tested to the Entrada. Use of sand-frac and other new drilling and completion techniques should produce increased flows from other wells where gas is encountered.

Seiber Nose and Danish Wash: Four wells were drilled by Agate Oil Company in T-19-S, R-24-E, on the southwest flank of the Seiber nose structure in a locality known as Danish Wash. Two of the wells are reported to have been completed as gas wells in the lenticular Dakota sandstone. The discovery well yielded gas at the rate of 1,470,000 cubic feet per day on a test. One other well was gauged at 500,000 cubic feet per day. Both wells are shut in.

Carter Oil Company drilled the No. 1 Larsen-State well (NE NW Sec. 2, T-20-S, R-24-E) on the east flank of Seiber nose in January 1955. It was completed as a flowing oil well from 1,428 feet depth in the upper eight feet of sand in the Brushy Basin member of the Morrison formation. The well was placed on production after sandfrac treatment, flowing at the rate of 52 barrels of 38 degree gravity oil per day. Production declined to 26 barrels per day after two months, and pumping equipment was installed. Production continued to decline to an average of 10 barrels per day after 10 months. The hole was drilled with cable tools, a technique which appears to be important to successful completions in the low-pressure impure sandstone reservoirs of the area. Four other wells drilled by Carter within 1,320 to 1,980 feet of the discovery well did not encounter oil or gas in commercial quantities. However, oil saturation or good staining was noted in samples from sands of the Dakota and Morrison formations. Although mudding-off of productive horizons may have contributed to these failures, the oil in the discovery well apparently occurs within sands deposited

in a narrow stream channel. Such channels are typical of the Morrison formation throughout eastern Utah. The nature of this oil reservoir illustrates some of the problems encountered in developing major production in this area.

A two-well oil field discovered early in 1961 by Raphael Pumpelly in Sec. 8, T-20-S, R-24-E, three miles southwest of Seiber Nose, yielded 9,159 barrels of oil from the Brushy Basin member of the Morrison formation during 1961. The wells are still producing.

Bar-X and Westwater Anticlines: Approximately 30 wells along the crest of the Utah portion of the Bar-X anticline and westward along the Westwater anticline have been completed as gas wells. Producing sands range in age from the Jurassic Entrada to the Cretaceous Castlegate sandstone. With the exception of the Entrada, all the sands are lenticular and discontinuous and generally cannot be correlated exactly between wells, though producing zones are generally correlative. Data accumulated by drilling in the area indicates that nearly every permeable and porous sand within the Dakota, Cedar Mountain, Buckhorn, and Morrison section can be expected to yield gas. Some of the wells produce from three or more separate sands. Oil has been produced from the Morrison formation in one well on the Bar-X structure in Colorado.

Harley Dome: Early drilling on Harley dome resulted in the discovery of natural gas containing helium. The structure has been set aside as a helium reserve by the U.S. Government. In October 1955, the Ute Royalty Corporation No. 1 Government well was drilled on a northern extension of the structure in NW NW NE Sec. 31, T-18-S, R-25-E. Initial production of natural gas was 3,050,000 cubic feet per day from a sandstone in the Brushy Basin member of the Morrison formation. Several dry holes were subsequently drilled on the structure. Production appears to be restricted to and controlled by discontinuous sand lenses.

San Arroyo: The San Arroyo structure is a northwest-plunging asymmetrical anticline extending for approximately 13 miles northwest from Sec. 31, T-16-S, R-25-E. An area of closure near the east end of the anticlinal trend is under development by Sinclair Oil Company. The six gas wells completed to date are capable of producing natural gas from the Dakota and Entrada sandstones. Shows of oil have also been noted in the Mancos shale. Gas from the Entrada sandstone is low in heat value as a result of contained carbon dioxide.

Fence Canyon, Horse Point, Diamond Ridge, East Canyon, Bryson Canyon, and Book Cliffs: Within the last two years several small gas fields including those listed above, have been completed on the Uncompahgre Highland in lenticular sandstones similar to those described above. None of these fields have been outlined by development drilling, but they illustrate the gas-productive potential of this region (See Table XVIII and Figure 111).

Northwest Salt Anticline Region: The prominent belt of faulted salt anticlines which flank the Uncompahgre Highland extends northwest into east-central Utah. Interest in finding oil and gas associated with the salt anticlines was greatly stimulated by natural gas and condensate discoveries in rocks of Mississippian and Devonian age in the vicinity of Lisbon anticline in T-30-S, R-24-E, late in 1959. In the Salt Anticline area the flowage of Paradox salt completely masks the structure of the underlying rocks. Exploration in the Salt Anticline area is concentrated in an effort to find fault and fold traps in the older rocks. Geophysical surveys and deep-well drilling indicate so far that these traps are most likely to be found beneath the southwest flanks of the salt anticlines. Because the structure of rocks beneath the salt is markedly different from the structure above the salt, surface synclines in the Salt Anticline region are not unfavorable places to prospect for oil in rocks of pre-salt age.

The Sagers Wash syncline apparently overlies and is a surface expression of the downthrown side of the Uncompahgre basement fault. It adjoins the Cisco anticline which parallels and marks the southwest edge of the Uncompahgre Highland. The Thompson anticline is a rather poorly defined, broad anticlinal nose extending from the Yellow Cat dome near the Colorado River, northwestward through the town of Thompson into the Book Cliffs, where it is rather weakly reflected by a re-entrant in the massive sandstones of the Mesaverde formation. The Pacific Western-Equity Oil Company Thompson No. 1 well, in Sec. 33, T-21-S, R-21-E, drilled on this structure, was abandoned in the Paradox salt at a depth of 13,767 feet. A thick section of Pennsylvanian and Permian arkosic sediments were drilled above the salt. Continental Oil Company in its well on Cisco anticline, approximately eight miles northeast, started in Cretaceous Mancos shale and penetrated Precambrian below the Triassic Chinle formation at approximately 3,700 feet. Relief on the Precambrian basement, in excess of 15,000 feet between the two areas, indicates the magnitude of the faulting which separates the Uncompahgre Highland and Paradox Basin.

The Crescent Wash syncline separates the Thompson anticline from the Salt Valley anticline. A highly deformed fault-graben marks the position of the Salt Valley anticline. Repeated flowage of evaporites of the Paradox formation into the core of the anticline during much of post-Pennsylvanian time produced a complex structure. Many wells have been drilled along the axis of the Salt Valley anticline. Shows of oil and gas are numerous in the Dakota, Morrison, and Paradox formations, but sustained production has not been obtained. Continental Oil Company drilled a Mississippian (?) test on the Salt Valley anticline in Sec. 22, T-22-S, R-19-E, during 1961 and the Spring of 1962. Very little information was released. The Paradox salt is reported to be 6,300 feet thick in the well.

The Court House syncline flanks the Salt Valley graben on the southwest, and is succeeded westward by the Green River anticlinal nose. The Green River nose plunges northwest through the town of Green River. The Little Grand fault crosses the nose from east to west, developing a possible structural closure on the upthrown block to the north. Four wells have been drilled on this structure near the Little Grand fault in an unsuccessful attempt to find production in the upthrown segment of the nose against the fault. Two deep tests by Amerada Petroleum Corporation started in the hanging wall of the fault zone, and passed through the fault into the upthrown block at about 2,500 feet. The Paradox formation was intersected at approximately 4,800 feet, and the Paradox salt at 5,100 feet. The two wells continued to total depths of 5,645 and 5,896 feet where they were abandoned in Paradox salt. Natural gas with condensate was encountered at high formation pressures of approximately 2,100 pounds per square inch in the Paradox salt section. Attempts to produce the wells commercially were finally abandoned because of excessive salt water invasion.

Superior drilled a dry 10,608 foot Devonian test on the Salt Wash structure in SW SW Sec. 24, T-21-S, R-15-E during 1961. No shows of importance were reported with the exception of a minor gas show in the Paradox salt.

Salt Wash: In May 1961, Pan American Petroleum Corporation completed a well on Salt Wash anticline in Sec. 15, T-23-S, R-17-E, pumping 115 barrels of oil per day from rocks of Mississippian age at a depth of 8,693 to 8,707 feet. Later in the year a west offset was completed flowing 47 barrels of oil per day. As of April 1962, Texaco Inc. is testing an apparently successful oil well which will extend production a mile to the west. Oil is produced from a porosity zone 270 to 300 feet below the top of the Mississippian.

Big Flat: The Big Flat anticline, a large prominent structure exposed at the surface in T-26-S, R-19-E, has been the site of numerous efforts to develop oil production dating back to 1949 when Tidewater drilled the first test. Good shows of oil were encountered in both the Paradox salt and in carbonate rocks of Mississippian age. Four more dry holes, two Paradox tests and two Mississippian tests were drilled before oil production from Mississippian porosity was finally established by Pure Oil Company in the SW SE Sec. 14 during 1957. The discovery well flowed 319 barrels of oil per day. Pure drilled two development wells. Only one is being produced. In addition Pure was unsuccessful in an attempt to find oil production from the Paradox salt in Section 23.

Two recent discoveries within the Paradox salt section in an interval known as the Cane Creek marker have caught the attention of the oil industry. The Cane Creek marker, interbedded black shale, dolomitic siltstone, and anhydrite, is near the base of the Paradox section between beds of massive salt. Pure Oil Company completed the first of these discoveries, No. 5 Big Flat Unit 1 in NW SE Sec. 27, T-25-S, R-19-E, during January 1962, flowing 453 barrels of oil per day from a depth of 7,202 to 7,228 feet. Southern National Gas was responsible for the second Cane Creek marker discovery, which is 8 miles south of the first one on the south plunge of the Big Flat anticline in SE NW sec. 6, T-27-S, R-20-E. That well was completed February 28, 1962 flowing 280 barrels of oil per day from a depth of 5,808 to 5,860 feet. A new wave of exploration aimed at this interval may be initiated in the northern Paradox Basin.

Many shows of oil have been reported from the Cane Creek marker in this part of the basin, notably at Big Flat, Cane Creek, and on the Moab (Seven Mile) anticline. One of the best shows was reported by Delhi Taylor in their No. 2 Utah well drilled in NW SW Sec. 18, T-25-S, R-21-E on the Moab anticline. During one test, 4,230 feet of oil was recovered from the Cane Creek marker. Oil was swabbed at the rate of 27 barrels per day. Mechanical difficulties prevented a successful completion, and the well was abandoned. Rocks of Mississippian age have never been penetrated on this structure, most of which has been withdrawn from oil and gas leasing as a potash reserve.

Attention was first called to the Cane Creek marker as a potential oil reservoir by early drilling on the Cane Creek anticline. Flows of oil up to 1,000 barrels per day were reported from this zone, but these flows declined rapidly and successful completions were never made. The Cane Creek anticline is also a potash reserve which is now being developed.

PROBABLE FUTURE DEVELOPMENTS

At the present time (May 1962) oil and gas exploratory effort in east-central Utah is concentrated in two distinct areas. Probably the most important is the effort to find other oil and gas reservoirs in the Salt Anticline region similar to those at Lisbon, Big Flat, and Salt Wash. Because of the structural complexity of the region and the high rewards for a discovery, such as Lisbon, exploration is expected to continue for many years. The chances are very good that it will someday become a major oil and gas producing province.

Another place where exploration is concentrated at present is the north plunge of the Uncompahgre Highland in Grand Valley and beneath the southern flanks of the Uinta Basin. The success ratio has been very good here. More small gas fields will no doubt be found where lenticular sandstones of Cretaceous and Jurassic age wedge out up-dip on gentle anticlinal noses. The search for that type of trap is continuing. As more market outlets for gas are established, more wells will be drilled.

CITED REFERENCES

- Baker, A.A., 1947, Stratigraphy of the Wasatch Mountains in the vicinity of Provo, Utah: U.S. Geol. Survey Oil and Gas Inv. Chart 30.
- Henbest, L. G., 1948, New Evidence of the Age of the Rico Formation in Colorado and Utah (abs.): Geol. Soc. America Bull., v. 59, p. 1329-1330.
- Herman, G. and Sharps, S. L., 1956, Permian and Pennsylvanian Stratigraphy of the Paradox Salt Embayment: Intermtn. Assoc. Petroleum Geologists Guidebook, Seventh Ann. Field Conf., p. 77-84.
- McKee, E. D., 1938, "The Environment and History of the Toroweap and Kaibab formations of Northern Arizona and Southern Utah": Carnegie Inst. Washington Pub. 492, 268 p.
- Peterson, V. C., 1954, The Mounds and Farnham area of the Northern San Rafael Swell, Carbon and Emery Counties, Utah: Intermountain Assoc. Petroleum Geologists Guidebook, Fifth Ann. Field Conf., p. 86-88.
- Sadlick, W., 1956, Some Upper Devonian-Mississippian problems in eastern Utah: Intermountain Assoc. Petroleum Geologists Guidebook, Seventh Ann. Field Conf., p. 65-76.
- _____, 1957, Regional relations of Carboniferous rocks of Northeastern Utah: Intermountain Assoc. Petroleum Geologists Guidebook, Eighth Ann. Field Conf., p. 56-76.
- Spieker, E. M., 1946, Late Mesozoic and Early Cenozoic History of Central Utah: U.S. Geol. Survey Prof. Paper 205, p. 117-161.
- Stewart, J. H., and Smith, J. F., Jr., 1954, Triassic rocks in the San Rafael Swell, Capitol Reef, and adjoining parts of southeastern Utah: Intermountain Assoc. Petroleum Geologists Guidebook, Fifth Ann. Field Conf., p. 28-29.
- Stokes, W. L., 1948, Geology of the Utah-Colorado salt dome region with emphasis on Gypsum Valley, Colorado: Utah Geol. Soc. Guidebook, no. 3, 50 p.
- _____, 1952, Lower Cretaceous in Colorado Plateau: Am. Assoc. Petroleum Geologists Bull., v. 36, no. 9, p. 1766-1776.
- _____, 1954, Stratigraphy of the southeastern Utah uranium region: Utah Geol. Soc. Guidebook, no. 9, p. 33.
- Wengerd, S. A., 1958, Pennsylvanian stratigraphy, southwest shelf, Paradox Basin: Intermountain Assoc. Petroleum Geologists Guidebook, Ninth Ann. Field Conf., p. 109-135.
- Wengerd, S. A., and Matheny, M. L., 1958, Pennsylvanian system of Four Corners Region: Am. Assoc. Petroleum Geologists Bull., v. 42, p. 2048-2107.

Paper 32 THE KAIPAROWITS REGION AND ADJACENT AREAS

by Edgar B. Heyl¹

This paper summarizes the salient geologic features of central and eastern Kane Counties, as well as part of Wayne County. The Kaiparowits and Paunsaugunt Plateaus, Boulder Mountain, Circle Cliffs upwarp, and the Henry Mountains are some of the important elements in this colorful cliff and canyon land. The region is drained by the Colorado River and its tributaries, and some areas are highly dissected and inaccessible.

STRATIGRAPHY

Objective beds for oil and gas production range from Cambrian to Cretaceous in age. Mesozoic and Cenozoic rocks are exposed over much of the region, but the only Paleozoic rocks exposed are small patches of Permian sediments on the crest of the Circle Cliffs upwarp. All Paleozoic systems except Ordovician and Silurian are recognized in the subsurface. The top of the Precambrian ranges in depth from 5,200 feet to over 15,000 feet, depending on the structural and topographic location.

Between the beginning of the Cambrian and the close of Silurian south-central Utah was a platform area that received marine sediments east of the great Cordilleran miogeosyncline. At some time in the Devonian, due to continued sinking in the geosynclinal trough, the region was tilted gently westward and subjected to erosion. Ordovician and Silurian beds which might have been deposited were removed, and the exposed Cambrian surface was peneplaned. Late Devonian seas then swept in and deposited a uniform layer of sediments across the entire region. The Late Devonian sandstones, shales, and dolomites lie unconformably on progressively older Cambrian rocks in an eastward direction. Following the deposition of Devonian sediments, Mississippian limestones and dolomites were laid down, thickening gradually in a westward direction.

In the early Pennsylvanian, orogenic activity related to the Ancestral Rockies occurred, and the Kaibab uplift came into existence in the southwestern part of the region. This uplift was probably a northwest extension of the Zuni uplift which developed in eastern Arizona and western New Mexico at this time. In addition to the Kaibab uplift, a minor positive area appears to have developed in the area of the present Circle Cliffs upwarp. These positive elements produced a profound effect on sedimentation, completely altering previously existing trends and processes. Numerous intraformational unconformities are present within the Pennsylvanian, and locally, on the Kaibab uplift, Pennsylvanian sediments appear to be absent.

The great Paradox evaporite basin formed in east-central and southeastern Utah during the Pennsylvanian, and a portion of this basin is present in the northeastern part of the area under discussion. Pennsylvanian rocks in the Paradox Basin consist of dolomites, limestones, black shales, and thick evaporites. Elsewhere in south-central Utah, however, Pennsylvanian sediments consist primarily of limestones and sandstones.

1. Consultant, Salt Lake City, Utah.

Early Permian limestones and sandstones lie unconformably on older beds across the entire region. Epeirogenic uplifting continued in the Permian, and the seas retreated. Continental deposits, mainly red shales and thick aeolian sandstones, were deposited. Once again, before the close of the Permian, the seas returned and limestones and sandstones were laid down. Locally, in the western part of the region, small evaporite basins were formed. Some of the beds deposited at this time are distinctly petroliferous.

Mesozoic and Cenozoic rocks are exposed on the surface and have been described in several papers (especially Gregory and Moore, 1931. Gregory, 1951, and Hunt, 1953). The generalized stratigraphic section for central Garfield County is as follows:

Oligocene (?)	Volcanics	
Paleocene & Eocene	Wasatch (?) fm.	
	Kaiparowits fm.	2,000
	Wahweap ss.	1,300
Cretaceous	Straight Cliffs ss.	1,250
	Tropic sh.	630
	Dakota (?) ss.	50
	Winsor fm.	600
	Curtis fm.	150
Jurassic	Entrada ss.	300
	Carmel fm.	550
	Navajo & Wingate ss.	2,000
	Chinle fm.	400
Triassic	Shinarump ss.	100
	Moenkopi fm.	700
	Kaibab ls.	400
	Toroweap fm.	400
Permian	Coconino ss.	1,200
	Hermit sh.	
	Cedar Mesa ss.	
	Pakoon fm.	300
Pennsylvanian	Hermosa fm.	300
	Molas sh.	100
Mississippian	Unnamed unit	200
	Redwall ls.	800
Devonian	Elbert or Martin fm.	300
	Unnamed unit	700
	Muav ls.	400
Cambrian	Bright Angel sh.	300
	Tapeats ss.	400
Precambrian	Sandstone and shale	

STRUCTURE

There are a number of anticlinal folds in south-central Utah, many of which have not been drilled for oil and gas. Detailed structural contour maps are not available except in the Henry Mountain area (Hunt, 1953) and the eastern part of the region (Baker, 1947). Generalized maps depicting structures can be found in Gregory and Moore (1931, p. 120) and Heylman (1958, p. 1804).

Most of the folding probably occurred in the Cretaceous and Early Tertiary. Faulting is conspicuously absent, although there are two great north-south fault zones, the Sevier and Paunsaugunt, in the western part of the region. The Sevier and Paunsaugunt faults are Pliocene and younger in age, and are probably related to normal faulting in the Basin and Range province to the west.

Extensive areas of volcanic rocks, including ignimbrites, exist in the northern part of the region under discussion, extending northward into central Utah. The laccolithic Henry Mountains rise in the eastern part of the region. In all probability, the igneous activity occurred during the Late Eocene and Oligocene. Quaternary basalt flows and cinder cones are found in the western part of the region, probably being associated with movement along the Sevier and Paunsaugunt faults. Despite the amount of igneous activity which has occurred in various parts of south-central Utah, structural deformation and contact metamorphism are surprisingly insignificant. In fact, coal inclusions have been found in the igneous rocks of the Henry Mountains, and metamorphic effects extend out only two or three inches from the contacts.

OIL AND GAS POSSIBILITIES

Forty important tests have been drilled for oil and gas in the region considered here, and the following three wells produced sub-commercial quantities of oil:

Tennessee Gas Transmission No. 1-A Poison Springs, Sec. 4, T-31-S, R-12-E, Producing interval 4,149-4,174, in the Hermosa formation.

California Company No. 1 Johns Valley, Sec. 22, T-35-S, R-2-W, Producing interval 7,361-7,412, in the Timpoweap member of the Moenkopi formation.

California Company No. 1 Upper Valley, Sec. 12, T-36-S, R-1-E. Producing intervals 6,041-6,302 in the Timpoweap-Kaibab, and 8,760-8,900 in the Mississippian. (Plate).

The Phillips No. 2 Escalante Anticline, Sec. 29, T-32-S, R-3-E, tested large quantities of non-inflammable gas from several zones between 1,455 and 3,679 feet. At least six other wells in the region had important shows of oil and gas, while a number of other wells had lesser showings. Oil seeps and oil-saturated outcrops are known along the Colorado River, on the Circle Cliffs upwarp, and in the vicinity of the Paunsaugunt fault south of Bryce Canyon National Park.

Due to topography, hard formations, and lost circulation problems, drilling for oil and gas in south-central Utah has proved difficult and expensive. This is especially true for wells which penetrate Paleozoic rocks. Drill-stem tests have recovered fresh water at considerable depths in some wells. The writer knows of certain hydrodynamic studies which have been made which tend to be discouraging.

Despite these adverse factors, the fact remains that oil and gas shows are numerous, and three wells have succeeded in producing small quantities of oil. Such units as the Timpoweap member of the Moenkopi formation, the Kaibab, Toroweap, White Rim, and Pakoon formations, and the Mississippian and older formations hold promise. These units locally exhibit good porosity, and the

Permian rocks in particular are petroliferous in nature. When taken into consideration that only 40 wells have been drilled in a region over 8,000 square miles in area, or one well every 200 square miles, south-central Utah must be considered to be essentially virgin.

CITED REFERENCES

- Baker, A. A., 1947, Geology of the Green River Desert-Cataract Canyon region, Emery, Wayne, and Garfield Counties, Utah: U.S. Geol. Survey Bull. 951, 122 p.
- Gregory, H. E., 1951, The geology and geography of the Paunsaugunt region, Utah: U.S. Geol. Survey Prof. Paper 226, 166 p.
- Gregory, H. E., and Moore, R. C., 1931, The Kaiparowits region, a geographic and geologic reconnaissance of parts of Utah and Arizona: U.S. Geol. Survey Prof. Paper 164, 161 p.
- Heylman, E. B., 1958, Paleozoic stratigraphy and oil possibilities of Kaiparowits region, Utah: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 8, p. 1781-1811.
- Hunt, C. B., 1953, Geology and geography of the Henry Mountains region, Utah: U.S. Geol. Survey Prof. Paper 228, 234 p.

Paper 33 PENNSYLVANIAN PALEOTECTONICS OF COLORADO PLATEAU

by Richard W. Fetzner¹

This subject is considered sufficiently important to reprint the following abstract. For full development of the ideas presented, refer to American Association of Petroleum Geologists Bulletin, v. 44, no. 8, p. 1371-1413.

ABSTRACT²

During the Pennsylvanian interval of time, the Colorado Plateau area underwent the most active period of tectonic activity of the Paleozoic era. Pennsylvanian paleotectonic relationships have been reconstructed from stratigraphic and lithologic data acquired from 264 control points. This was accomplished through the use of isopach maps, lithologic ratio maps, vertical sandstone distribution maps, field evidence, and paleontological data.

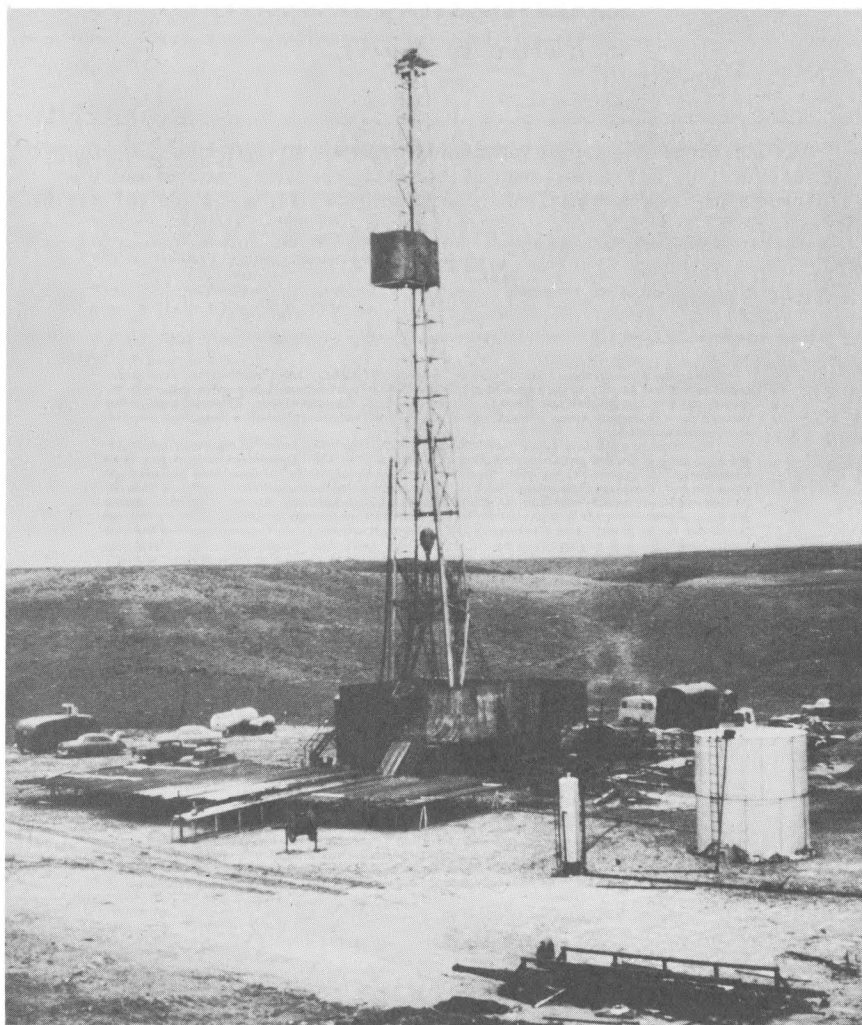
Pennsylvanian tectonic elements of the Colorado Plateau area defined a northwest-trending parageosynclinal seaway. Greatest subsidence occurred in the north where the Paradox Salt basin formed as an asymmetrical half graben. On the south, depositional centers formed in the Pennsylvanian San Juan and Lucero basins. The seaway opened northwest onto the rapidly subsiding Oquirrh shelf, northeast into the northern Colorado trough, west into the Cordilleran geosyncline, southeast into the southern Colorado trough, and south and southwest into the Pedregosa basin and the Sonoran geosyncline. The seaway was bounded to the northwest by the Emery uplift, to the northeast and east by the Uncompahgre and San Luis uplifts, and to the west and southwest by the Kaibab-Zuni uplift. The Defiance uplift, a structural subsidiary of the Kaibab-Zuni lineament, projected north into the southern Paradox basin, where it strongly affected depositional patterns during Pennsylvanian time.

Throughout most of Pennsylvanian time, the Emery uplift was a low, partly submerged, structural arch. A southeastern spur of tectonism, probably archipelagic in nature, affected depositional patterns from Desmoines to Wolfcamp time in the northwestern Paradox basin. Earliest and greatest Uncompahgre tectonism occurred in its southern part. Here it became a clastic source area in Atoka time, remained orogenically positive into the Permian, and during this time interval shed a tremendous coarse clastic delta to the southwest. The northwestern Uncompahgre responded to uplift later in the Pennsylvanian, but probably permitted marine access between the Eagle and Paradox evaporite basins during Desmoines time. Consequently, Paradox evaporites may be the composite product of two evaporite basins. The San Luis uplift, which was slightly positive in pre-Pennsylvanian time, did not respond to sharp uplift until late Pennsylvanian time. The Penasco uplift underwent early and late Pennsylvanian tectonism, but impressed only minor influence on the regional lithofacies. Although the Kaibab-Zuni uplift existed as a nearly continuous structural lineament during most of the Pennsylvanian, greatest and earliest tectonism occurred in the eastern, or Zuni segment. The Defiance uplift was probably positive in the Mississippian, and underwent successive tectonic pulses during Atoka-early Desmoines, late Desmoines, and late Pennsylvanian-early Permian times. Major hydrocarbon production in the Four Corners area displays close relationship to this tectonic element geographically and geologically.

Because of sedimentary and tectonic barriers, a thick sequence of evaporites was deposited within the Paradox Salt basin. The Emery and Uncompahgre uplifts created restriction on the northwest, north, and east, and the Kaibab-Zuni uplift provided restriction on the southwest. The combination of a clastic barrier projecting into the Four Corners area from the northeast and the Defiance uplift projecting into the Four Corners area from the southwest formed nearly continuous physical restriction across the southern Paradox basin and provided conditions necessary for cyclical evaporite deposition within the basin.

1. Geologist, Sun Oil Company, Richardson, Texas.

2. Permission to reprint this abstract has been granted by the author and the American Association of Petroleum Geologists.



Aneth Discovery Well (Texaco No. 1 CNavajo). Looking Northwest: Beds of Jurassic Brushy Basin in hills immediately behind the well. Dakota Scarp in the background. Well spudded November 22, 1955; completed February 17, 1956; initial potential - 1704 barrels per day. (Photo courtesy R. S. Breitenstein, Texaco, Inc.)

Paper 34 BASEMENT ROCKS AND RELATIONSHIP TO OVERLYING SEDIMENTS OF THE PARADOX BASIN

by *W. Don Quigley*¹

INTRODUCTION

Since the discovery of oil and gas in Mississippian and Devonian rocks in the Paradox Basin in southeastern Utah in 1959, the potential of the older Paleozoic strata has been more fully realized. The recent discoveries at Lisbon, Big Flat, and Salt Wash have stimulated extensive exploration and drilling of the older Paleozoic formations throughout the basin. Data from development drilling within the fields have demonstrated that the structural attitude of the older Paleozoic rocks is quite different from that of the post-Pennsylvanian strata. Consequently, determination of new favorable areas must be based on some type of sub-surface information. Geophysical techniques, mostly seismic, have been utilized extensively in collecting data that might provide clues indicating the location of buried structures affecting Mississippian and older rocks. Due to the thick evaporite section of Pennsylvanian sediments which are found unconformably overlying the Mississippian and older rocks in many parts of the basin, considerable variation in the velocity of sound waves may occur, thus making difficult the proper interpretation of the seismic records. For this and other reasons, results of seismic exploration work have been somewhat discouraging in the basin, and other methods of geophysical exploration are now being employed in conjunction with the seismic work.

The lack of structural conformity between the rocks above and below the evaporite section in the Pennsylvanian strata is the greatest obstacle to more hydrocarbon discoveries in the older Paleozoic rocks in the Paradox Basin. Drilling for Mississippian and older prospects on the basis of surface structural information has been most unreliable and unsuccessful.

A study of the basement rocks in the region may provide some useful information toward determination of present structural attitude of the Lower Paleozoic sediments. The Probability that the structure of the older Paleozoic strata conforms reasonably well with the configuration of the basement surface is much more likely than conformance to the structure of the post-Pennsylvanian strata. Consequently, delineation of the basement surface is most important and could provide essential information.

DESCRIPTION OF THE BASEMENT ROCKS

Information on the lithology and characteristics of the basement and Precambrian rocks of the Paradox Basin is meager. There are no surface exposures of these rocks in the basin. The closest exposure is found on the adjacent Uncompahgre Plateau where the Precambrian rocks consist of complexly interrelated granites, gneisses, and schists. Other exposures of the Precambrian series are found in the Grand Canyon, San Juan Mountains, Zuni Uplift, and Uinta Mountains, all of which are somewhat distant from the basin. A very few wells have been drilled into the Precambrian rocks in and around the basin. These provide information inferring that the basement rocks may have certain characteristics.

1. Consulting Geologist, Salt Lake City, Utah.

That the basin Precambrian complex contains both igneous and metamorphic rocks is quite certain. In addition, information from a recent well drilled by Texaco on the Nequoiz Arch indicates that a series of sediments, which are only slightly metamorphosed may underlie the known basal Cambrian sandstones. These sediments could either be Lower Cambrian or Precambrian in age.

Sketchy information on the basement rocks can be derived from the study of the xenoliths in sills and laccolithic intrusive complexes of the San Rafael Swell, Henry Mountains, Abajo Mountains, and the La Sal Mountains. According to Mr. E. M. Shoemaker (1956), most of the inclusions in the laccolithic complexes of the mountain ranges in the basin and on the San Rafael Swell are hornblende-rich rocks of uncertain origin. Shoemaker believes that these rocks originate from depths in the crust and are not representative of the shallower Precambrian rocks such as those exposed on the Uncompahgre Plateau.

Uncompahgre Precambrian Rocks

Precambrian rocks are widely exposed on the Uncompahgre Plateau. These consist of a complex series of crystalline metamorphic and plutonic intrusive rocks which have never been subjected to a comprehensive and systematic study. Only parts of the complex have been described by various authors. According to Shoemaker (1956), "These rocks are primarily schistose or strongly gneissic rather than massive plutonic intrusives, and most of the schistose and foliated rocks appear to be sedimentary in origin. The rocks range from slates to injection gneisses. Dark colored mica schists and mica hornblende gneisses predominate in exposures north of Unaweep Canyon, and lighter colored gneisses and massive granite predominate in Unaweep Canyon, east of Gateway, Colorado, and to the south along the southwest flank of the plateau. Some quartzite was reported by Cross from the west end of Unaweep Canyon."

"Most of the dark-colored rocks are quartz-biotite schists or gneisses with subordinate amounts of hornblende, plagioclase, potash feldspar, and locally garnet. In some gneisses the folia are alternately hornblende and biotitic. A biotite schist from eastern Unaweep Canyon was found in thin section to be composed of layers alternately rich in plagioclase and potash feldspar, and contained subordinate amounts of biotite and hornblende."

"The lighter colored gneisses are composed predominantly of quartz, plagioclase, and potash feldspar, with subordinate amounts of biotite and hornblende. A typical specimen from central Unaweep Canyon consists of about 60% quartz, 20% sodic plagioclase, 15% microcline, 3% biotite, 2% hornblende, and traces of epidote, sphene, opaque iron oxides, and apatite."

"A wide variety of igneous rocks intrude the metamorphic complex of the Uncompahgre Plateau. Perhaps the most distinctive and widespread intrusive is a coarse porphyritic biotite granite."

"Abundant pegmatite dikes cut the metamorphic complex in Unaweep Canyon. These pegmatites consist mainly of albite and quartz with only trace amounts of microcline, and muscovite and contain scattered garnets."

"A few lamprophyre dikes are present in Unaweep Canyon and locally are intimately associated with the pegmatites. These, studied in thin section, range from hornblende kersanite to biotitic spessartite."

"Other granite plutons intruding the metamorphic complex of the Uncompahgre Plateau appear to be both older and younger than the porphyritic biotite granite. Near Gateway, Colorado, the biotite granite cuts an older gray medium-grained gneissic granite. The older granite is composed of orthoclase, quartz, microcline, oligoclase, biotite, and hornblende with accessory apatite and sphene."

"Probably one of the youngest intrusive masses in the Precambrian complex is a pale pinkish-gray, medium grained, two-mica granite exposed in eastern Unaweep Canyon. The top of the intrusion is well exposed in the canyon walls, and the contact with the metamorphic host is sharp, even, and nearly horizontal. This granite consists of about 40% quartz, 35% slightly perthitic microcline, 15% albite-orthoclase, 7% muscovite, 2% biotite, 1% garnet, and minute traces of apatite, zircon, magnetite, and hematite. Muscovite appears to be replacing the biotite."

Age calculations of the various granites found in the above exposures vary from 1,050 million to 1,650 million years. Thus, the granites probably belong to the Archeozoic Era and may be either Keewatin or Timiskaming in age.

Magnetic susceptibility tests of numerous specimens of Precambrian rocks from the Uncompahgre as reported by H. R. Joesting (1958) vary from about zero to 3.1×10^{-3} c.g.s. (centimeter-gram-second) units. Since the samples were obtained from outcrops, the true susceptibilities of some or all were reduced by weathering. Many of the magnesia-ferric minerals may have been altered to ferrous minerals thus reducing the magnetic susceptibility. However, the susceptibility of some of the granite types was many times higher than that of the schists and gneisses. Susceptibility of the pegmatite and lamprophyre dike material changed from zero to 0.053×10^{-3} c.g.s. units. The two-mica granite noted above had a susceptibility of 0.6×10^{-3} c.g.s. units as compared to 3.1×10^{-3} c.g.s. units for the widespread porphyritic biotite granite.

A well drilled by Equity Oil Company at the north end of the basin on the north-west extension of the Uncompahgre in Sec. 20, T-21-S, R-23-E, Grand County, Utah penetrated granite wash immediately below the top of the Triassic-Moenkopi. The description of the basement rocks at this location is as follows:

3317 - 3335	Granite wash, with clear quartz, pink feldspar, with interbedded maroon and purple shale.
3335 - 3397	Granite wash, with clear quartz, feldspar, biotite, some green waxy shale.
3397 -	Granite, gray, quartz, feldspar, white albite, and abundant biotite.

The above description suggests that an igneous mass composed of coarse porphyritic biotite granite lies immediately below the top of the Moenkopi in this area, and was subjected to a long period of erosion and weathering before being covered by the upper Moenkopi during Triassic time.

San Rafael Swell Precambrian Rocks

Information on the nature and characteristics of the basement rocks on the San Rafael Swell is derived exclusively from well data. Five wells on the Swell were drilled deep enough to encounter Precambrian rocks. Descriptions of the basement rocks encountered in these wells are variously described as follows:

1. El Paso - Pack Saddle No. 1 - Sec. 12, T-18-S, R-12-E. Top of Precambrian - 6740'; Total Depth 6806'; Amount penetrated - 66 feet.
Description:

6740-50' Conglomerate quartzitic, feldspar pebbles, trace of shale.
6750-6806 Granite, pink, gray, and dark gray, quartz, feldspar, mica-
ceous, fresh and some weathered.

2. Renolds Mining Corp. No. 1 Sinbad - Sec. 12, T-22-S, R-12-E. Top of Precambrian - 5066'; Total Depth - 5105'; Amount Penetrated - 30'.
Description:

Granite, gray, biotitic, composed of orthoclase, microcline, quartz, and biotite.

3. American Metals Climax Inc. - Black Dragon No. 1, Sec. 32, T-21-S, R-13-E. Top of Precambrian - 4580'; Total Depth - 4640'; Amount penetrated - 60 feet.

Description:

Granite, pink to orange with biotite, feldspar, quartz, and some muscovite.

4. Pure Oil No. 1 Desert Lake - Sec. 1, T-17-S, R-10-E. Top of Precambrian - 10,480'; Total Depth - 10915'; Amount of Precambrian penetrated - 75 feet.

Description:

Quartzite, clear, coarse to fine grained; shale, green metamorphosed; quartzite, pink white, coarsely crystalline, micaceous; granite, pink to clear, coarsely crystalline, with quartz crystals, micaceous and feldspar.

5. Pan American No. 1 USA Cullen - Sec. 11, T-15-S, R-13-E. Top of Precambrian - 7354'; Total Depth - 7417'; Amount Precambrian penetrated 63 feet.

Description:

Sandstone, red, brown to buff, micaceous; shale, red, brown; garnet; quartz, clear; green to orange feldspar; some hornblende; pyroxene; and green mica.

Based on the above descriptions of the Precambrian rocks penetrated by the wells on top of the San Rafael Swell, the common and most widespread rock type is a biotite-rich, pink to gray granite with only minor amounts of granite wash on top. The description of the pink granite agrees closely with the description of the youngest plutonic granite (pink, two-mica) bodies of the Uncompahgre Plateau. The flank wells encountered metamorphosed sediments beneath the Tintic, suggesting an ancient intrusive igneous core for the Swell.

Nequoia Arch Precambrian Rocks

The Nequoia Arch trends northwest across the southwestern part of the paradox Basin. Evidence of the presence of this arch has been obtained from both surface and well data. Information on the Precambrian rocks has been obtained from some of the wells drilled on or near the arch. Descriptions of these rocks are as follows:

1. Texaco - Temple Springs No. 1 - Sec. 14, T-25-S, R-13-E. Top of Precambrian 6206'; Total Depth - 7314'; Amount of Precambrian penetrated - 1108 feet.

Description:

Interbedded shales, sandstones, and some quartzite which were only slightly indurated. Shale, red to brown, soft and gummy; sandstone, gray to white, loose and quartzitic; quartz, white, milky, and clear; shale, splintery and micaceous; shale, dark green, with black hard quartz mineral; sandstone, gray to green, very fine grained, hard and tight.

2. Texaco - Temple Springs No. 2 - Sec. 22, T-25-S, R-14-E. Top of Precambrian - 6856'; Total Depth - 7010'; Amount of Precambrian penetrated - 154 feet.

Description:

6856 - 6900' Shale, dark green, waxy, slightly micaceous; sandstone pink, fine to coarse grained, angular; shale, red to brown, micaceous.

6900 - 6920' Shale, dark green, waxy, slightly micaceous.

6920 - 6930' Shale, maroon, micaceous, and some red siltstone.

6930 - 7010' Shale, dark green, slightly micaceous. Shale, maroon very micaceous.

3. Texaco - Nequoia No. 6 - Sec. 32, T-27-S, R-15-E. Top of Precambrian - 8070'; Total Depth - 8096'; Amount of Precambrian penetrated - 26 feet.

Description:

Granite, pink, with biotite, quartz, feldspar.

Obviously there is considerable difference in the basement rocks on and those near the Nequoia Arch. The core of the arch is probably granite and may represent an ancient plutonic intrusion in the Precambrian metamorphic complex. However, the description of the section beneath the Tintic quartzite in the two Temple Springs wells does not appear similar to the descriptions of the metamorphic complex of the Uncompahgre Plateau. In fact, the soft, slightly metamorphosed nature of these sediments suggests an age younger than the previously noted age of the metamorphic complex. These sediments may be Late Precambrian or Early Cambrian in age and may be part of an unrecognized sedimentary section which underlies the assumed basal Cambrian sandstones in parts of the Paradox Basin.

Monument Upward Precambrian Rocks

Several wells on the Monument upward in southeastern Utah have been drilled deep enough to encounter Precambrian rocks. These rocks are described as follows:

1. Midwest Exploration Co. - Elk Ridge No. 1 - Sec. 30, T-34-S, R-19-E. Top of Precambrian: 3617'; Total Depth - 3630'; Amount of Precambrian penetrated - 172 feet.

Description:

Schist, light green, very micaceous and siliceous.

2. Utah Southern Oil Co. - Cedar Mesa No. 1 - Sec. 28, T-40-S, R-18-E. Top of Precambrian - 3617'; Total Depth - 3630'; Amount of Precambrian penetrated, 13 feet.

Description:

Schist, green, muscovite, micaceous.

3. Shell Oil Co. - Bluff No. 1 - Sec. 32, T-39-S, R-23-E. Top of Precambrian - 8669'; Total Depth - 8762'; Amount of Precambrian penetrated 94 feet.

Description:

8668-8680' - Shale, dark brown, micaceous, some salt and pepper siltstone.

8680-8690' - Shale, dark purple, brown, reddish brown with quartz filled fractures; and hard, slightly micaceous, slightly sandy shale with quartz filled fractures.

8690-8720' - Shale, green to black, dark brown, dense, with a few biotite grains, very fractured with quartz and calcite veins in fractures.

8720-8740' - Shale as above with scattered chlorite and anhydrite-crystals on fracture planes and trace of calcite in matrix.

8740-8762' - Shale as above with pyrite crystals on shear plane.

The descriptions of the Precambrian rocks on Monument upwarp given above indicate that they are largely sedimentary with some alteration due to metamorphism. Those on top of the upwarp are more highly metamorphosed than those in the Shell Oil Company's Bluff No. 1 well on the flank.

The above descriptions of the Precambrian rocks in and around the Paradox Basin indicate that numerous rock types were overlapped by Cambrian seas; however, the control is not sufficient to permit the compilation of a Precambrian paleogeologic map. It is apparent that slightly metamorphosed upper Precambrian or lower Cambrian shales and sandstone underlie the Cambrian sandstones (Tapeats, Tintic, or Ignacio) in some parts of the basin, with gneisses and schists found in other parts, while Precambrian granitic rocks are found in still other areas. Thus far, no definite pattern is evident.

TECTONIC HISTORY OF BASIN ROCKS

In order to obtain a basic concept as to the present general surface configuration of the basement rocks, it is necessary to study and briefly relate the tectonic history of the basin. For simplicity in this discussion, the rocks of the basin will be separated into four general layers; namely: Precambrian, Pre-Pennsylvanian, and Post-Pennsylvanian. The major tectonics affecting the basement and overlying Paleozoic rocks occurred during these intervals. Of course, tectonism occurred in most all periods of geologic time, but effort is made herein to group some of these periods together.

Relatively little is definitely known about the actual tectonics which have affected the basement rocks of the Paradox Basin. However, certain inferences can be made based on information obtained from the positive structural elements adjacent to the basin, and those which traverse the basin.

Precambrian

Most of the present local tectonic elements in the basin and surrounding region are Laramide in age and many do not effect the Precambrian rocks. These numerous tectonic elements are described by Vincent Kelly (1955) in detail. Generally, the older Precambrian tectonic elements appear to have been oriented in a north-south, northeast, or east-west direction rather than the current general northwest orientation.

Evidence and information on the Archeozoic tectonics of the basin is fragmental and obscure. Precambrian deformations were probably numerous and varied. From the descriptions given previously on the Precambrian rocks of the Uncompahgre Plateau, it is evident that many plutonic bodies were intruded into the Precambrian sediments. Most of these intrusions were probably Archeozoic in age and there is little evidence of later intrusion prior to the widespread stock and associated laccolithic type emplacements in and around the basin during Tertiary time.

The early intrusions in the Precambrian rocks have greatly obscured the evidence of Archeozoic geosynclines and geanticlines. The fairly thick mantle of shales and quartzites occurring in and around the Paradox basin indicated that it was located on a depositional shelf or margin of a geosyncline for a part of Precambrian time. That these sediments were probably subjected to severe tectonic movement prior to Cambrian time is indicated by the exposures of the Cambrian-Precambrian unconformity in the San Juan Mountains east of the basin. According to D. L. Barrs (1958), "Every exposure of Paleozoic sediments overlying stratified Precambrian rocks exhibits a seventy to ninety degree discordance, and much of the region was intruded by granitic stocks and batholiths prior to the Ignacio sedimentation. However, erosion reduced topography to an exceptionally smooth peneplain upon which the uppermost Cambrian sands were deposited. A well developed weathered surface is present along Mountain View Crest immediately south of Needle Creek, where the upper three to six feet of Eolus granite are weathered almost to a soil beneath the Ignacio quartzite. Even though a nearly smooth surface is evident at local outcrops, some relief was present, since a boulder conglomerate from the base of the Ignacio at Coalbank Pass, and beds as high as the upper Devonian Ouray limestone, lie directly on the Precambrian near Ouray, Colorado."

As suggested by Barr, a long period of erosion and peneplanation took place during the Proterozoic Era and continued through Lower Cambrian time. However, some sedimentation must have occurred locally to account for the nearly unmetamorphosed sediments found beneath the Cambrian sandstones in some of the wells of the basin.

Presumably there were numerous tectonic deformations which occurred during Precambrian time in conjunction with the large batholithic and sill-like intrusions. Most of the positive elements were leveled by the long period of erosion in Late Precambrian time. However, in the general region of the Grand Canyon, transgressing Cambrian marine waters encountered considerable relief on the Precambrian terrain. Some islands rising a thousand feet above sea level interrupted the regularity of the Tapeats sedimentation.

Pre-Pennsylvanian

The Pre-Pennsylvanian strata include Cambrian, Devonian, and Mississippian sediments. Tectonism was regional in nature during most of the period.

During Cambrian time the general Four Corners region subsided gradually and Cambrian seas transgressed from west to east. The age of the so-called basal Cambrian sandstones becomes progressively younger from west to east, such that the basal Ignacio sandstone in the San Juan Mountain area is believed to be latest Cambrian or even earliest Ordovician in age. The ancestral cores of the Zuni uplift, San Juan Mountains, and Uncompahgre plateau may have been emergent during Late Cambrian time and remained positive during Ordovician and most of Silurian time. The Cambrian seas regressed to the west in Late Cambrian time or Early Ordovician, leaving the sediments exposed to erosion.

In general, the absence of Ordovician and Silurian strata throughout the region with only a disconformity marking their interval, indicates either gently emergent conditions during these periods or a regional emergence toward the close of Silurian time so that any sediments deposited during the interval were removed.

Deformation in Devonian time was probably gradual and regional in nature rather than sharp and local. Early Devonian time saw the rise of the Trans-Continental arch with the Colorado sag extending northwestward across most of the Paradox Basin.

Toward the close of Devonian time the upward emergence of the Trans-Continental Arch reached a maximum and even part of the Colorado sag was exposed; however, most of the Devonian sediments were preserved across the Paradox basin since this region remained below sea level. Regionally, the thickness of Devonian rocks increase westward across the basin. The basin area continued to receive conformable limestone sediments which were deposited on through Mississippian time on the eastern shelf of the Cordilleran geosyncline.

Pennsylvanian

Early Pennsylvanian time marked the beginning of a period of extensive tectonism for the Paradox Basin region. The long dormant cores of the Defiance-Zuni and Uncompahgre uplifts became active again. Trans-basin arches began to form. The Nequoia arch and San Rafael Swell (Emery high) areas became slightly positive. The position of many of these positive elements may have been nearly coincident with that of the plutonic masses intruded into the Precambrian sediments in Archeozoic time. The zones of weakness developed at that time may have persisted and were readily affected by subsequent tectonism.

Considerable faulting and local folding, affecting both Precambrian rocks and overlying sediments, took place in this Early Pennsylvanian period. Some of these folds and faults may have exerted some influence on the general location and orientation of the later Laramide structures.

The general uplift of the region in Early Pennsylvanian time raised certain areas above sea level. Relief was not great, but the upper Mississippian sediments were locally subjected to erosion. The unconformable Molas formation overlying the Mississippian limestones is composed of residuum from this erosion. The Molas and later Pennsylvanian formations were deposited in and around the previously formed structures.

During middle and late Pennsylvanian time, the outlines of the present Paradox Basin were formed. Continued regional epeirogenic uplift formed shelf and land-locked sea areas. These had intermittent communication with deeper and more widespread marine waters to the northwest and to more restricted Pennsylvanian areas to the southeast. The Uncompahgre continued to rise and by late Pennsylvanian time had formed a definite barrier between the Paradox basin on the west and the Central Colorado basin on the east.

Many of the east-west and northeast-trending positive elements across the basin continued to grow but were not exposed above sea level. Most continued to receive sediments but at a lesser rate than adjoining depressions, and this resulted in a thinning and pinching out of some of the strata. Local discontinuities are common within the Pennsylvanian section. The Pennsylvanian seas of the Paradox Basin became completely land-locked in Des Moines time. The rising Emery-San Rafael element cut off the accessway to the widespread Pennsylvanian seas to the west and northwest, while the upward movement of the Uncompahgre and Zuni highlands on the east and southeast shut off the communication in that direction. The result was the widespread formation of evaporitic sediments within the basin. Subsequent ingress of marine waters abetted by increased erosion of the surrounding highlands during Late Pennsylvanian time led to the deposition of carbonates and a thick section of limy siltstones, arkosic sandstones, red silty shales, and chert.

Post-Pennsylvanian

During early Permian time rapid sinking of many of the positive tectonic elements across the basin allowed the influx of early Permian seas which resulted in the formation of the lower Permian carbonates on the west, and lower Rico calcarenitic marine limestone on the east side of the basin. Most deposition in later Permian time was non-marine in nature; however, the transition to non-marine strata was intermittent with a recurrence of transgressive marine waters at various intervals. The transition is usually one of complex lateral and vertical gradation from thin-marine beds to predominantly terrestrial red-bed facies.

Rapid uplift and growth of the Uncompahgre during middle and late Permian caused the dumping of tremendous quantities of arkosic sandstone and limestone debris along the western margin of the plateau onto shallow and sometimes emergent high-shelf areas. The loading of these sediments, along with local tectonism probably caused the differential movement of the plastic evaporite beds below. Contemporary movement along early Pennsylvanian faults may have triggered the salt flowage. At any rate, the upward movement of the salt caused gradual arching of the overlying strata. The movement of the salt was very slow and continued with intermittent periods of no movement throughout Triassic and most of Jurassic (up to Morrison) time. Local movement may even have continued on into Cretaceous time. However, the present structural attitude of the salt anticlines did not develop until Tertiary time. The movement of the salt and resultant folding, collapse, and faulting of overlying sediments probably had little effect on the basement rocks. Kelly suggests that some downwarping might have occurred with the flowage.

The trans-basin arches and folds formed in late Mississippian and early Pennsylvanian time were probably active during periods of Permian time. Considerable change in lithology and interfingering of sedimentary facies occurred during the Permian due to regional and local movement, as well as the transgression and regression of marine waters.

The basin area was subjected to only minor tectonism during Traissic-Jurassic time. Few, if any, changes in the basement surface and structural attitude of the overlying sediments developed during these periods. Generally the area was regionally elevated intermittently with seas transgressing and regressing to the west. Some of the previous structures were elevated above sea level and subjected to erosion. Sea waters were trapped locally and evaporites were deposited. Some of the time the seas receded far to the west leaving most of the basin region above sea level and continental deposits of eolian sand developed. Volcanism in Late Jurassic time probably did not originate within the confines of the basin, but in areas to the west and covered parts of the subject area with ash.

At the beginning of Cretaceous time another northwest-trending epeirogenic uplift took place in southwestern Utah which affected most of the Paradox Basin region. Folding and faulting of the basement rocks along with the overlying sediments occurred. Local highlands were present in the basin contributing to deposition of coarse conglomerates and sandstones. Upper Morrison sediments were reworked and deposited as Cedar Mountain and Burro Canyon formations and local disconformities between the respective strata were developed.

A period of relative quiescence seems to have characterized the Paradox Basin region during most of middle Cretaceous time. Erosion and sedimentation must have balanced each other, since a stratigraphic hiatus exists between the Cedar Mountain - Burro Canyon formations of early Cretaceous age and the overlying Dakota formation of probable late middle Cretaceous age. In some places, angular discordance can be observed between the respective strata testifying to moderate tectonic movement during this period. Whether or not these movements were deep seated is unknown.

A widespread subsidence of the whole Rocky Mountain region took place during Late Cretaceous time. All of the tectonic elements of the Paradox Basin region were covered by marine waters. Several thousand feet of black, marine shales, siltstones, argillaceous limestones, and argillaceous, calcareous sandstone were deposited in the Rocky Mountain geosyncline. Toward the close of Cretaceous time, epeirogenic uplift again became dominant. The Mancos marine seas became shallow, and local highlands began to emerge. Faulting and local movement was common. Numerous northeast-trending faults have been found on the northern margins of the basin which affect the Mancos formation, but not the overlying Mesaverde formation of very, late Cretaceous age. This period of faulting probably marked the beginning stages of the widespread Laramide orogeny which followed. The earlier tectonic elements, Uncompahgre Plateau, San Rafael Swell, Nequoa Arch, Monument Upwarp, and Trans-basin arches were probably rejuvenated again at this time. However, much of the region still had only moderate relief and was transgressively inundated by marine waters during the time of deposition of the Mesaverde formation which is characterized by both marine and continental lithology.

The Laramide orogeny produced considerable deformation of the strata across the Paradox Basin. Numerous tectonic elements were formed. Some of these appear to have no relationship to the older established elements of early Paleozoic time; others were greatly influenced by these earlier trends; and still others appear to have reoriented the older uplifts and arches. Some of the Laramide tectonic elements did affect the Precambrian rocks and older Paleozoic sediments, whereas others affected only strata of Pennsylvanian or younger age. Differential folding of post-Mississippian sediments may have been caused by compressional forced as a result of the increased movement of salt in the salt anticlines along the eastern margin of the basin in early Tertiary time.

Subsequent tectonics which might have affected the basement rocks of the Paradox basin are relatively insignificant. Tertiary time saw general uplift with the formation of continental lacustrine basins. The local laccolithic igneous domes: La Sal Mountains, Henry Mountains, Abajo Mountains, Temple Mountain, Ute Mountains, and other stocks of early Tertiary time modified the structural attitude of the adjacent strata to some extent. However, the basement rocks and overlying older Paleozoic strata probably were not structurally altered other than by simple fracturing and stoping, allowing the emplacement of magmatic material in the immediate proximity of the stocks. The greatest deformation and arching caused by the sills, dikes, and tongue-like intrusive bodies appears to have taken place in the near-surface strata, leaving the lower Paleozoic and Precambrian rocks relatively undisturbed.

BASEMENT HIGHS AND LOWER PALEOZOIC STRUCTURES

If one assumes that the present surface of the basement rocks in the Paradox Basin is primarily due to the tectonic movements which have taken place subsequent to Precambrian time, then this topography is probably expressed as structure in the immediately overlying strata, possibly including Mississippian formations. This assumption is not completely valid since it is known that there were some islands of Precambrian rocks rising above the peneplain during Cambrian time. However, the long period of time from Archeozoic to middle Cambrian was sufficient to allow the development of a peneplain with only minor topographic relief, and, therefore, it is safe to assume that in most places in the basin, basement surface highs are similarly expressed in the Mississippian and older strata.

Certain positive tectonic elements in and around the basin have been rejuvenated several times during geologic history and effected the basement rocks and all overlying strata each time. These are: Uncompahgre Plateau, Nequoia Arch, San Rafael Swell, Defiance-Zuni uplift, and Monument upwarp. The orientation of the elements was not always identical to that at present, but their loci have remained fairly constant with only minor rotation of axes marking each period of rejuvenation.

Uncompahgre Plateau

The Uncompahgre is a northwest trending, essentially symmetrical geanticline which borders the eastern and northeastern sides of the basin and was extremely active throughout geologic time with frequent oscillations. Remnants of Mississippian limestone lie on Precambrian rocks in a few local spots on the plateau. These sediments along with all subsequent strata which were deposited on the flank or over the top of the Uncompahgre, depending on the state of emergence or subsidence of the element at the time of deposition, have been folded by the latest rejuvenation of the uplift. The axis of the uplift plunges gradually northwestward across the northern end of the basin. Small local secondary basement arches attached to the Uncompahgre may have extended westward for a short distance into the basin deforming the overlying Paleozoic strata in those areas.

Nequoia Arch

The Nequoia Arch is presently a long northwesterly-trending anticline which crosses the south-central part of the basin. Reflection of this arch in surface strata is nearly imperceptible, and it is only partly delineated by well control. Stratigraphic information from wells implies certain geologic events. An igneous pluton has penetrated the Precambrian metamorphics and sediments. This intrusion probably occurred during the Archeozoic Era and may have been rejuvenated at some later time. The arch became slightly positive in conjunction with the widespread early Pennsylvanian orogeny, but probably did not rise above sea level. Orientation of the element was perhaps more northerly. The element was even more positive during part of Permian time and may have risen above sea level for a brief period. The orientation was still nearly north-south or even slightly northeast. Final uplift and reorientation to northwest probably occurred during the Laramide orogeny. There is some indication that this later movement was differential with the major thrust exerted against the older rocks. It is, therefore, quite probable that the axial plane of the fold migrates with depth.

San Rafael Swell

The San Rafael Swell is a long, north-south trending, asymmetrical anticline with steep dips on the eastern flank and gentle dips on the western side. The present structural attitude of the surface rocks does not precisely reflect the structure of the deeper rocks. There are a number of pre-middle-Permian local structures which are not reflected in the overlying sediments. Even the general axis of the deeper ancestral element does not coincide with the present surface axis.

It is quite possible that the core of the San Rafael Swell is an ancient plutonic intrusion which has risen in various rejuvenated stages during geologic time. The Pure Oil Company No. 1 Desert Lake well on the west side of the Swell encountered quartzite and metamorphosed green shale above the granite indicating that Precambrian sediments did exist in the region. Likewise, the Pan American No. 1 USA Cullen well at the north end of the Swell encountered only slightly indurated sandstone and shale overlying granite and these are considered Precambrian sediments. This well also encountered the Precambrian section immediately below a Permian section. Similarly, the Kerr-McGee T.P. Utah 27 No. 1 well in Sec. 7, T-23-S, R-13-E, on the Swell had a section of the normal stratigraphic column missing. This well went directly from Coconino (Permian) into Deseret (Mississippian) at a depth of 400 feet, thus demonstrating that part of the Permian, all of the Pennsylvanian, and part of the Mississippian strata are missing. Other well data show considerable stratigraphic variation, formation pinchouts, and intertonguing in Mississippian and Pennsylvanian strata. Variations in thickness of Pennsylvanian beds exceed 700 feet within a distance of three miles, and over 1,300 feet in seven miles. Lower Permian carbonates also vary considerably in thickness. Consequently, it is obvious that the Swell has been intermittently a positive tectonic element during geologic time. Folding has been differential and present day surface structures are not necessarily superimposed over the deeper structures which affect the basement and conformable overlying lower Paleozoic rocks. Laramide folding of the upper strata seems to have slid over some of the previously folded lower sediments.

Monument Upwarp

The Monument upwarp, in the southern part of the basin, is a north-south trending anticline which is of fairly recent geologic age; Permian and late Cretaceous. The upwarp is a low, broad asymmetrical anticline about 100 miles long and 30 miles wide. As mentioned earlier, the initial uplift occurred in Permian time, as evidenced by the abrupt thinning and change in the composition of the Cutler formation. In fact, the deposition of eolian sandstone indicates that the area was above sea level part of the time. The axis of the Permian uplift, however, was probably east of the Late Cretaceous (present) axis. A number of local folds are reflected in surface rocks on the east limb of the main structural element. These folds may be the result of compressional forces developed by the Abajo igneous intrusion which affected the upper strata more than the older sediments.

Other Basement Highs

There are a number of other Mississippian structures which have been found as a result of drilling and which tend to confirm the presence of other basement arches across the basin.

The Lisbon, Kane Creek, Lockhart, Big Flat, Salt Wash Mississippian structures may have an en echelon alignment related to a broad, gentle basement arch. The configuration of the above surface structures is quite dissimilar to the deeper counterpart. The surface structures are influenced greatly by the flowage of salt in the region and tend to mask the Mississippian structure below. The Lisbon area is a good example: the older Mississippian structure on which the Lisbon oil field is located is not reflected in the surface rocks; the old structure was not greatly affected by the Laramide orogeny nor by the salt intrusion, with the exception of possible rejuvenated movement along old fault planes. The present surface anticline is superimposed over a Mississippian syncline or graben. There are probably a number of other Mississippian structures in the Lisbon area which have little relationship to the surface expression of the exposed rocks.

Results of geophysical work indicate that other Mississippian structures and basement arches may be present in other parts of the basin.

GEOPHYSICAL METHODS

The development of the oil and gas fields in the lower Paleozoic strata in the basin clearly show the lack of conformity between the structural attitude of these rocks and that of the near surface formations. As a result, sub-surface data disclosing existence of other deeply buried structures must be obtained principally by geophysical methods. The three common geophysical techniques are: magnetic, gravity, and seismic. The various virtues of the three methods are discussed below.

Magnetic

Since the intensity of the earth's magnetic field is primarily due to the physical configuration and magnetic characteristics of the basement metamorphic and igneous rocks, the effect of the overlying strata is for the most part negligible. When the magnetic susceptibility of the basement is uniform, variations in the

intensity of the earth's magnetic field is inversely proportional to the depth to basement from the point of reading. In this case, magnetic contours can be used qualitatively to delineate basement topography and the structure of conformably overlying strata. Changes in magnetic susceptibility of basement rocks, augmented by the structural and depositional inconsistencies of the sediments, may produce magnetic anomalies which are not indicative of structure. Thus, the limitations of the use of magnetic data to resolve structure must be recognized. However, these limitations do not entirely mitigate the effectiveness of magnetic measurements in resolving sub-surface structural relationships. Often the magnetic inconsistencies can be recognized and properly considered in the interpretative treatment of the data.

Magnetic measurements prove quite effective in locating faults and are far more reliable for this purpose than any other geophysical method. Frequently, the fault plane itself causes an anomalous response due to increased mineralization, so even those faults which do not effect the basement can often be detected. Admittedly, not all faults produce anomalous magnetic intensities, but experience demonstrates that most do. Therefore, a high level of confidence may be reasonably assigned to fault delineation by the magnetic method.

Airborne magnetometer work is generally more useful in a regional sense, rather than for delineation of local anomalies. Experience has shown that a greater degree of reliability in magnetic anomalies of low magnitude is possible with surface measurements.

Considerable additional information about the configuration of the basement rocks can be obtained by subjecting the magnetic data to second derivative analysis. Mathematically, this is a means of determining the curvature of the data or the rate of change with respect to linear extent. When these derivative values are contoured, the zero contour may be assumed to roughly delineate segments of the basement which have discreet susceptibility factors. Study of the curvature map thus produced reveals the individual basement segments, and magnetic anomalies associated with the basement blocks can rather confidently be ascribed to the effects of relief, and thus may reflect structural elements.

In the event sufficient well control is available in an area subjected to magnetic investigation, further treatment of the data can be made to produce a basement topographic contour map, and, by corollary, structure map of the overlying conformable sedimentary strata. In this treatment of the data certain arbitrary operations are used which can introduce error.

However, these errors tend to erase anomalies rather than to introduce pseudo anomalies, so any positive magnetic anomalies still remaining after this treatment probably do reflect basement highs.

A number of magnetic anomalies which suggest basement highs have been delineated in and around the Paradox Basin. To date, the information has been quite reliable, a few of these have been drilled and the presence of Mississippian structure has been confirmed. There is also a direct correlation between the structure of the Lisbon field and the defined magnetic anomaly.

Gravity

Some insight into the nature and configuration of basement rocks has been gained by gravity studies. Although density determinations of basement rock samples are necessarily limited in number, those available do represent a reasonable sampling of the various types of igneous and metamorphic rocks that may be expected to comprise the basement complex. Densities of sedimentary rocks present no problem since exposures of most of the column exist. Listed below are examples in the Uncompahgre Plateau province.

Age or Formation	Density (g-cm ³)	Remarks
Precambrian	2.60-3.07 (Sat. bulk)	Thirteen samples from Uncompahgre Plateau and surrounding area.
Pre-Paradox	2.60 (est. av.)	Carbonates, sands, shales
Paradox	2.14 Halite 2.31-2.33 Gypsum	These are estimated to comprise 90% of the formation.
Upper Hermosa	2.62	Limestones, shales, sands-weighted average from drillers log of well in Moab area.
Permian (Cutler-Rico)	2.55 (50% water saturated)	From 30 ' surface samples.
Mesozoic	2.50	Wingate through Salt Wash (Jm) Determined by gravity measurements at top and bottom of canyon west of Uravan, Colorado.

It is evident that a significant density contrast exists between the clastic-carbonate and evaporite sediments. Thus, it is entirely possible to resolve structures induced by salt flowage by analysis of the gravity anomalies with which they are associated. This has been done successfully by Joesting and Byerly (1954) in investigations carried on by the U.S. Geological Survey. They found, however, that in numerous instances gravity anomalies could only be attributed to density contrasts within basement rocks. Since this incongruity was observed to follow a random pattern, it suggests that the basement complex is a somewhat heterogeneous composite of igneous and metamorphic rocks. No more than rather broad generalizations can be drawn from gravity data since the relative thickness of the Pennsylvanian salt section is the principal source of gravity anomalies.

Generally, Precambrian metamorphics can be expected to have densities in the range of 2.60 to 2.65 g/cm³, which are comparable to those of the clastic sediments. Where an abnormally thick sedimentary section is implied by gravity data, it is quite likely that metamorphics are present.

As discussed previously, a granite porphyry intrusive into older granite has been noted in the Uncompahgre uplift, and this porphyry has high magnetic susceptibility but less than normal density. Where incompatibility of magnetic and gravity anomalies has been observed, it can most reasonably be explained by the presence of this porphyry.

It may be deduced from this analysis that the Precambrian surface is comprised of a somewhat heterogeneous assemblage of acid igneous and metamorphic rocks. Certain lineaments throughout the Paradox Basin have a generally northwest-southeast trend, but these may reflect structure of Paleozoic or later tectonic origin. Certainly, there is evidence that some contacts between igneous facies strike more nearly east-west. One of the enigmas is the relationship of metamorphic to igneous. It is not clear whether the metamorphics occur as the erosional remnants of a once ubiquitous mantle, or whether the metamorphics occur as the erosional remnants of a once ubiquitous mantle, or whether they are an integral part of a Precambrian series which sustained a complex paleo-geologic history. If the latter is true, as indicated previously, basement lineaments should be expected to display a notable degree of parallelism. Gravity studies tend to support this concept but only as a postulate. Gravity measurements do indicate rather conclusively the complexity of the basement rocks in both composition and configuration.

Seismic

Very little information on basement rocks has ensued from seismic investigations. Any concepts evolved from seismic analysis have been structural, and these by inference from reflecting horizons extent in Paleozoic strata. Until comparatively recently, resolution of Paleozoic horizons has been unreliable and difficult. Techniques have been developed which overcome some of the velocity problems inherent to the evaporite facies, and record quality has also been improved.

For the most part, seismic work has been concentrated on resolving local structural features. However, some idea of the regional framework is obtained from a composite analysis of local areas. For instance, Lisbon Valley, Big Flat, and Salt Wash appear to be somewhat discrete structural features developed along a basement tectonic lineament which transects the northern portion of the Paradox Basin. This is, perhaps, the most extensive basement feature indicated by seismic data. In the Four Corners area, and adjacent to the San Rafael Swell, structural trends have also been delineated. While these appear to be locally discrete, they may, in some cases, be elements of major basement features which extend for considerable distances into the basin.

Seismology indicates the presence of Paleozoic structures and structural trends which have no recognizable surface expression. Very little has been learned about rock types and their distribution by this geophysical means.

SUMMARY

The basement rocks underlying the Paleozoic and younger strata of the Paradox Basin are probably composed of a complex assemblage of metamorphic rocks varying in degree of metamorphism, and intruded with numerous varieties of acid igneous rocks. Generally, these intrusions are ancient in age and may have been emplaced along certain zones of weakness which have persisted throughout geologic history. The orientation of some of the recurrent positive elements may have deviated slightly with each subsequent uplift.

Prior to Paleozoic sedimentation, the topography of the basin was evidently quite flat with only minor relief because of the long period of peneplanation before middle Cambrian time. Tectonic movement was generally regional in nature

between Precambrian and early Pennsylvanian time. Pennsylvanian time was undoubtedly the most important and widespread tectonic period that affected the basement and overlying lower Paleozoic sediments of the Paradox Basin region. It might also be considered the most important period from an economic viewpoint. Many of the Mississippian structures in which oil and gas have been, and ultimately will be, found were formed during this period and many have probably retained their identity during subsequent periods of tectonism, being altered only by faulting and reorientation.

Numerous arches and positive elements in and around the basin which are reflected in the basement rocks have been discussed above. Some of these are well known and are either expressed in the surface strata or have been confirmed by well information; others are indicated only by geophysical work.

The development of some of the recent oil fields in the Paradox Basin has demonstrated the lack of structural conformity between the older Paleozoic strata and that of the post-Pennsylvanian strata; however, there may be general conformance between the structural attitude of these older sediments and the surface of the basement rocks. Consequently, determination of basement surface highs could also indicate overlying lower Paleozoic structures which might contain hydrocarbon accumulations.

CITED REFERENCES

- Barrs, D. L., 1958, Cambrian Stratigraphy of the Paradox Basin Region: Intermountain Assoc. Petroleum Geologists Guidebook.
- Byerly, P. E., and Joesting, H. R., 1959, Regional Geophysical Investigations of the Lisbon Valley area, Utah and Colorado: U.S. Geological Survey Prof. Paper 316-C.
- Joesting, H. R., and Byerly, P. E., 1958, Regional Geophysical Investigations of the Uravan Area, Colorado: U.S. Geological Survey Prof. Paper 316-A.
- Kelly, Vincent, 1955, Tectonics of the Four Corners Region: Four Corners Geol. Assoc. Guidebook.
- Shoemaker, E. M., 1956, Precambrian rocks of the north-central Colorado Plateau: Intermountain Assoc. Petroleum Geologists Guidebook.

Paper 35 DESERT CREEK ZONE SOUTHEAST SAN JUAN COUNTY, UTAH

by Kenneth E. Carter¹

INTRODUCTION

During Pennsylvanian time the Paradox depositional basin occupied most of southeastern Utah and parts of southwestern Colorado, northwestern New Mexico, and northeastern Arizona.

Thick arkoses are present in the northeastern part of the basin, adjacent to the strongly positive, northwest-trending Uncompahgre front. To the southwest the arkoses interfinger with cyclic deposits of evaporites which attain a thickness of at least 5,000' in the central portion of the basin. The evaporite facies thins southwestward and grades to "shelf" limestones and dolomites deposited in a penesaline- to normal-marine environment.

Nearly all the Pennsylvanian production discovered thus far is on the southwestern shelf, particularly where "shelf" carbonates are transitional to evaporites. Hydrocarbon accumulations are trapped in porous carbonate build-ups within the Desert Creek zone. These build-ups have been defined as reefs, biostromes, bioherms, banks, and algal forests by various workers in the area. The presence of calcareous algae, associated with such carbonate build-ups, has been recognized for some time, and intensive study, particularly since the discovery of the Aneth field, has indicated that algae are of extreme importance in the development of oil and gas reservoirs.

In this paper the stratigraphy of the Desert Creek zone and the relationship to the production of oil and gas is discussed. The study has been confined to the 36 square townships in the extreme southeast corner of San Juan County, Utah. All the major oil and gas fields, productive from the Desert Creek zone, are within this area.

RESUMÉ OF DEVELOPMENT—DESERT CREEK ZONE

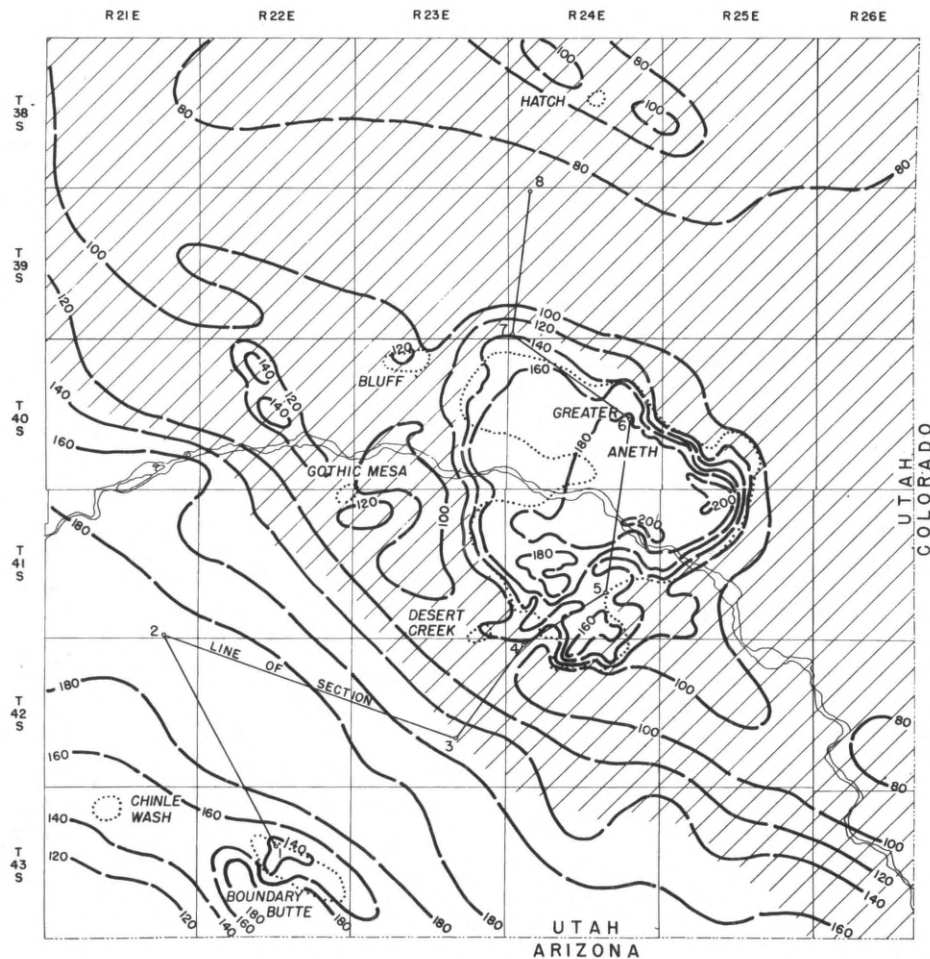
Within the area studied, the first production from the Desert Creek zone was established on the Boundary Butte anticline. The Western Natural Gas -- Byrd Frost, Navajo No. 1, Sec. 25, T-43-S, R-22-E, was completed in 1948 in the upper Desert Creek and overlying Ismay zones for an initial potential of 9 million cubic feet of gas per day. The discovery attracted limited attention because of the lack of market facilities.

The area was essentially dormant until the discovery of the Desert Creek field in Sections 35 and 36, T-41-S, R-23-E. The discovery well was drilled by the Shell Oil Company in 1954 and was completed in the Desert Creek zone at a depth of 5,300 feet, for an initial potential of 248 barrels of oil per day.

The economic potential of the area was not fully recognized until the discovery of the Aneth field in 1956 by the Texas Company. The discovery well was

1. Consulting Geologist, Durango, Colorado.

Figure 118.



EXPLANATION



EVAPORITE FACIES
CARBONATE - EVAPORITE RATIO < 8:1

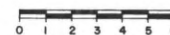


"SHELF" FACIES
CARBONATE - EVAPORITE RATIO > 8:1



PRODUCING FIELDS
THE ONLY FIELDS SHOWN ARE THOSE
PRODUCING FROM THE DESERT CREEK
ZONE.

SCALE



MILES

THICKNESS - FACIES MAP
DESERT CREEK ZONE
SOUTHEAST SAN JUAN COUNTY, UTAH

drilled in Sec. 23, T-40-S, R-24-E and was completed through perforations 5,828-5,874 for 1,704 barrels of 43° gravity oil per day. Discovery of the Cahone Mesa, White Mesa, McElmo Creek, and Rutherford fields followed shortly thereafter. Subsequent development drilling has joined these fields, and they are now known to produce from a common reservoir. These fields are herein called the Greater Aneth Area.

As of January 1, 1962, there were over 550 producing wells in the greater Aneth area and over 46,000 acres proven for production. In 1961 the field produced 25,174,568 barrels of oil.

STRATIGRAPHY

The Paradox member of the Hermosa formation is characterized by complex lateral and vertical lithologic variations. Cyclic deposition of evaporites occurred in the central part of the basin with each cycle, or partial cycle, separated by black shale. Hite (1960) recognizes 29 cyclothems in the evaporite facies which he has numbered in sequence from youngest to oldest. The areal extent and facies relationship are different for each cycle, but, in general, thinning and a gradational change to carbonate rocks occur towards the southwestern shelf.

Early in the development of the oil and gas fields of southeastern San Juan County, the Desert Creek zone was believed to represent one partial cyclothem. Additional well control now suggests that the Desert Creek zone represents two partial cycles. Well-to-well correlation from the southeastern part of San Juan County to Gibson Dome and the Lisbon field in the northern part of the county indicates the Desert Creek zone is correlative with salt beds 4 and 5, as pointed out by Hite (1960).

The thickness and generalized facies relationships of the Desert Creek zone are shown on Figure 118. Two major facies are differentiated within the area studied based on the ratio of carbonates to evaporites. The cross-hatched area outlines the "evaporite" facies, which consists of dark gray to brown dolomite, shaly limestone, calcareous siltstone, thin, gray to black shales and anhydrite. Although these sediments are referred to as the "evaporite" facies, the carbonate-evaporite ratio varies from 0 to 8:1. Dolomite has not been included with the "evaporites", although some is of primary origin. These sediments are characteristic of a predominantly penesaline to saline environment. In the remainder of the area, the Desert Creek zone is composed of limestone and dolomite with minor amounts of shale, siltstone, and sandstone which were deposited in a normal marine environment.

The thickness of the evaporite facies is comparatively uniform, averaging about 80 feet. The thickness of the carbonate facies varies from 120 feet to over 200 feet, averaging about 170 feet, or over twice the average thickness of the evaporite facies.

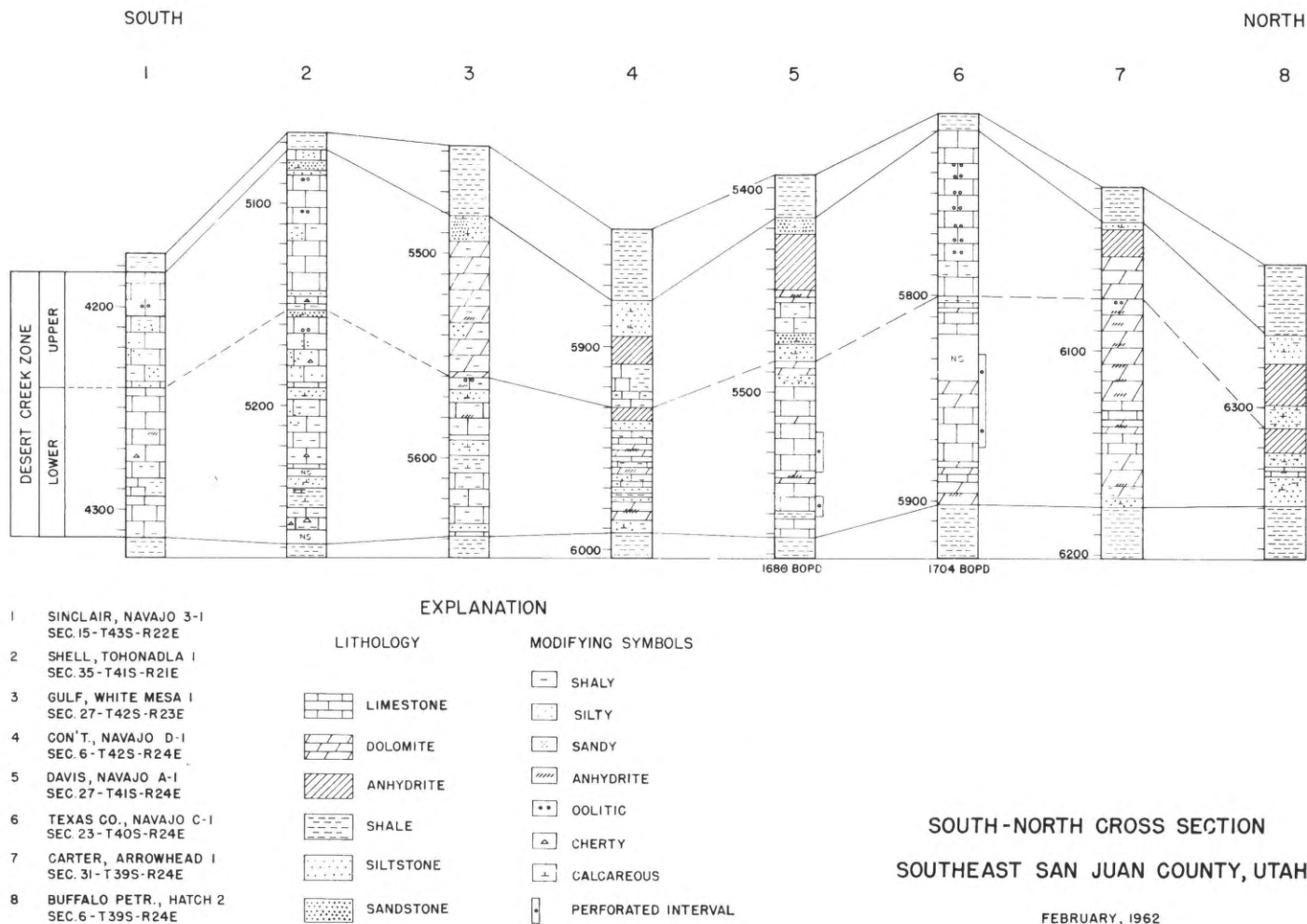


Figure 119.

EVAPORITE FACIES

The evaporite facies consists of two partial cyclothems as illustrated by wells 4 and 8 on Figure 119. At well 4 the lower cycle consists of dark gray, calcareous, micaceous siltstone, dolomite, and limestone with thin interbeds of dark gray to black shale and dark gray, very fine-grained sandstone. The lower partial cycle is terminated by an eight-foot thick gray anhydrite. The carbonate rocks are dark gray to brown, microcrystalline, shaly to silty and anhydritic. The limestones are very dense, hard, and tight. The dolomites are microsucrosic and earthy with poor to fair intercrystalline porosity and low permeability.

The upper cycle, in ascending order, consists of dark gray to brown shaly, silty, cherty, microcrystalline limestone with interbedded dark gray, calcareous shale. Above this interval is a 14' thick bed of anhydrite overlain by dark gray calcareous to dolomitic siltstone. The Desert Creek is bounded above and below by black, carbonaceous shale.

North of the greater Aneth area the lithology of the evaporite facies is similar except that the percentage of carbonate rock is much lower. The limestones and dolomites grade northward to calcareous or dolomitic, shaly siltstone (well 8, Figure 119).

CARBONATE FACIES

The areas of carbonate deposition include the greater Aneth area and a part of the southwest shelf. Although these rocks have been grouped together, significant lithological and environmental differences exist.

Southwest of the evaporite facies is a northwest-trending area of thickening outlined by the 180' thickness contours. The section consists of dark gray to brown, shaly, silty, microcrystalline limestone with thin interbeds of dark gray calcareous siltstone and shale. The clastic content of the lower part of the section is high, with a progressive decrease in clastics towards the upper part of the section. Crinoids and fusulinids are common, particularly in the shaly limestones.

It is difficult to trace the upper and lower cycles previously described into the carbonate facies. It is believed, however, that the lower cycle is equivalent to the interval 5,154-5,268 feet in well 2, Figure 119. The division between the two cycles is placed at the top of a gray, very fine-grained, calcareous sandstone which overlays a light gray, microcrystalline, oolitic limestone. The top of the upper cycle also is marked by thin bedded sandstone and siltstone immediately above a tan, microcrystalline, oolitic limestone. The thin oolitic zone at the top of the Desert Creek zone is present throughout most of the southwest shelf and is found in the greater Aneth area. The oolitic limestones are believed to have been deposited in shallow, agitated waters which mark the lowering of sea level that terminated each cycle.

These sediments are not typical of a high shelf facies. The dark color and high shale content of the limestones suggest deposition in a semi-restricted environment which probably was transitional between the evaporite facies to the northeast and the higher shelf area to the southwest.

In the Boundary Butte - Chinle Wash area (T-43-S, R-21 and 22-E) the Desert Creek zone thins to 120 feet. The limestones are less shaly and both limestones and shales are lighter colored than to the northeast. In the Chinle Wash field, gas production is obtained from the upper Desert Creek zone, and in the Boundary Butte field, oil and gas are produced from the upper and lower parts of the zone.

GREATER ANETH AREA

Of greatest economic significance is the carbonate facies of the Desert Creek zone developed in the greater Aneth area.

The Aneth reef complex is a nearly circular mound of highly fossiliferous limestone and dolomite. The carbonate mass has a 12-mile diameter and a maximum thickness of over 200 feet. At the periphery, the Desert Creek zone thins rather abruptly to 100 feet or less, and grades to sediments of the evaporite facies.

The lower part of the Desert Creek zone consists of gray to tan, porous, fossiliferous limestone and dolomite. Fossil debris includes brachiopods, foraminifera, crinoids, and occasional corals. Abundant calcareous algae (*Ivanovia* sp.) may be present and are important both as a rock-builder and as a sediment-binding constituent. Porosity is vugular and intercrystalline with the vugs varying in size from pinpoint to over an inch in diameter.

The boundary between the lower and upper part of the Desert Creek zone is marked by a thin shale or shaly lime. The upper part of the Desert Creek zone is predominantly oolitic limestone with porosity developed as a result of the leaching of oolites.

The carbonate facies of the upper part of the Desert Creek zone is of lesser areal extent than the carbonate facies of the lower part of the zone. The anhydrite from 5,423-5,450 feet (well 5, Figure 119) may be developed well within the producing area, particularly in the southern portion of the field.

Porosity and permeability are variable, but average about 8-10% and 5 millidarcies. However, porosity of nearly 30% and permeability of over 1,000 millidarcies are known. Net pay thickness varies from 10 feet to over 100 feet, with a field average of 35 to 50 feet. Crude from the greater Aneth area is of paraffinic base, green in color, and with an average gravity of 41° A.P.I.

Approximately 46,000 acres are proven productive and cumulative production as of January 1, 1962, was 111,833,444 barrels of oil. The average yield per acre as of January 1, 1962, was 2,400 barrels of oil. Estimated recoverable reserves are approximately 5,400 barrels of oil per acre, or 250,000,000 barrels of oil for the field.

The factors responsible for the localization of the Aneth reef complex are obscure. Thickness mapping of the stratigraphic units below the Desert Creek zone are suggestive of thinning. Such thinning may reflect a mild structural and topographic high which provided a more favorable environment for the growth of plant and animal organisms than the surrounding sea bottom. Unfortunately, very few wells have been drilled below the Desert Creek zone in the greater Aneth area, and the data are inconclusive.

In the Aneth reef complex it is believed that the carbonate rocks of both cycles probably reached their maximum thickness during the initial normal marine phase of each cycle.

The progressive lowering of sea level during the remainder of the cycle resulted in the gradual emergence of the Aneth complex concurrent with an increase in salinity of the surrounding waters. Penesaline carbonates were deposited culminating in the deposition in anhydrite.

It is believed this relationship best explains the interfingering and infilling of pore space by anhydrite, particularly on the southern edge of the field.

OTHER PRODUCING FIELDS

Other producing areas include the Desert Creek, Gothic Mesa, and Bluff fields. In these fields the better reservoir development occurs in limestones and dolomites in the lower part of the Desert Creek zone. These rocks are similar lithologically to those in the greater Aneth area, but thicknesses are not as great, nor is porosity and permeability as well developed. In these fields the carbonate-evaporite ratio approaches the 8:1 limiting value arbitrarily used to differentiate the carbonate-evaporite facies.

EXPLORATION PROBLEMS

Although most of the oil and gas fields in southeast San Juan County are associated with mild structural deformation, the development of suitable reservoir rocks is the prime factor in the localization of oil. In many instances, the association of structure with the producing area is probably fortuitous with the presence of a structure producing the incentive to drill. Consequently, conventional structure-finding tools are of limited value in exploration.

In the absence of a direct oil-finding method, meticulous lithologic and environmental studies appear to be the most promising approach. With additional control, it is possible to work with smaller stratigraphic units which will provide "leads" which may be masked by working with thicker units.

The importance of algae in the development of a suitable reservoir rock has become apparent during the past few years. A better understanding of the relationship of algal growth to environment should provide additional prospective areas.

CITED REFERENCES

- Hite, R. J., 1960, Stratigraphy of the Saline Facies of the Paradox Member of the Hermosa formation of southeastern Utah and Southwestern Colorado: Four Corners Geol. Soc. Guidebook, 3rd Field Conf., p. 86-89.

Paper 36 OIL AND GAS POSSIBILITIES OF THE ISMAY ZONE

by William C. Hafeman¹

INTRODUCTION

The Ismay zone of the Paradox Basin immediately underlies the Upper Hermosa formation, and is underlain by the Desert Creek zone which is productive in the Aneth Complex. The Ismay zone is of Pennsylvanian Des Moines age and can be separated into two cycles or zones, as indicated on Figure 120. The two zones are further subdivided into two distinct phases for this report. Thus, the format will be an upper and a lower Ismay zone with each zone subdivided into an upper and a lower phase.

Regional aspects of the two Ismay zones indicate a depositional similarity. The main differences between the zones are the more widespread deposition of evaporites and the common occurrence of algal carbonates in the lower Ismay zone. The occurrence of hydrocarbons within the Ismay zone further differentiates the two independent cycles. To date, the Upper Ismay zone has a very disappointing production history, but commercial accumulations of hydrocarbons in the Lower Ismay zone have been found in several localities on the southwestern shelf of the Paradox Basin.

AREA AND SCOPE OF STUDY

The area of study includes approximately 20,000 square miles in the southeastern portion of Utah and adjacent parts of New Mexico, Arizona, and Colorado, as indicated on Figure 122.

In the course of the study, samples and cores were examined from wells throughout the Paradox Basin. Emphasis was placed on wells drilled within the structural Blanding Basin, where all of the present commercial Ismay production occurs.

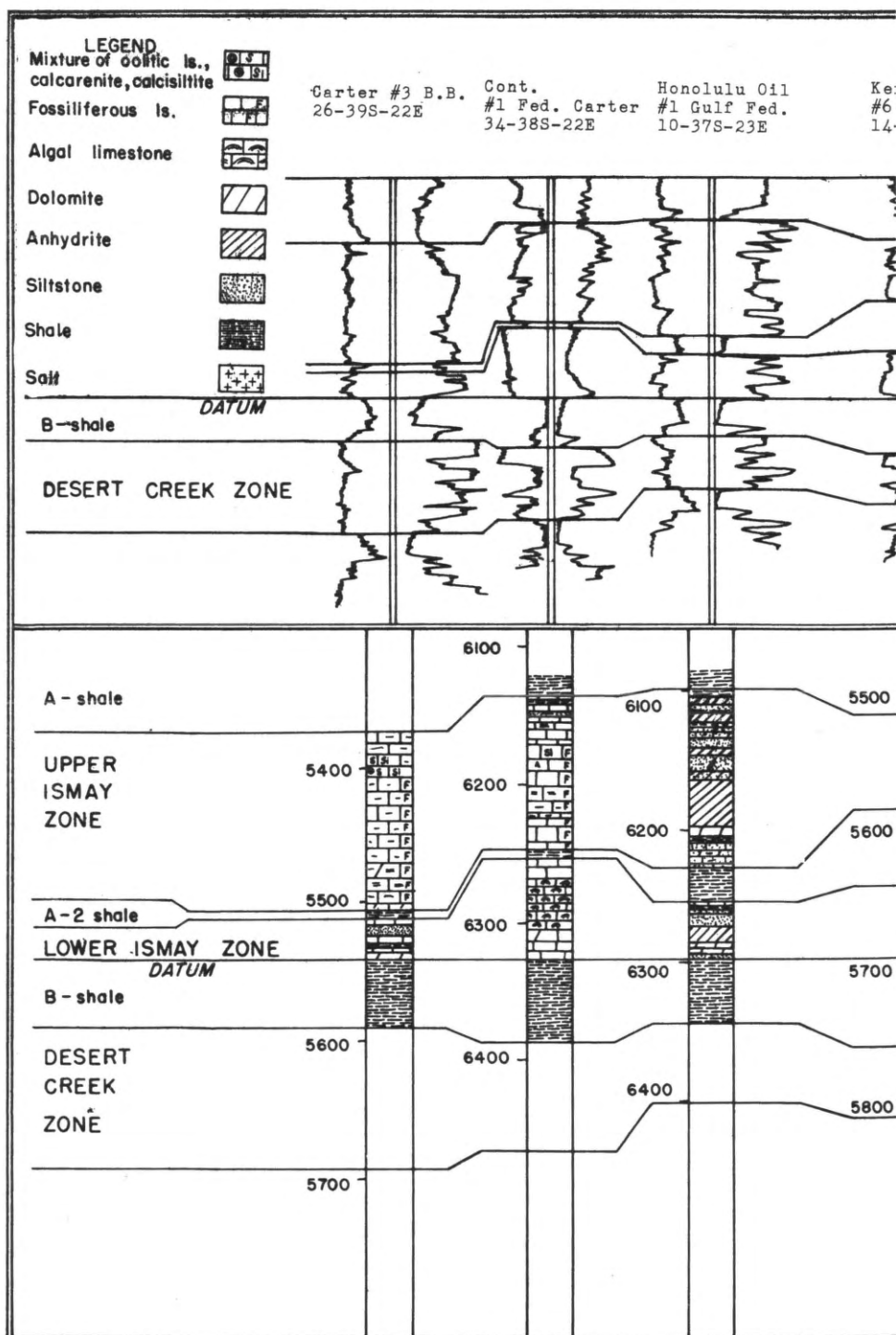
Figure 121, a basinwide cross-section, shows regional correlations across the Paradox Basin in the Upper Ismay and Lower Ismay zones and illustrates the changes of lithologies within the zones. The correlations illustrated in Figure 121 are based on studies of columns extending from the Mississippian carbonates to the top of the Pennsylvanian Hermosa formation; however, only the Ismay zones and portions of underlying and overlying units are illustrated.

LOWER ISMAY ZONE

The Lower Ismay zone is the second major producing horizon in the Blanding Basin. (The underlying Desert Creek zone has the greater reserves.) Production is primarily from vuggy, algal limestones which are present on the limestone shelf areas of the Blanding Basin.

Throughout most of the Paradox Basin, the Lower Ismay zone can be divided into two phases. However, in several areas in the Paradox Basin, the presence of two phases within the Lower Ismay zone is either not indicated or cannot be differentiated.

1. Consulting Geologist, Salt Lake City, Utah.



Kern Co. Ld. Skelly Oil Co.
 #6 Coal Bal. #1 Church Rock Unit
 14-35S-25E 26-31S-23E

Reynolds Mining
 1 Gibson Dome
 35-29½S-20E

Cont.
 #1 Hoover Fed.
 20-29S-15E

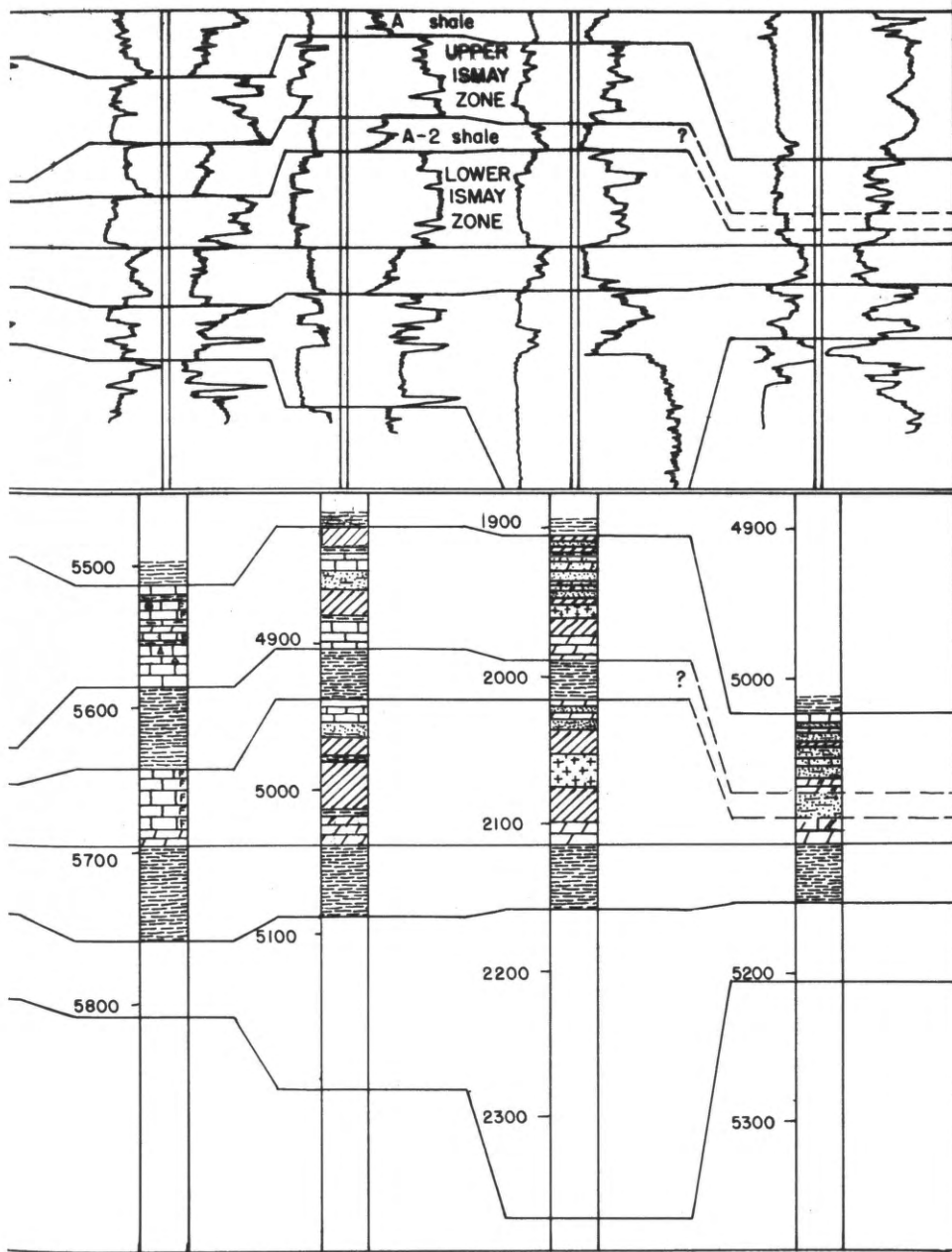


Figure 120. Cross Section showing Upper Ismay Facies Changes.

Figure 122 shows the distribution pattern of the various upper phase facies of the Lower Ismay zone. The deposits in the lower phase are similar in many areas to those in the upper phase. The main facies divergence between the two phases lies in the areas immediately adjacent to the main salt basin and within the long southeasterly extension of the salt basin. In these areas, all evaporites are present in the upper phase, and carbonates are present in the lower phase.

Main Salt Basin Evaporites

The main salt deposits of the Lower Ismay zone are normally separable into an upper and lower phase. The phases show local variations in salinity, but these variations are not consistent, and either phase may contain sulphates or chlorides. The lower phase normally contains chlorides.

The evaporitic interval of the entire Lower Ismay zone is 165 feet thick in the Cane Creek area (T-26-S, R-20-E). According to present control, the depositional axis for Lower Ismay evaporites lies within the Cane Creek area and trends in a northwesterly southeasterly direction. The salt deposits form a prominent neck that trends into the southeastern extension of the Lower Ismay evaporites, indicating that the evaporitic trend is both an integral part of the salt basin and an extension of it.

Lower Phase—Shelf Areas

The lower phase deposits of the "shelf areas," as denoted by Figures 122 and 123, are sucrosic, dolomitic limestones, or limy dolomites. These deposits are differentiated from the overlying algal carbonates of the upper phase and their "off trend" equivalents of calcilutite and siltstones by textural, chemical, and environmental differences.

The sucrosic carbonates of the lower phase are slightly argillaceous, and microscopic streaks of carbonaceous material are very common. In many areas, the magnesium content of the lower phase is discernible only through solubility tests. Effective porosity seldom occurs in the lower phase when the magnesium content can be substantiated only by the final stages of acid insolubility tests or when the dolomite bed is a few feet thick.

The lower phase is present throughout the southwestern shelf area and varies locally from 5 to 35 feet in thickness. The greatest development is in T-40 and 41-S, R-26-E, where the sucrosic carbonates flank and overlie the Desert Creek build-up. The sucrosic carbonates are also present throughout the Ismay field area in T-40-S, R-26-E, but are not as well developed as in the Aneth Complex area. Oil has been recovered from the pinpoint vugs and intercrystalline porosity of the lower phase in the Ismay field and east flank of the Aneth Complex.

West of Comb Ridge, thin sucrosic, dolomite beds are locally present in the lower phase. However, no effective porosity has been encountered in the thin dolomite lenses.

No evidence of a dolomitic phase has been found in the Lower Ismay limestones of the northeastern shelf area east of the anhydrite trend. In fact, the Lower Ismay zone is not readily divisible into phases by physical or chemical criteria on the northeastern shelf area. Some wells have several feet of recrystallized, earthy textured limestone near the base of the Lower Ismay zone, but the earthy limestone is neither extensive nor is it sufficiently developed to be considered as a separate phase. Consequently, all the limestones of the northeastern shelf area will be discussed as one unit in the Upper Phase-Shelf Areas section of this paper.

Lower Phase—Evaporitic Areas

Lower phase carbonates immediately underlie the upper phase anhydrites that are peripheral to the main salt basin and the evaporites of the "trough" area.

The lower phase carbonates, underlying the upper phase evaporites, are very similar to those of the southwestern shelf area, and, in like manner, they vary considerably in thickness. In the Lisbon anticline area, 22 to 25 feet of calcareous dolomites are present in the lower phase, but the carbonates thin to the southeast and become more clacareous. Carbonate thicknesses in lower phase cores taken 35 to 50 miles southeast of Lisbon, ranged from 4 feet of limestone to 15 feet of limestone and dolomite. Control points along the evaporitic "trough" indicate that the carbonate deposits underlying the upper phase evaporites are best developed in the Lisbon Anticline-Church Rock area.

LOWER ISMAY—UPPER PHASE DEPOSITS

The facies change of upper phase deposits within the Paradox Basin is depicted by Figure 122.

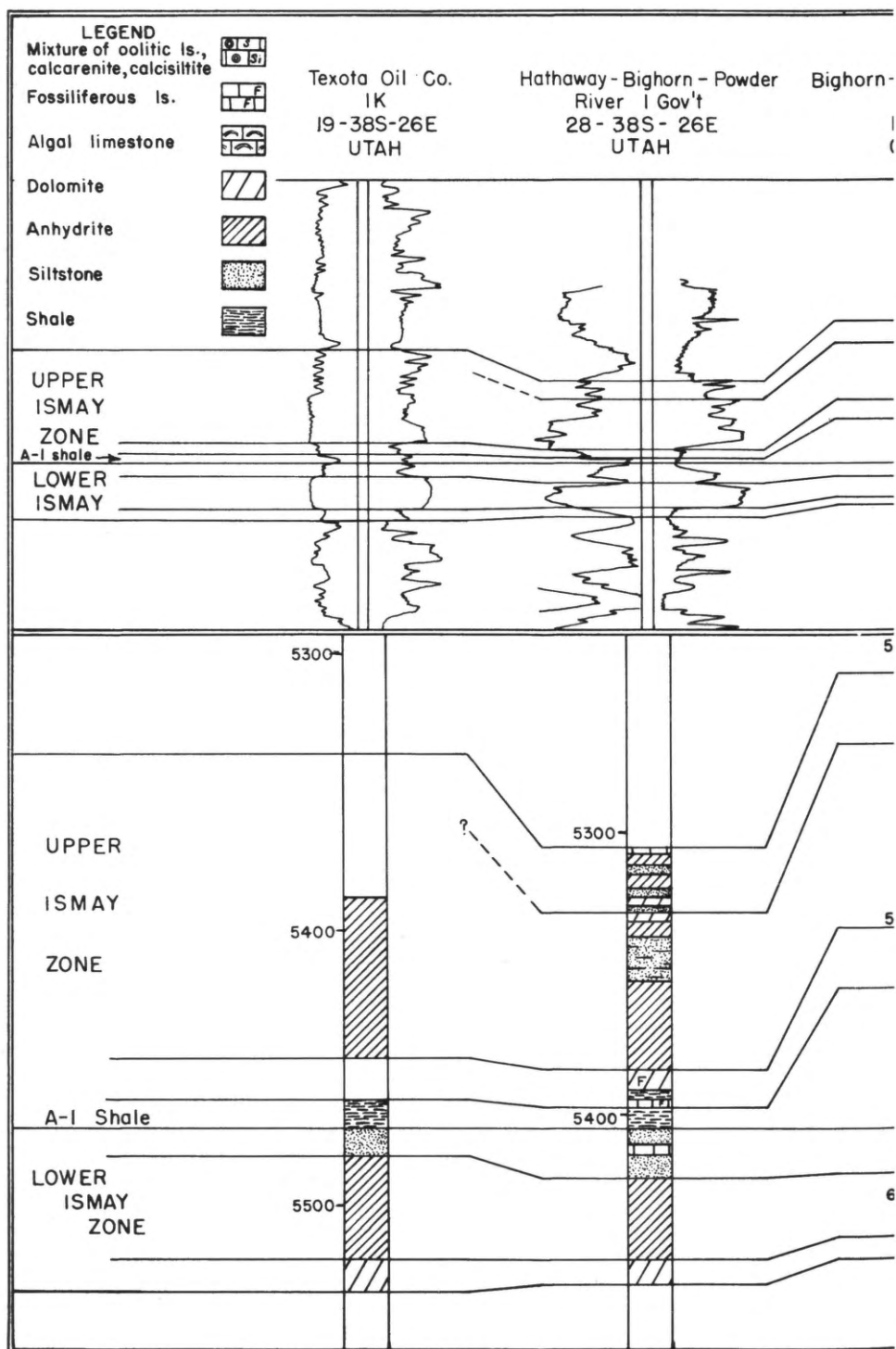
Upper Phase—Evaporitic Areas

The upper phase deposits of the main salt basin area have been discussed under the heading "Main Salt Basin Evaporites." The anhydrite facies of the upper phase adjoins the salt deposits as lateral equivalents and forms a long, broad extension of the main restricted basin. The limb of evaporites averages 30 miles in width and extends into southwestern Colorado and northwestern New Mexico.

The Carter Aztec No. 2 well, Sec. 9, T-39-S, R-26-E, is the only test to encounter salt in the upper phase of the Lower Ismay "trough" deposits. The occurrence of 9 feet of salt in the Carter test indicates that the restricted environment of the evaporitic "trough" was similar to that of the main salt basin, but the thickness of "trough" evaporites is considerably less. The average thickness of all evaporites in the "trough" area is only 20 to 35 feet.

The anhydrites of the upper phase are also present as a band adjoining the main salt deposits. This anhydrite band may be present to the east of the salt deposits--between the salt and the arkoses west of the Uncompahgre Uplift--thus forming a halo around the salt; but subsurface control is lacking in this area and the depositional pattern can only be surmised.

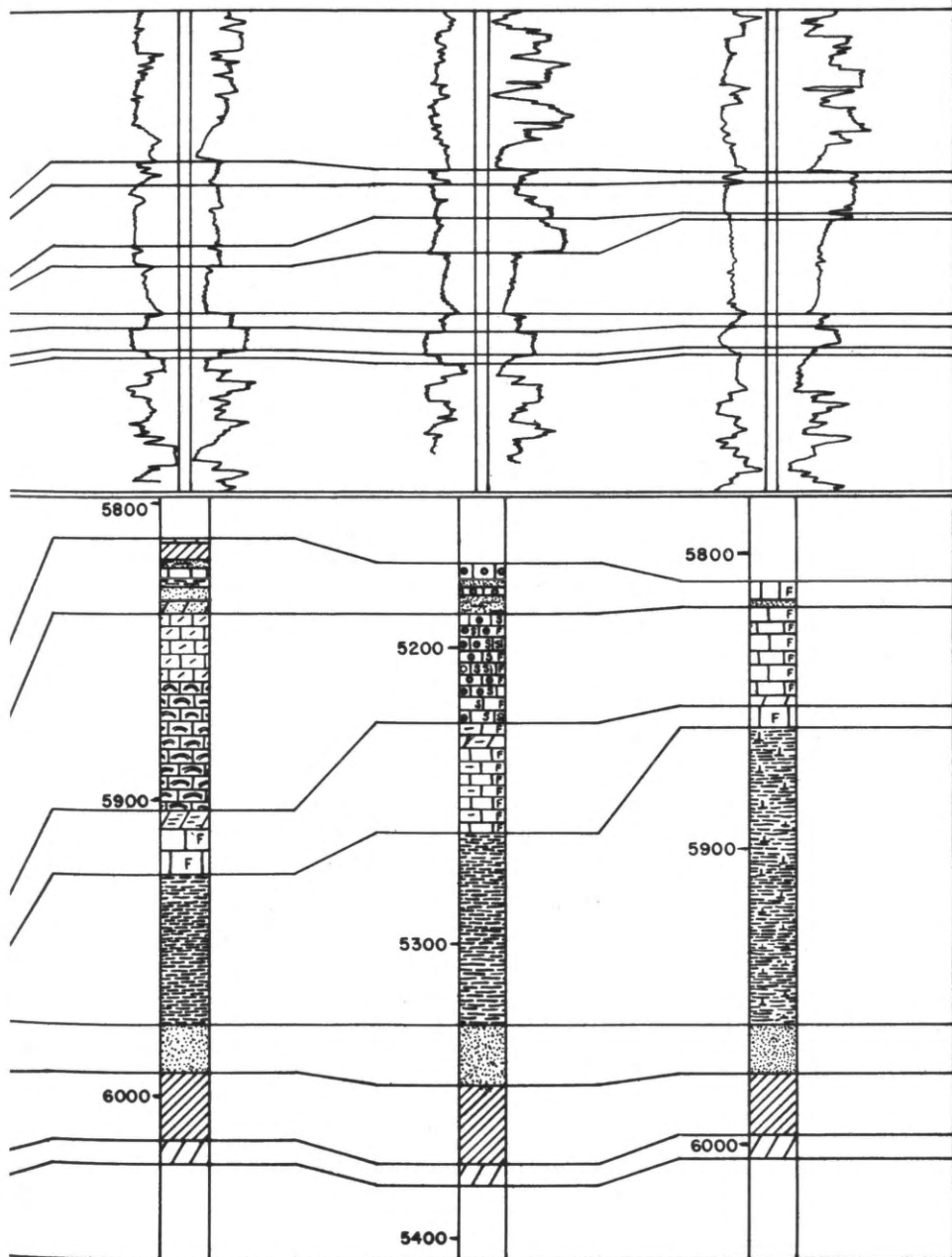
The anhydrite band west and south of the salt deposits ranges from 10 to 35 miles in width, except in T-27 to 29-S, and R-12 to 15-E, where a pronounced westward extension is present in the Lower Ismay evaporites. In this area, the anhydrite facies of the upper phase extends some 18 miles west of its normal trend line. (An extension of evaporites in this area is present in many pre-Isamay zones, thus indicating the persistence of the salt basin configuration.) The entire Lower Ismay zone is absent west of the zero edge of the anhydrite in the area north of the Henry Mountains.



Bighorn-Powder River Corp.
 1-A Fed.
 15-37N-20W
 COLORADO

Hathaway & Bighorn
 USC No. 3
 11-37N-20W
 COLORADO

Weaver
 Penrose Gov't No. 1
 34-38N-19W
 COLORADO



Upper Phase—Shelf Areas

The upper phase of the limestone shelf areas is the main objective horizon of most Lower Ismay tests. The most widespread development of porosity in the upper phase of the Lower Ismay occurs on the southwestern shelf.

The porosity occurs in vuggy, algal carbonates and has been encountered in various tests on the Monument Uplift as well as in the Blanding Basin. Formational pressures west of Comb Ridge are very low, and no commercial accumulation of hydro-carbons has been encountered to date.

Reservoir rocks in Ismay zone fields of the Blanding Basin are trends of porous limestones that have undergone various degrees of infilling by secondary recrystallization. The effectiveness of the vuggy porosity is a function of the degree of secondary crystal growth in the vugs. The porous trends are related to the occurrence of an algal growth; therefore, the porous trends are coincidental with depositional environments and are predictable to a high degree.

The algae responsible for the porous development has been identified as *Ivanovia*^{1/}. The algae framework is a system of interlacing "blades." The edges of the blades appear to be laminar in cross section, but this appearance is due to minute crystal growths on the external surfaces of the blades rather than laminarity. The porosity between the blades is primarily responsible for hydrocarbon accumulation. When the vugs between the blades are infilled with secondary crystal growth, the porosity loses effectiveness in proportion to the degree of infilling. Since the upper-phase porosity is primarily related to an algal growth, the entire Lower Ismay zone thickens when a porous algal section is encountered. This is basically a stratigraphic build-up caused by lime-secreting algae. Nonalgal areas adjacent to porous algal accumulations are thinner, nonporous, and represented by thin argillaceous limestone and a relatively thick siltstone deposit. In areas of close control, a detailed stratigraphic examination of polished core chips show a sedimentary change between wells with algal porosity and off-trend wells. The following comparison is based on core examinations of two wells drilled less than an 80-acre location apart. Of these two wells, Gulf No. 1 West Desert Creek represents a moderate algal development and Gulf No. 2 West Desert Creek represents an off-trend well that is near an algal growth. Both wells are located in Sec. 1, T-41-S, R-22-E, San Juan County, Utah.

No. 1 West Desert Creek	No. 2 West Desert Creek
Top of Lower Ismay Zone	
2 ft. Fossiliferous limestone	2 ft. Fossiliferous limestone
1 ft. Quartz siltstone	11 ft. Quartz siltstone
-----Intrazonal Time Line-----	
2 ft. Calcilitite	4 ft. Calcilitite, calcarenite and pseudo-oolitic limestone
4 ft. Dense algal limestone	1 ft. Dense algal limestone
23 ft. Algal limestone (vuggy porosity, partially dolomite filled)	2 ft. Calcisiltite, calcarenite and calcilitite
2 ft. Calcilitite	1 ft. Algal limestone and calcisiltite (porosity filled with secondary crystals)
(Upper Phase)	1 ft. Calcisiltite and Calcilitite
	3 ft. Algal limestone with much calcisiltite (porosity filled with crystals)
	4 ft. Mixed calcisiltite and calcilitite
	5 ft. Argillaceous Quartz Siltstone
-----Intrazonal Time Line-----	
15 ft. Lower Phase (sucrosic carbonates)	12 ft. Lower Phase (sucrosic carbonates)
-----Base of Lower Ismay Zone-----	

1. Jour. Sed. Pet., March 1960, p. 59-84.

The significant points apparent in the above comparison are:

1. Thirty-one feet of algal limestone and calcilutite in the No. 1 well is equivalent to 21 feet of calcarenite, calcilutite, and quartz siltstone with small traces of algal limestone in the No. 2 well.
2. The clastic nature of the limestone in the No. 2 well indicates an environment subjected to wave or current action, which would be the type of environment adjacent to a stratigraphic build-up that yields some barrier influence.
3. The relatively thick deposit of quartz siltstone deposited near the end of Lower Ismay time in the No. 2 well performed the function of a filler, leveling the thinner interval in the No. 2 well to the height of the adjacent algal growth in the No. 1 well.
4. The small amount of porosity present in the poorly developed algal interval of the No. 2 well is almost totally filled with secondary crystals of anhydrite, dolomite, and calcite; thus, all effective porosity is lost.
5. The porosity in the algal sequence of the No. 1 well is partially filled with secondary dolomite crystals, but infilling has not reached the point of blocking the intervugular connections.

In tests farther removed from an algal development, all traces of algal limestone are gone and the thickness of the entire Lower Ismay zone is thinner than the intervals within the algal trends or immediately adjacent thereto. The overall thickness of the Lower Ismay zone ranges from 25 feet for some non-algal areas to 75 feet for algal growth areas. Averages for nonalgal areas are 35 feet and for algal growth areas, 60 feet.

The permeability loss due to infilling of vugs by secondary crystals of anhydrite, dolomite, and calcite has caused a number of dry holes within porous algal trends. The occurrence of secondary crystal growth is predictable to some degree, within a porous trend, but very detailed core examinations of other tests within the algal trend are necessary to determine the relationship of crystal growth patterns to the configuration of the algal trend.

The importance of structure cannot be overemphasized for entrapping hydrocarbons in the Lower Ismay zone. There are numerous Lower Ismay failures in the Blanding Basin that are directly attributable to a low structural position or lack of a structural trap. The porous but structurally low wells normally recover salt water on drill-stem tests, indicating the effectiveness of the porosity. However, a closed structure is not essential for entrapment. The most prolific production from the Lower Ismay zone occurs in the Ismay field in T-40-S, R-25 and 26-E, of Utah and T-35-N, R-20-W of Colorado, which is a stratigraphic trap on a large plunging structural nose. The entrapment in this field is related to a change of facies whereby the porous algal carbonates of the upper phase of the Lower Ismay zone are stratigraphically equivalent to dense updip evaporites. The flanks of the structural nose are sharp enough to prevent spill age of the hydrocarbons, and the updip barrier gives the effect of a closed structure. Structural contours based on close spacing will give minor amounts of closure within the field proper; however, this closure is due to a stratigraphic build-up.

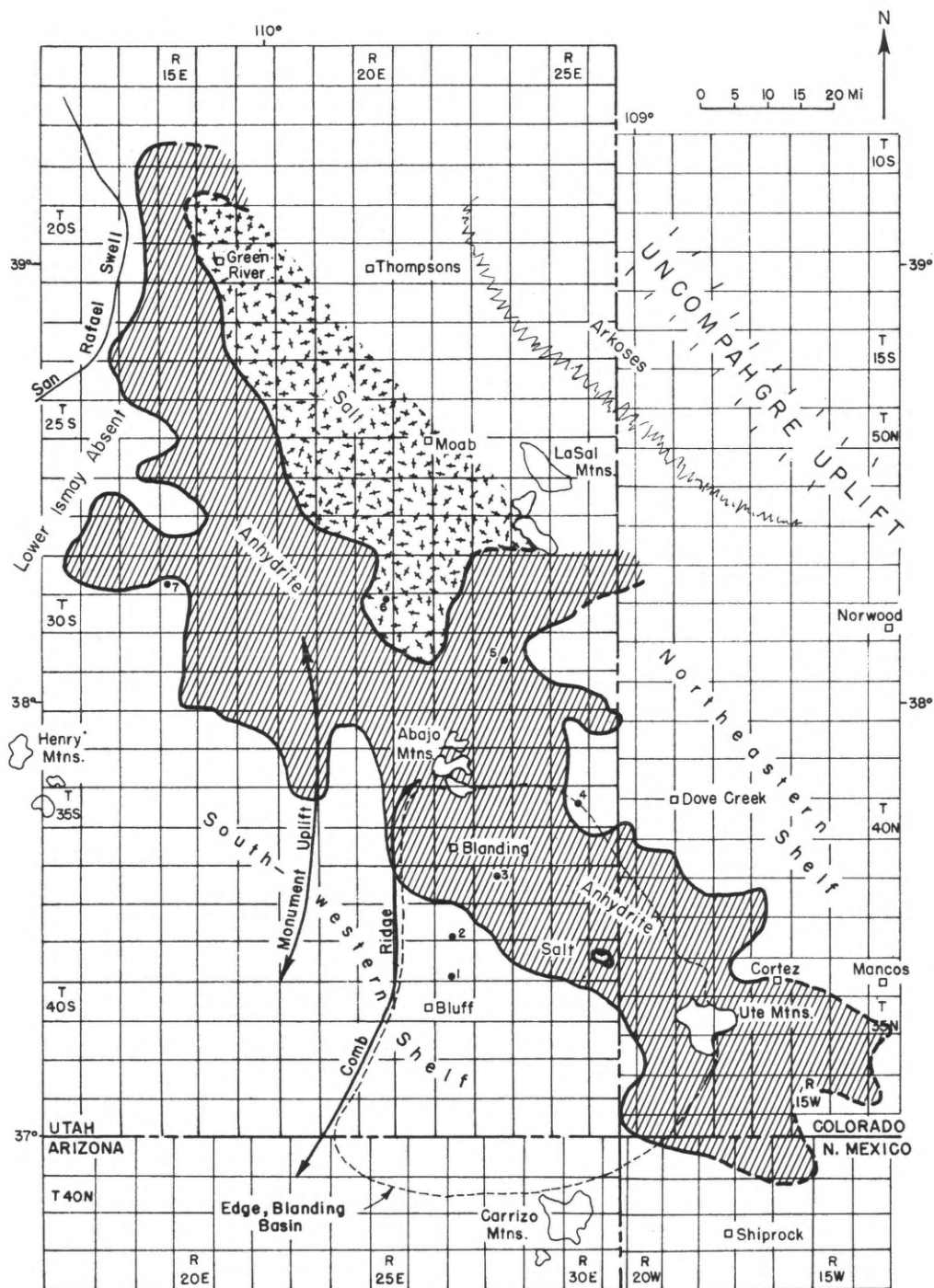


Figure 122. Regional facies of the Upper Phase, Lower Ismay Zone.

Recoveries from the upper phase carbonates of the Lower Ismay zone have been quite disappointing on the northeastern shelf. Although the well density in this area is considerably less than on the southwestern shelf, a number of tests in the Egnar unit area, San Miguel County, Colorado, have encountered porosity in the Lower Ismay zone. The porosity in two of the wells is related to a growth of *Chaetetes* colonial coral which was highly recrystallized, and the third well had a fair development of vuggy porosity and open vertical fractures.

The Carter Glade unit test in Dolores County, Colorado, encountered the most encouraging shows in the Lower Ismay zone on the northeastern shelf. The porosity occurred in vugs and vertical fractures. A drill stem test of the Lower Ismay zone in the Glade unit well yielded a gas flow at the rate of 8,170 MCGFPD. The flow pressures were very good, and no water was recovered on the test. Attempts to complete this well were disappointing, as large volumes of salt water were recovered from all perforations and the accompanying gas yields were generally low or absent. The Glade unit well is located on a surface axial trend that continues northward into the Egnar unit area.

The principal difference of limestone types that are encountered in the two shelf areas is the common occurrence of algal carbonates on the southwestern shelf and their absence on the northeastern shelf. Also, the carbonates on the southwestern shelf are normally divisible into two sedimentary phases, whereas those on the northeastern shelf are generally related to one sequence of sedimentation.

AGE RELATIONSHIPS BETWEEN "TROUGH" EVAPORITES AND SHELF CARBONATES

At this time, no conclusive stratigraphic proof has been found as to the time-of-deposition relationship between the upper phase anhydrites of the "trough" and the stratigraphically equivalent carbonates adjacent to the "trough". The three possible depositional relationships that exist are: (1) the carbonates are younger than the phase equivalent anhydrites of the trough, (2) the carbonates and anhydrites were deposited concurrently, (3) the anhydrites of the "trough" are younger than stratigraphically equivalent carbonates of the shelf areas.

A clastic deposit is continuous over both the anhydrite and limestone facies, and its base seems to be a time line. If the carbonates are younger, there would be some depositional evidence of freshening in the "trough" area at the end of anhydrite precipitation and prior to the deposition of the overlying clastic. Since there is no evidence of freshening, the carbonates are not believed to be younger than equivalent evaporites.

To allow concurrent deposition of open marine and restricted environment sediments, a special set of conditions must have been present; either a barrier was present between the two environments, or special current, temperature, and density conditions must be empirically assumed. Since barrier conditions are not even remotely suggested by detail well control in T-37, 38, and 39-S, either special conditions of current, temperature, and density control existed or the deposits are not time equivalents.

It seems probable that the third possibility (the anhydrite is younger than the adjacent limestone deposits) is the most likely explanation for reasons given below:

1. The thin alternation of carbonates and shale interbeds underlying the anhydrite deposits of the "trough" area could be equivalent to the entire Lower Ismay limestone of adjacent areas.

2. The anhydrite represents an environment of desiccation which would be more likely to occur when the seas withdrew at the end of a depositional period.

3. No special barrier or other influences are required if the anhydrite is assumed to represent the final stages of deposition and to mark the recession of the Lower Ismay seas.

(The above conditions of sedimentation and the possible explanations thereof apply equally to the "trough" area of the Upper Ismay zone.)

UPPER ISMAY ZONE

The Upper Ismay zone is comprised of deposits from two environments of deposition, which are divisible into phases. The two phases are well developed on the carbonate shelf areas and in the anhydrite extension areas only. The Upper Ismay zone will, therefore, be considered as a unit with respect to the main salt basin area.

Main Salt Basin Evaporites

The Upper Ismay zone is represented by saline deposits in the area of generally thick Paradox Basin salt deposition, as shown in Figure 123. The strike of the zero salt line for the Upper Ismay zone is essentially northwest-southeast which coincides with the stratigraphic strike of older Pennsylvanian deposits and the Pennsylvanian structural grain.

Present subsurface control indicates that the Upper Ismay salt deposition is near a maximum in the area of the Superior Salt Wash test, Sec. 34, T-22-S, R-17-E, where 630 feet of Upper Ismay salt was encountered. During Upper Ismay time, salt deposition occurred in the northwestern reaches of the Paradox Salt Basin, as evidenced by 140 feet of Upper Ismay salt in the Carter No. 1 Sphinx in Sec. 35, T-19-S, R-14-E.

Along the western edge of zero salt deposition, the Upper Ismay zone rapidly passes into an erosional rubble zone and is then absent to the west because of nondeposition or removal.

The anhydrite facies of the Upper Ismay zone is restricted to a relatively narrow band, generally paralleling the Upper Ismay zero salt line, and a long narrow "trough-like" deposit of evaporites which extend into northwestern New Mexico from the Blanding, Utah area. The connection of this salient with the main evaporitic body to the north is indicated by dashed lines in Figure 123.

Upper Phase—"Trough" Area

Two wells have encountered salt in the evaporitic "trough". The California Company test in Sec. 22, T-33-N, R-18-W, Montezuma County, Colorado, encountered 30 feet of salt in the upper phase of the Upper Ismay, and the Carter Oil Company test in Sec. 23, T-36-N, R-20-W of the same county,

encountered several feet of upper phase salt. The total thickness of evaporites, both salt and anhydrite, is considerably less than that of the Upper Ismay precipitates in the Main Salt Basin, but these evaporites represent only the upper phase deposits in the "trough" area. The Main Salt Basin evaporites represent the entire Upper Ismay time. The maximum thickness of evaporites penetrated in the "trough" area was found at the above mentioned California Company well, where 76 feet of salt and anhydrite were encountered.

UPPER ISMAY CARBONATE PHASES

The carbonate facies of the Upper Ismay zone are present in both the upper and lower phases on the southwestern and northeastern shelf areas and in the lower phase of the "trough" area.

Lower Phase—"Trough" Area

The lower phase underlying the evaporitic salient is a sequence of thin argillaceous sucrosic dolomites with shale interbeds. The sucrosic carbonates usually have some indicated porosity on mechanical logs, but the permeabilities are very low. The carbonate phase is best developed in the Lisbon anticline area.

Carbonate Phase—Shelf Areas

In the area west of Comb Ridge, the Upper Ismay deposits are very silty limestones which are not readily divisible into phases. Locally, the upper portion of the limestone is oolitic or calcarenitic with pinpoint vugular or oolitic porosity. In T-37-S, R-18-E, the Mountain Fuel No. 1 Mormon Flats test cored 13 feet of good oolitic porosity near the top of the Upper Ismay limestone. In the area of Bluff, Utah (T-40-S, R-21-E) and northeastward to the southwestern side of the evaporitic "trough," the Upper Ismay limestone has two distinct phases. The upper phase is light colored, silty, and normally capped by a clastic limestone which is either oolitic, calcarenitic, calcisiltitic, or some combination thereof. The lower phase is argillaceous, dark, somewhat cherty, and normally devoid of lime clastics. In the area of Blanding, Utah, several of the Johnson Creek unit tests encountered vuggy and oolitic porosity in the Upper Ismay limestone.

Along the northeastern side of the anhydrite trough, the Upper Ismay limestone is predominantly two phased, as it is to the southwest. The upper, clean, lime clastic phase has yielded minor amounts of oil from pinpoint vugs and oolcasts in the Bighorn-Hathaway tests in T-37-N, R-20-W and the Nabors No. 2 Rowley well, in T-36-N, R-18-W, Montezuma County, Colorado. In the No. 2 Rowley well, 35 feet of fragmental limestone were cored and porosity was present in the upper 25 feet of the core. Detailed microscopic examination of the core revealed the fragments to be primarily fossil sand, oolites of sand size (with superficial oolites predominating), calcarenite, and pseudo-oolites. The well was initially potentialized for 29 BOPD, 30 BWPD, and 328 MCFGPD from the fragmental limestones.

In addition to the aforementioned wells that encountered clastic limestone in the Upper Ismay zone, the following tests penetrated a similar fragmental sequence along the northeastern side of the evaporitic trough: Three States

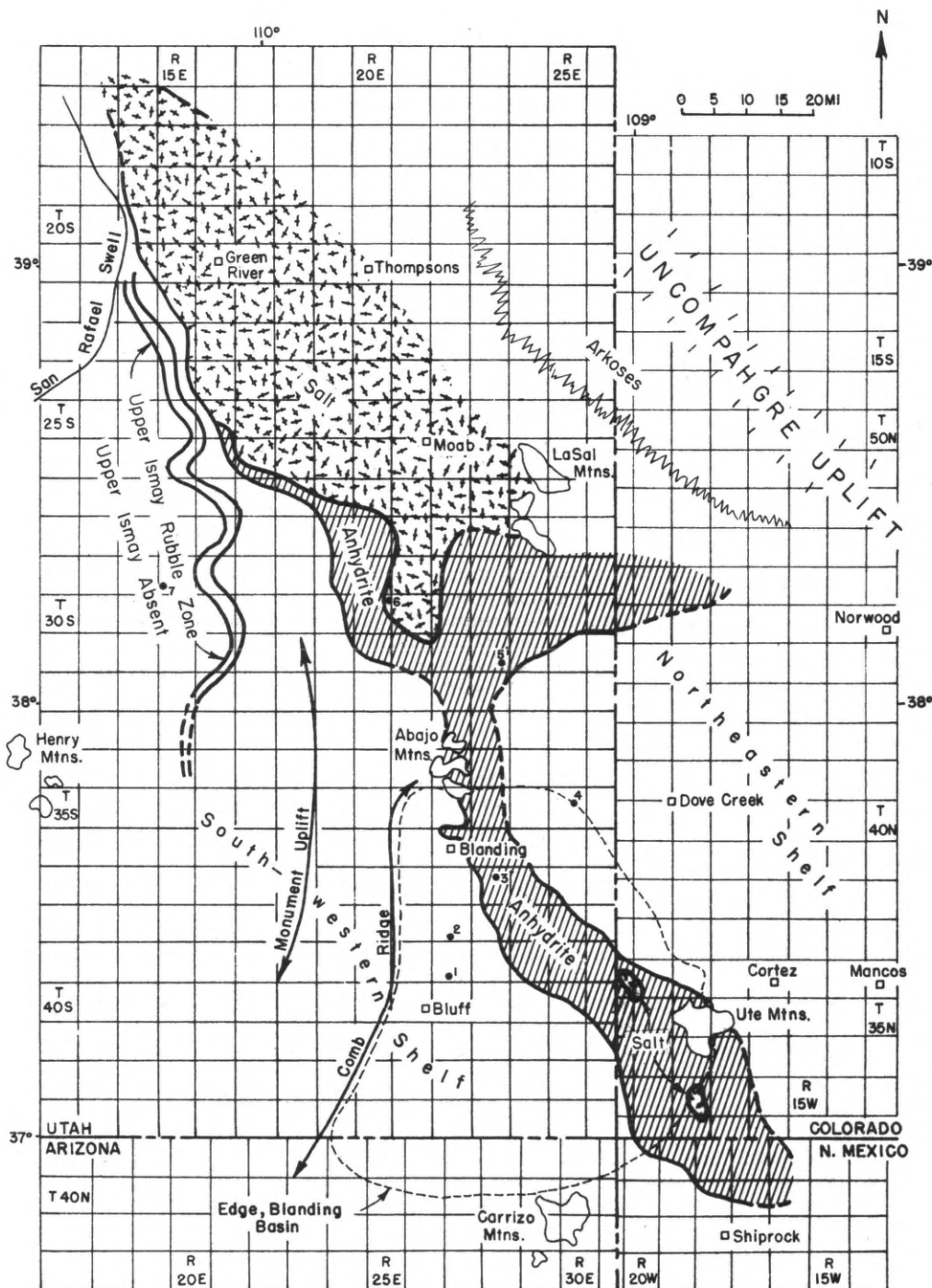


Figure 123. Regional Facies of the Upper Phase, Upper Ismay Zone.

No. 1 Dudley, Sec. 13, T-36-N, R-18-W; Nabors No. 1 Rowley, Sec. 9, T-36-N, R-18-W; Pan Am. No. 1 Fehr, Sec. 21, T-37-N, R-19-W; Texota 1B, Sec. 24, T-37-N, R-20-W. All of these tests are in Montezuma County, Colorado. In Utah, the Kingwood No. 2 Montezuma test in Sec. 22, T-36-S, R-24-E penetrated a fragmental limestone section at the top of the Upper Ismay carbonate. The Kingwood test is also located on the northeastern flank of the evaporitic trough. In Montezuma County, Colorado, a test by Bighorn-Hathaway in Sec. 15, T-37-N, R-20-W, encountered a porous section in algal carbonates immediately adjacent to the anhydrite trough. Figure 120 shows the lithologies of the stratigraphic equivalents of the Upper Ismay zone. In the three center wells anhydrite, algal carbonates, and fragmental limestones are present from west to east. This change occurs within a distance of three miles. A drill-stem test of the porosity in the algal carbonates recovered salt water, but the important factor in this test is the occurrence of an algal growth. The occurrence of vuggy porosity in the algal growth led to additional drilling immediately adjacent to the evaporitic trough. All subsequent tests to locate an algal trend adjacent to the anhydrite proved unsuccessful. Either the Bighorn-Hathaway test encountered a growth of very limited dimensions or the width of the growth area is so narrow that several tests perpendicular to the growth trend would be necessary to locate the algal carbonates if the trend does parallel the anhydrite.

UPPER ISMAY CROSS SECTION

Figure 120 shows the stratigraphic change from anhydrite to algal carbonates, to fragmental limestone, and to dense precipitated limestone. One other noticeable change is apparent on the cross section. To the northeast of the evaporitic trend, the A2 shale which underlies the Upper Ismay zone increases rapidly in thickness and the Upper Ismay zone thins correspondingly. The occurrence of an increase in the A2 shale thickness at the expense of the overlying Upper Ismay zone is a true facies change, one in which the lower phase of the Upper Ismay limestone grades into a marine shale. This facies change occurs northeast and eastward from and along the entire length of the evaporitic "trough".

FLAGGY DEPOSITS AT END OF ISMAY TIME

Throughout most of the Blanding Basin portion of the Paradox Basin, the main development of the Upper Ismay zone is separated from an overlying thin-bedded limestone or anhydrite interval by a dense siltstone or gray shale bed. The upper "flaggy" development represents deposition on a local scale, for the number of thin limestone beds present varies rapidly from one to two. The beds are normally 4 to 10 feet thick. The limestone beds are stratigraphically equivalent to one or two thin anhydrite beds that vary in number by local control and do not conform to the exact geographical limits of the underlying evaporitic salient; however, these beds do show a reasonably similar distribution. The thin anhydrite beds are normally 4 to 7 feet thick. The limestone beds of this interval do not have sufficient development to consider them as capable of commercial hydrocarbon accumulation. This sequence is not present in southern portions of the Blanding Basin, nor is it present in many places north of the Blanding Basin. The interval is apparently indicative of minor oscillations of the sea prior to the end of Ismay time.

Paper 37 GEOLOGY OF THE LISBON OIL AND GAS FIELD SAN JUAN COUNTY, UTAH

by Robert P. Kunkel¹ and Robert B. Schick²

INTRODUCTION

Oil and gas in the Lisbon field is trapped in a faulted anticline of probable pre-Pennsylvanian origin, hidden beneath the southwest flank of the Lisbon Valley salt anticline (Figures 124 and 125). As of April 1962, 15 oil and gas wells had been completed in the field. Production is from the Paradox member of the Hermosa formation (Pennsylvanian age), limestone and dolomite of Mississippian age and two Devonian units, the Ouray limestone and the McCracken sandstone member of the Elbert formation. The principal reservoir is in porous fractured Mississippian carbonate rocks. This reservoir contains recoverable reserves of approximately 35 million barrels of oil and 250 billion cubic feet of gas, with an estimated gross value of \$130 million, before royalties.

This paper presents a summary of known information about the Lisbon field to aid in pointing out the possibilities of finding oil and gas throughout the entire Salt anticline region. These possibilities can be brought into a sharper focus by a better understanding of the Lisbon field.

The Lisbon Valley salt anticline is one of several major northwest-trending surface folds caused by flowage of massive salt deposits in the Paradox member. Salt accumulated in the Paradox basin, a sharp asymmetrical downfold that formed in a deep trough on the southwest flank of the Uncompahgre mountain range, early in the Pennsylvanian Period. The Lisbon Valley salt anticline, Figure 125, is the most shelfward of these major anticlinal trends, which cover an area 100 miles long by 30 miles wide. Other smaller salt anticlines occur west and northwest of Lisbon. Some of the best-known uranium deposits in the nation have been found in the vicinity of the Lisbon Valley salt anticline (Lekas and Dahl, 1956).

GEOLOGIC HISTORY OF THE REGION

Soon after the close of Mississippian time, the area of the present Uncompahgre uplift began to rise as part of the ancestral Rocky Mountain chain. A basin started to form west of the Uncompahgre uplift early in the Pennsylvanian period, and lower Hermosa limestones and shales were deposited. A series of evaporitic depositional cycles followed and the Paradox member accumulated in this ocean-filled trough paralleling the Uncompahgre uplift. Late in the period, salt began to shift into linear trends and intrude upward in response to vertical forces along older lines of weakness and in response to the load of rapidly accumulating overlying rocks. The position of these linear trends is thought to be controlled primarily by high-angle faulting or folding in rocks older than the salt which caused troughs to form approximately at the locations of the present salt anticlines.

1. Consulting Geologist, Salt Lake City, Utah.

2. Consulting Geologist, Salt Lake City, Utah.

Maximum growth of the salt anticlines took place between Late Pennsylvanian and Late Triassic time, during the deposition of the upper Hermosa, "Rico", Cutler, and Moenkopi formations. Upward growth continued at a more subdued rate until Jurassic-early Morrison time. Following deposition of the Cretaceous Mesaverde formation, folding, leaching, and erosion, accompanied by subsidence faulting, further modified the salt anticlines until they reached their present state of development (Jones, 1959; Shoemaker, Case and Elston, 1958; Stokes, 1948, 1956; and Cater, 1955). Today these salt anticlines are the site of an intensive search for oil and gas as a direct result of the discovery of the Lisbon field in T-30-S, R-24-E, S.L.M.

STRATIGRAPHY

Rocks cropping out at the surface of the Lisbon Valley salt anticline range from the Hermosa limestone of Pennsylvanian age (Honaker Trail - Wengerd, 1958) to the Cretaceous Dakota sandstone. The Hermosa limestones are exposed near the crest of the anticline and successively younger rocks crop out down dip to the southwest. Massive cliff-forming sandstones of the Triassic and Jurassic Glen Canyon series occur on the extreme southwest flank of the anticline. To the northeast, Cretaceous strata of the Dakota sandstone and Burro Canyon formation and some portions of the Jurassic Morrison formation have been exposed by erosion associated with faulting parallel to the axis of the surface anticline.

A representative section, typical of the rocks encountered in the Lisbon field, follows:

<u>Age</u>	<u>Formation</u>	<u>Thickness</u>	<u>Description</u>
Jurassic (?)	Navajo	170-320'	Cross-bedded and fine-grained eolian reddish-orange to reddish-gray sandstone.
	Kayenta	230'	Irregularly-bedded reddish-brown sandstone and thin shales.
Triassic	Wingate	280-360'	Massive eolian cross-bedded reddish-brown sandstone.
	Chinle	600'	Irregularly-bedded poorly-sorted reddish-brown sandstone and siltstone and reddish-brown and greenish-gray shale; the red-orange fine-grained sandstone near the base is probably equivalent to the Moss Back (Shinarump) member.
	Moenkopi	0-500'	Interbedded reddish-brown sandstone and siltstone and reddish-brown to gray-green shales; thins toward the top of the anticline where it is absent.
Permian	Cutler	1500'	Irregularly-bedded pale-red, grayish-red and reddish-orange shales, reddish-brown sandy silt-

stone and fine to coarse arkosic sandstone; thickens in all directions from the crest of the surface anticline.

Pennsylvanian	"Rico" and upper Hermosa	1675-1700'	Interbedded gray to brown dense finely-crystalline limestone, cherty argillaceous micaceous shale, siltstone and fine-grained sandstone; thickens toward the southeast.
	Upper Paradox member (includes Ismay zone)	350'	Interbedded dark-gray to black calcareous shale, gray-brown dense limestone, gray to brown dense cherty dolomite and white very finely crystalline anhydrite.
	Paradox salt member	2700-6000'	White coarsely-crystalline salt with interbedded shale, dolomite anhydrite, and gypsum; thins slightly over the oil field and thickens toward the surface anticline.
	Lower Hermosa	15-150'	Interbedded gray-brown dense anhydritic partly argillaceous dolomite, gray-brown dense partly chalky limestone, orange-brown and white opalescent chert, white very finely crystalline anhydrite and gray, greenish-gray and purplish-gray soft shale some with limestone nodules.
	Molas	20-165'	Varicolored shales (reddish-brown, grayish-purple, light-gray, pale-green) and greenish dense limestones.
Mississippian	Undifferentiated	300-500'	From Mitchell (1961) "<u>D Member</u>: (top Predominantly aphanitic limestone of algal mat origin. Contains oolitic limestone beds usually near the base. Occasionally or in part dolomitized. <u>C Member</u>: Predominantly crinoidal limestone and vuggy dolomites derived from crinoidal limestone. Minor thin asphanitic and oolitic zones. Rare horn coral usually recognizable. <u>B Member</u>: Predominantly vuggy dolomites derived from crinoidal limestones with white tripolitic chert. Contains variable fauna, bryozoa, brachiopods, and other fossil material usually poorly preserved due to high alteration.

A Member: Predominantly dolomite of usually finer grain size than C or B members. Generally recognizable oolite or algal (?) oolite beds of top and bottom of member. Contains asphaltic limestone." (Bottom).

Devonian	Ouray	100-300'	Limestone, white, light-gray and light grayish-brown, dense to lithographic, finely-crystalline; a few thin laminations of green shale; some intercrystalline porosity; thin beds of light-gray very finely crystalline dolomite near the bottom; thickest in the center of the field.
	Upper Elbert	125-175'	Interbedded grayish-brown, dense, medium to very finely crystalline dolomite, gray, medium to very finely crystalline limestone and green shale; upper part is mostly dolomite; becomes sandy toward base; thinnest in the southwest part of the field.
	McCracken Member	75-125'	Interbedded white to brown poorly sorted dolomitic sandstone (with grains sub-rounded); some silty some friable, with fair porosity; brownish-gray dense very fine to medium crystalline dolomite with streaks and stringers of sandstone, green shale and dark-gray very sandy slightly argillaceous glauconitic siltstone near base; fractured; thickest in the southwestern part of the field.
	Aneth	400'	Gray, brown and brownish-gray resinous dolomite with a few thin brown shale streaks.
Cambrian		485'	Upper half is interbedded shale, dolomite and siltstone with a trace of sandstone. Colors are greenish-gray and brownish-gray. Lower half is mostly sandstone and siltstone with colors grading to reddish-brown.

Rocks penetrated in the Lisbon field are typical of the sequence found throughout the Paradox Basin. Several rock units are unusually thin. The Moenkopi formation is not present over the crest of the salt anticline, but a thin section is present at the Lisbon field. The section between the base of the salt and the top of the Molas (Pennsylvanian) is extremely variable in thickness, as is the Molas. Rocks of Ordovician and Silurian age are missing from this part of Utah, or at least they have not been identified.

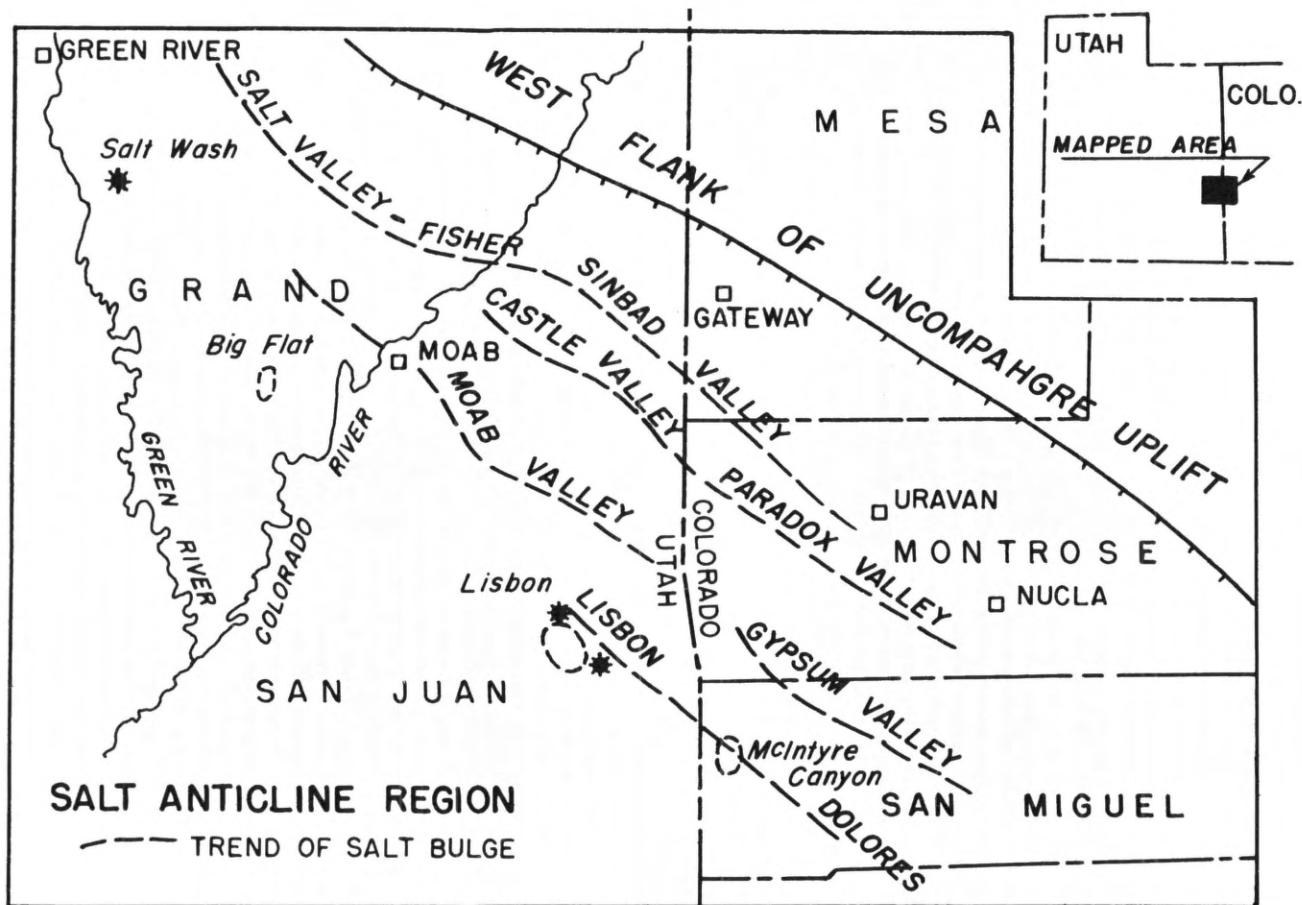


Figure 125.

STRUCTURE

The oil and gas in Mississippian and Devonian rocks, the principal reservoirs in the Lisbon field, is trapped in a faulted anticline. The anticline is illustrated by structure contours on Figures 127 and 128 and by the cross sections of Figures 129 and 130.

As indicated by Figure 124, a structure map with contours drawn on top of the Ismay zone of the upper Paradox member, the anticline within Mississippian and Devonian rocks is not well reflected in younger rocks. Flowage within the Paradox salt has almost completely masked the presence of the older anticline. (The Ismay zone is a carbonate unit between the base of the upper part of the Hermosa formation and the top of the Paradox salt.)

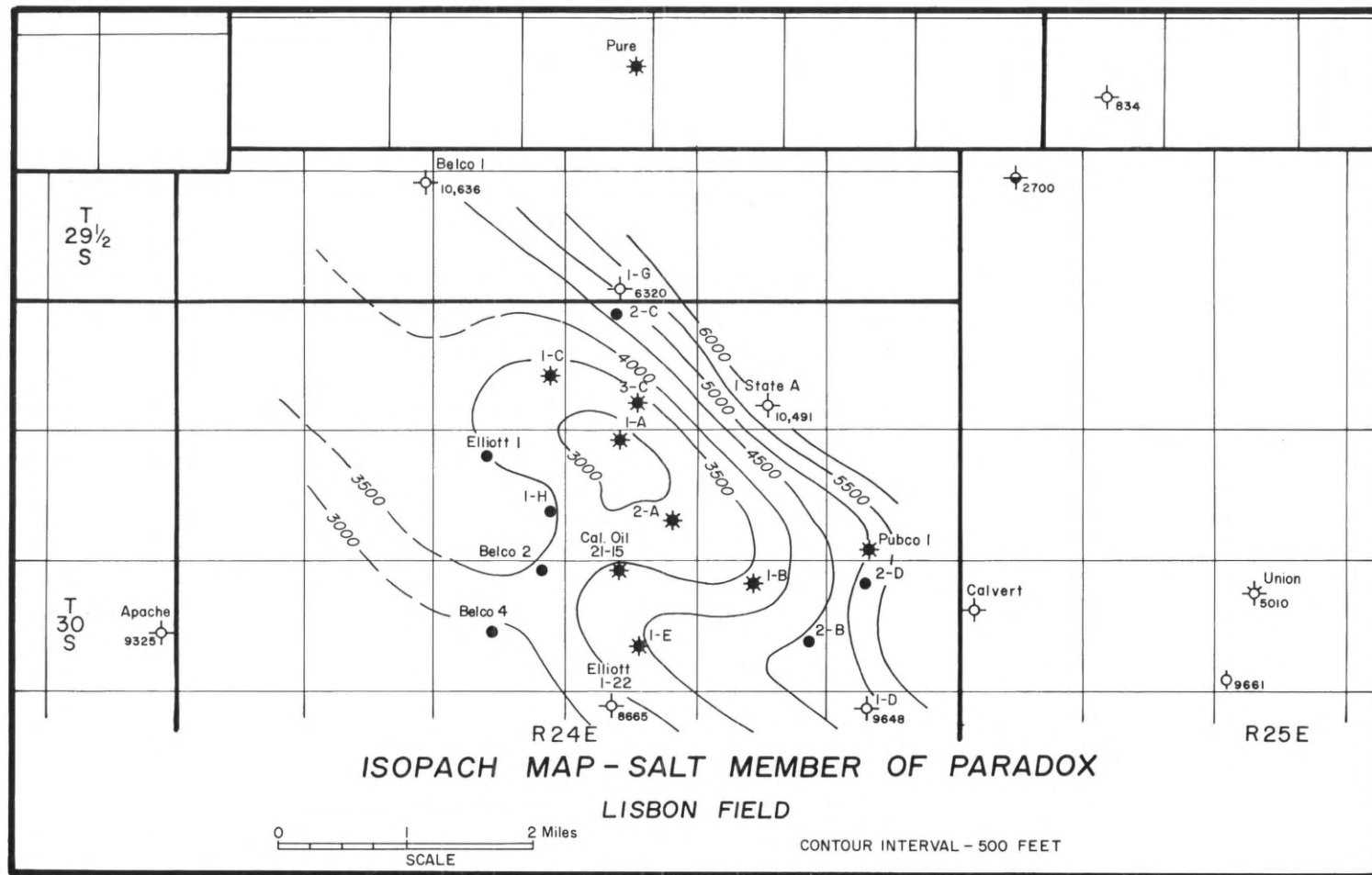
Slightly negative areas, formed by pre-salt faults and folds, are generally thought to be the primary factors controlling the locations of the salt anticlines. It is quite likely that uplift during Late Pennsylvanian time, along the fault that forms the north boundary of the Lisbon field, contributed somewhat to the movement of salt from the northeast and southwest into the Lisbon Valley salt anticline. The movement, or flowage, of the salt forced overlying sediments upward and formed a new anticline which is parallel to the original structure, but approximately two miles northeast of it. A syncline or trough, along the site of the present salt anticline must also have received greater thicknesses of salt than did adjacent areas.

Isopach studies of rock units in the Lisbon field (Parker, 1961) illustrate that a northwest-trending structural influence controlled sedimentation there as early as Devonian time. However, the site of the field was quite low during the time of deposition of the McCracken sandstone, slightly higher during Elbert time, and low while Ouray and Mississippian rocks were being deposited.

One of the most interesting features of the Lisbon field is the lack of correlation between the structure of the producing formations and that of the surface formations. Devonian and Mississippian structures are relatively similar in shape but these older structures do not conform to the surface structure (Figures 127 and 128). This anticline in Mississippian and older rocks is masked by lateral variations in the thickness of the Paradox salt (Figure 126). The salt thins to 3,000 feet in the Lisbon field, and thickens to at least 6,800 feet in the area paralleling the crest of the surface anticline. Part of this increase in thickness is related to deposition and part is the result of flowage and faulting. The greatly thickened mass of salt would logically flow when subsequent fault movements and the weight of overlying sediments exerted pressure upon it. Figure 130 illustrates the thickening of the salt toward the northeast.

OIL AND GAS DEVELOPMENT

Development drilling has proceeded rather slowly at Lisbon as a result of unsolved problems relating to spacing and production procedures. The discovery well was completed in January, 1960. Temporary spacing of one well per 320 acres was established in February, 1961, by the State of Utah Oil and Gas Conservation Commission. Half-section drilling units (E1/2 and W 1/2) were set up with the wells to be drilled in the SE 1/4 and the NW 1/4 of each section. All wells drilled prior to the temporary ruling were recognized as the permitted well for the proposed drilling unit upon which it was located.



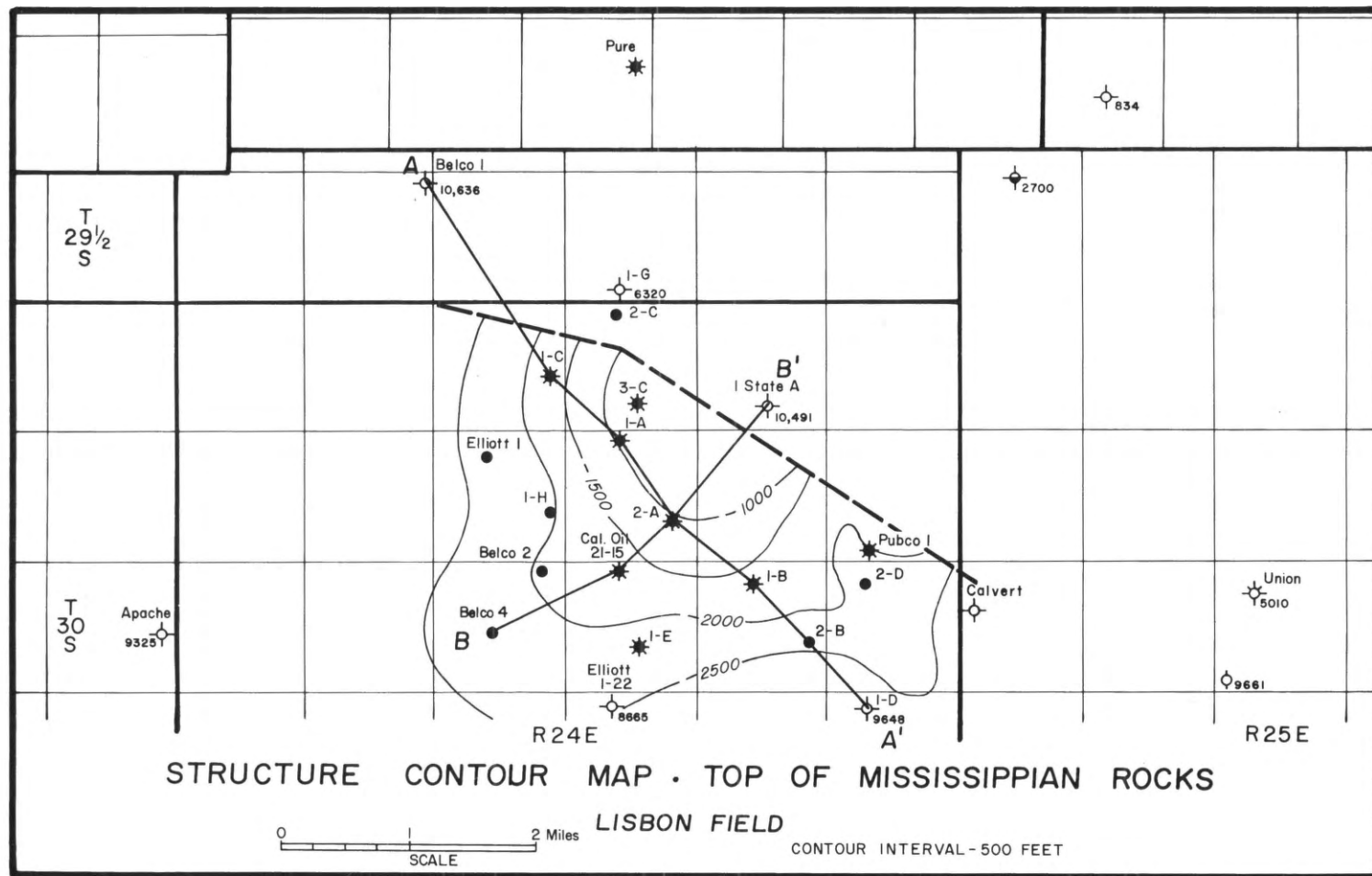
In all, 18 wells have been drilled in the Lisbon field as of April 1, 1962. Of this total, three are dry holes, three are dual producers from the Mississippian and McCracken reservoirs, two produce from both Mississippian and Ouray rocks, one produces from the Pennsylvanian Paradox member, and nine produce from the Mississippian reservoir only. In addition, two new field discoveries, one drilled by Pubco in T-30-S, R-25-E, and one drilled by Pure Oil Company in T-29-S, R-24-E, have been made since the discovery of the Lisbon field. These new fields appear to be separate from the Lisbon field. A list of the Lisbon field wells and the discovery wells in the newly-discovered fields follows:

PRODUCING WELLS -- LISBON FIELD

Company	Well Name	Location	Producing Formations & Initial Potential			
			Paradox	Mississippian	McCracken	Ouray
Pure	1A	NE NE NW 10-30S-24E		179 BOPD 4376 MCFGPD	587 BOPD	
Pure	2A	SW NE SE 10-30S-24 E		40 BOPD 1500 MCFGPD	308 BOPD 149 MCFGPD	
Pure	1B	SE NE NW 14-30S-24E		406 BOPD 6382 MCFGPD	287 BOPD	
Pure	2B	NE SE 14-30S-24E		351 BOPD 7000 MCFGPD		
Pure	1C	N1/2 NE SE 4-30S-24E		453 BOPD		
Pure	2C	N 1/2 NE NW 3-30S-24E	103 BOPD 129 MCFGPD			
Pure	3C	NW SW SE 3-30S-24E		158 BOPD 3350 MCFGPD		
Pure	2D	SW NE NW 13-30S-24E		319 BOPD 1905 MCFGPD		
Pure	1E	SW NW SE 15-30S-24E		1044 BOPD 1905 MCFGPD		
Pure	1H	NE SE 9-30S-24E		2732 BOPD		
Belco	2 State	C NE NE 16-30S-24E		461 BOPD		68 BOPD
Belco	4 State	NE SW 16-30S-24E		468 BOPD		
Calif. Oil	21-15 Arnold	NE NE NW 15-30S-24E		432 BOPD		187 BOPD 4 BWPD
Elliott	1C	S 1/2 NE NW 9-30S-24E		272 BOPD 686 MCFGPD		
Pubco	1 Federal	SW SE SW 12-30S-24E		1288 BOPD 2863 MCFGPD		

DISCOVERY WELLS -- ADJOINING FIELDS

Pure	1 USA Big Indian	SE NE 33-29S-24E		7400 MCFGPD		
Pubco	2-21-F Federal	SE NW 21-30S-25E		17400 MCFGPD		



The oil and gas reservoir in Mississippian rocks is primarily fractured dolomite containing intercrystalline and vuggy porosity. It is thought to be an interconnected unit serving as a common source of supply of trapped hydrocarbons. Net-pay thickness is nearly 400 feet.

A band of oil lies above the oil-water contact, which is approximately 2,570 feet below sea level. This oil ring is in contact with water below and with a gas cap above. A gradation takes place throughout the hydrocarbon column, with the heavier hydrocarbons at the bottom and with decreasing amounts of liquid and an increasing amount of vapor toward the top. The volume of the gas zone is much larger than the volume of the oil zone. The gas is low in heating value (about 775 to 850 BTU per thousand cubic feet). In some parts of the reservoir it contains up to 40 per cent carbon dioxide and nitrogen, 1.2 per cent helium, and three per cent hydrogen sulfide. Helium content ranges between .6 and 1.2 per cent and averages .7 per cent. An average of 43 per cent of the gas is inert.

Soon after the field was discovered, there was some disagreement between operators as to the best method of producing the Mississippian reservoir to obtain the maximum amount of oil and gas at a minimum investment. One group held that a retrograde gas cap was present in which liquids would come out of solution and coat the reservoir surface as pressure decreased. As a result, a certain amount of oil would be lost to recovery. Repressuring should prevent this. This group did not believe that there was an active water drive in operation. They suggested recycling the gas to maintain original pressures. Another group contended that there is an active water drive, and that the water will flush the reservoir as it moves upward when hydrocarbons are removed and will aid in maintaining pressures. An engineering and geological committee has been established by the operators. This committee has drawn up a unit plan of operation and submitted it to the U.S. Geological Survey for approval. Approval is expected about May 1, 1962. Until the plan is approved, production is limited to 150 barrels of stock-tank oil, per well per day, but the daily gas production per well may not exceed 300,000 cubic feet. A new well may be produced at a maximum daily average rate not exceeding either 500 barrels of oil or 1,000,000 cubic feet of gas until it has produced a cumulative total of either 30,000 barrels of oil or 60,000,000 cubic feet of gas, whichever occurs first.

Under terms of the proposed unit, Pure Oil Company will operate the field. Oil and gas will be collected through a gathering system and be brought to a plant which is to be located just west of the center of Section 22. At the plant, all liquifiable hydrocarbons will be removed. The dry gas will be reinjected into the reservoir, except for a small amount which will be used as fuel for the plant.

Present plans call for operation of two injection wells in the beginning. More may be drilled, or other wells already drilled may be converted to injection wells if needed. Pure's No. A-1 and A-2 wells, at the top of the anticline in the gas zone, have been selected. Both wells have been completed as dual producers from the Mississippian and McCracken reservoirs. The Mississippian section has been segregated by packers at the top and bottom. Gas will be injected through 2-3/8 inch buttress thread tubing at a surface pressure of 2,500 pounds per square inch. The system will be designed to withstand pressures up to 4,000 pounds per square inch. Initially, 6,000,000 cubic feet per day will be injected. Eventually injection rates may be increased to as much as 35,000,000 cubic feet per day.

Unitization plans include only the Mississippian reservoir. The McCracken sandstone reservoir is considered to be an entirely separate unit.

HISTORY OF EXPLORATION AND DRILLING

Drilling on the Lisbon Valley salt anticline started in 1927 when a Paradox test was drilled by Union Oil Company in the NE 1/4 SW 1/4 Sec. 16, T-30-S, R-25-E. Union reported oil shows in the Paradox salt and gas shows at several points below the oil show. The well was abandoned at 5,010 feet in the salt. The next test was attempted by Pioneer Uranium during 1955 on the crest of the anticline in the NW 1/4 Sec. 6, T-30-S, R-25-E. This well was drilled to a total depth of 2,700 feet and probably bottomed in the Triassic Moenkopi formation.

Pure Oil Company spudded the discovery well, No. 1 Northwest Lisbon (renamed A-1), on August 14, 1959, in the NE 1/4 NE 1/4 NW 1/4 Sec. 10, T-30-S, R-24-E. The prospect was a subsurface "high" 2,000 feet structurally lower and 5 1/2 miles northwest of the surface crest of the Lisbon Valley salt anticline. Seismograph surveys were primarily responsible for delineating the structure beneath the prospect. Natural gas and condensate were discovered in carbonate rocks of Mississippian age and oil was discovered in the McCracken sandstone of Devonian age. This was the first Devonian production in the state. Gas flows ranging from 1,200,000 to 17,000,000 cubic feet per day were recorded from drill-stem tests within 450 feet of Mississippian section (Budd, 1960). The well was completed on January 4, 1960, flowing 587 barrels of 44 degree gravity oil from perforations in the McCracken sandstone between 8,251 and 8,348 feet. At a later date, the well was recompleted in the Mississippian section flowing 4,376,000 cubic feet of gas and 179 barrels of oil per day from a depth of 7,576 to 7,970 feet. Two additional pay zones have since been established in the field. In October 1960, Belco Petroleum Co. found oil in Ouray limestone (Devonian) in the No. 2 Belco-State well drilled in the NE 1/4 NE 1/4 of Section 16. In January 1961, Pure completed their No. 2 Northwest Lisbon-C well flowing 103 barrels of oil and 129,000 cubic feet of gas from a faulted zone in the salt section of the Paradox member. The Paradox discovery was drilled in the N 1/2 NE 1/4 NW 1/4 of Section 3.

In September 1961, Pure came up with another Mississippian discovery for Utah when they completed a wildcat three miles north of Lisbon and separated from the field by a major fault. This discovery, No. 1 U.S.A. Big Indian, in the SE 1/4 NE 1/4, Sec. 33, T-29-S, R-24-E, was drilled on the southwest side of the Lisbon Valley salt anticline surface fault. It flowed 7,400,000 cubic feet of gas per day with eleven barrels of condensate per million cubic feet of gas.

As of April 1, 1962, 15 wells have been successfully completed in the Lisbon field. In addition, dry holes have helped to outline the producing areas and furnish additional information (Figures 124, 126, 127, 128).

ECONOMICS

It has been reported that Mississippian porosity averages 10 per cent and permeability averages three millidarcies. The gravity of the oil is 50-70 degrees A.P.I. For Conservation Commission hearings to determine the nature of the reservoir, the following liquid analysis was made of a bottom hole gas sample @ 2,950 psia and 144°F :

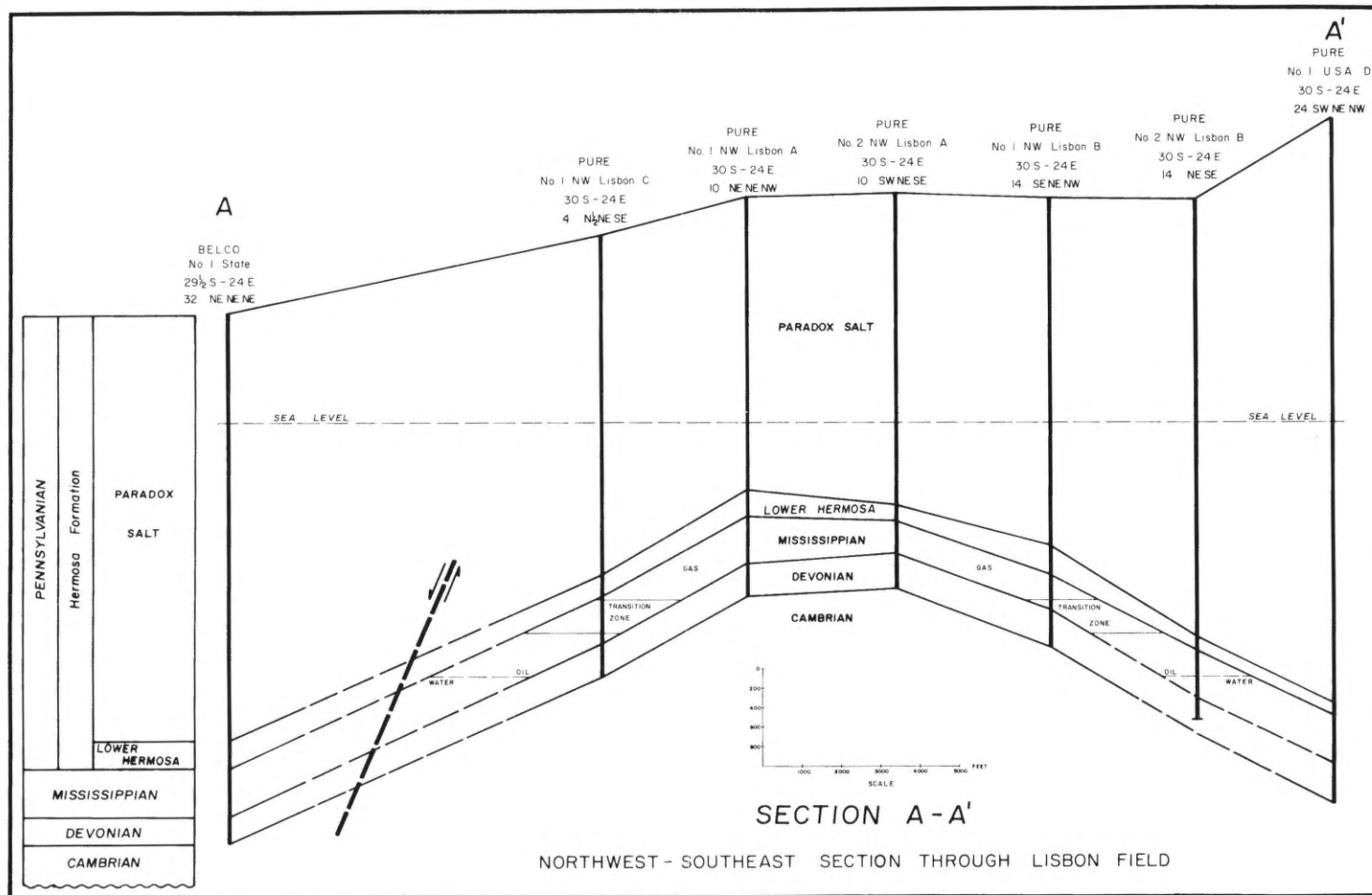


Figure 129.

<u>Components</u>	<u>Mol. %</u>	<u>Components</u>	<u>Mol. %</u>
Nitrogen	4.75	Iso Pentane	1.77
Methane	24.48	N Pentane	2.60
Ethane	8.36	Hexane	2.98
Propane	5.82	Heptane plus	18.56
Iso Butane	1.56	Carbon dioxide	23.82
N Butane	4.48	Hydrogen sulfide	.82

(Belco Exhibit, analyzed by Wright Petroleum Laboratories, Tulsa, Oklahoma).

As the result of joint efforts of the many operators in the Lisbon field, agreement as to reserves, methods of operating, plant investment and life of the field has been reached.

Ignoring the possibility of a water drive, assuming gas cap expansion, reinjecting a portion of the produced gas, and providing for gas treating facilities, it is assumed a capital investment over the life of the field of \$6 million, in addition to drilling and completing the wells, will be required to produce all of the hydrocarbons. This investment, plus over \$1 million in intangible development costs will be required to produce a gross recoverable reserve of 35 million barrels of oil (STB) and 250 billion cubic feet of gas. These reserves will be produced over a period of thirty years and will probably yield a gross field revenue of at least \$130 million during the life of the field, based on an average of \$2.59 per barrel to be received at the well head. Accuracy of these figures is naturally limited by the accuracy with which such calculations can be made at this very early period in the development and production history of the field.

At present, plans are being made by Pure Oil Company to build a crude oil line 70 miles south of Aneth where it will connect with lines to Los Angeles and the Gulf Coast. Cost of the new line is estimated to be between \$700,000 and \$1,000,000. The line could transport up to 42,000 barrels of oil per day.

No data is available to the writers from which to report reserves on the Devonian Ouray and McCracken zones.

Several of the first exploration wells ranged in cost between \$400,000.00 and \$500,000.00, completed. Certain economics, together with more accurately defined drilling objectives, now allow a well completion cost of about \$250,000.00.

FUTURE POTENTIAL

Pure Oil Company has completed a new Mississippian discovery (and a new field) in their Big Indian No. 1 U.S.A. well, Sec. 33, T-29-S, R-24-E.

Production is from a depth of 9,886 to 10,150 feet, an interval 264 feet in thickness. A one-mile north offset was plugged and abandoned. The offset is about 300 feet structurally lower than the discovery. Mississippian porosity contained water. The Big Indian discovery is 414 feet higher than Pure's No. 1 State A, a dry hole drilled just north of the fault which forms the north edge of the Lisbon field.

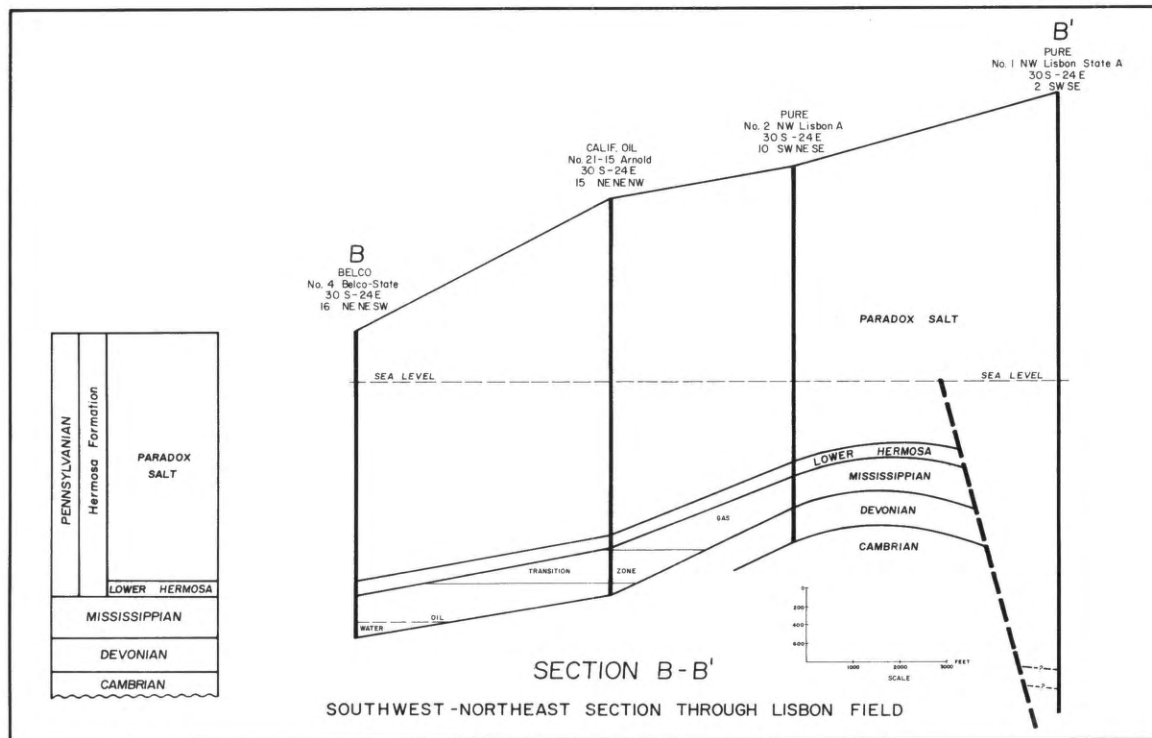


Figure 130.

Pubco recently discovered a new field in Sec. 21, T-30-S, R-25-E. The well was gauged at 17,500,000 cubic feet of gas per day from perforations in the Mississippian section between 9,270 and 9,400 feet, an interval 130 feet in thickness. Calculated absolute open flow is reported to be 66,000 MCFGPD, the largest in the area. This discovery is located almost at the top of the salt anticline, but Mississippian rocks are 1,500 feet structurally lower here than they are at the highest point in the Lisbon field. Calvert drilled the first Mississippian dry hole in T-30-S, R-25-E in December 1961, which separates the two fields. A one-mile southeast step-out from the Pubco discovery has been temporarily abandoned. The top of the Mississippian is 453 feet lower there than at Pubco's discovery.

What the Lisbon area lacks in known aerial extent is somewhat compensated for by the thick vertical extent, which is nearly 400 feet in the Mississippian section. However, the known aerial extent of Mississippian production in the region has recently been expanded by these new discoveries.

The attention of the entire oil and gas industry in the Rocky Mountain region is focused on the salt anticline area as a result of the oil and gas discoveries at Lisbon. There, porous carbonate rocks of Mississippian age are in contact with oil-rich shales of the Pennsylvanian Paradox member along numerous faults. Also hydrocarbon source material is present within Mississippian rocks themselves. Tectonic forces, sufficiently active to force the Paradox salt into major anticlines have created fault and fold hydrocarbon traps. As a result, ideal source rocks and reservoir rocks are found together in a faulted and folded area to complete the formula for the accumulation of oil and gas. The major stumbling block between exploration and the successful discovery of these fields is the lack of correlation between the position of anticlines above the salt and below the salt.

The secret of successful exploration in the salt anticline country seems to be a good understanding of the tectonic history of the region and a geophysical department which can accurately map the top of Mississippian rocks beneath several thousand feet of salt and several unconformities.

The salt anticline region covers 3,000 square miles. Less than a dozen holes have been drilled into Mississippian rocks there, with the exception of those drilled in established fields on and along the Lisbon Valley salt anticline. Consequently, lots of drilling can be expected in the coming years. The area of most exploratory interest today is a broad band of country with the approximate center line extending from the Lisbon Valley anticline, northward through Moab and on to the northwest, following the Moab Valley and Salt Valley anticlines. The west side of this area extends northwest approximately through the junction of the Green and Colorado Rivers.

The principal incentive for prospecting in this region is the presence of geologic conditions similar to those at Lisbon. More major fields are most likely to be present. As they are found, the Salt Anticline area of eastern Utah and western Colorado may well become a major oil and gas producing region.

CITED REFERENCES

- Budd, H., 1960, Notes on the Pure Oil Co. Discovery at Northwest Lisbon: Four Corners Geol. Soc. Guidebook, 3rd Ann. Field Conf., p. 121-124.
- Cater, F. W., Jr., 1955, The salt anticlines of southwestern Colorado and southeastern Utah: Four Corners Geol. Soc. Guidebook, p. 125-131.
- Jones, R. W., 1959, Origin of salt anticlines of Paradox Basin: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 8, p. 1869-1895.
- Lekas, M. A., and Dahl, H. M., 1956, The geology and uranium deposits of the Lisbon Valley anticline, San Juan County, Utah: Intermountain Assoc. Petroleum Geologists Guidebook, 7th Ann. Field Conf., p. 161-168.
- Mitchell, J. G., 1961, A Detailed lithologic zonation of the Mississippian at Northwest Lisbon field, San Juan County, Utah: Rocky Mountain Assoc. Geol. Symposium on Lower and Middle Paleozoic Rocks of Colorado, p. 175-184.
- Parker, J. M., 1961, McIntyre Canyon and Lisbon Oil and Gas fields, San Miguel County, Colorado, and San Juan County, Utah: Rocky Moun. Assoc. Geol. Symposium on Lower and Middle Paleozoic rocks of Colorado, p. 163-173.
- Shoemaker, E. M., Case, J. E., and Elston, D. P., 1958, Salt anticlines of the Paradox Basin: Intermountain Assoc. Petroleum Geologists Guidebook, 9th Ann. Field Conf., p. 39-59.
- Stokes, W. L., 1948, Geology of the Utah-Colorado Salt Dome Region with emphasis on Gypsum Valley, Colorado: Utah Geol. Soc. Guidebook to the Geology of Utah, no. 3, 50 p.
- _____, 1956, Nature and origin of Paradox Basin salt structures: Intermountain Assoc. Petroleum Geologists Guidebook, 7th Ann. Field Conf., p. 42-48.
- Wengerd, S. A., 1958, Pennsylvanian stratigraphy, southwest shelf, Paradox Basin: Intermountain Assoc. Petroleum Geologists Guidebook, 9th Ann. Field Conf., p. 109-133.

Paper 38 OIL AND GAS OCCURRENCES IN THE PROPOSED CANYON- LANDS NATIONAL PARK AREA OF SOUTHERN UTAH¹

by Milan S. Papulak²

INTRODUCTION AND LOCATION

This paper discusses the area of the proposed Canyonlands National Park and the immediately adjacent, geologically similar terrain. The area achieved two-fold significance during 1962. First, it was the site of three new oil discoveries, and second, it was the locale chosen for the proposed Canyonlands National Park. The latter, because of political controversy, has achieved nation-wide attention.

The proposed Canyonlands National Park is located about 12-36 miles southwest of Moab, with its center near the junction of the Green and Colorado Rivers. The area is characterized by deep, vertical-walled canyons, flat lying plateaus, and sparse desert-type vegetation. The two major rivers with their tributary streams have revealed a multiplicity of color in the rocks laid bare by erosion. Imposing geologic and geomorphic features offer points of distinctive scenic interest. Geologically, the proposed park area is located in the salt anticline region, roughly in the central portion of the Paradox Basin.

Three separate bills have been presented to Congress concerning the proposed national park. Utah Senators Wallace F. Bennett (Rep.) and Frank E. Moss (Dem.) have each drafted a proposal, while Utah Representatives David S. King and M. B. Peterson (Dem.) co-sponsored the third bill. An additional proposal has been made by Secretary of Interior Stewart Udall, calling for a 332,000-acres park (Figure 132). The controversy resulting from these proposals resolves into two issues - the size of the park, and the question of multiple use of the withdrawn lands. The outcome of the disagreement over these basic issues will bear heavily on future oil and gas exploration in this area.

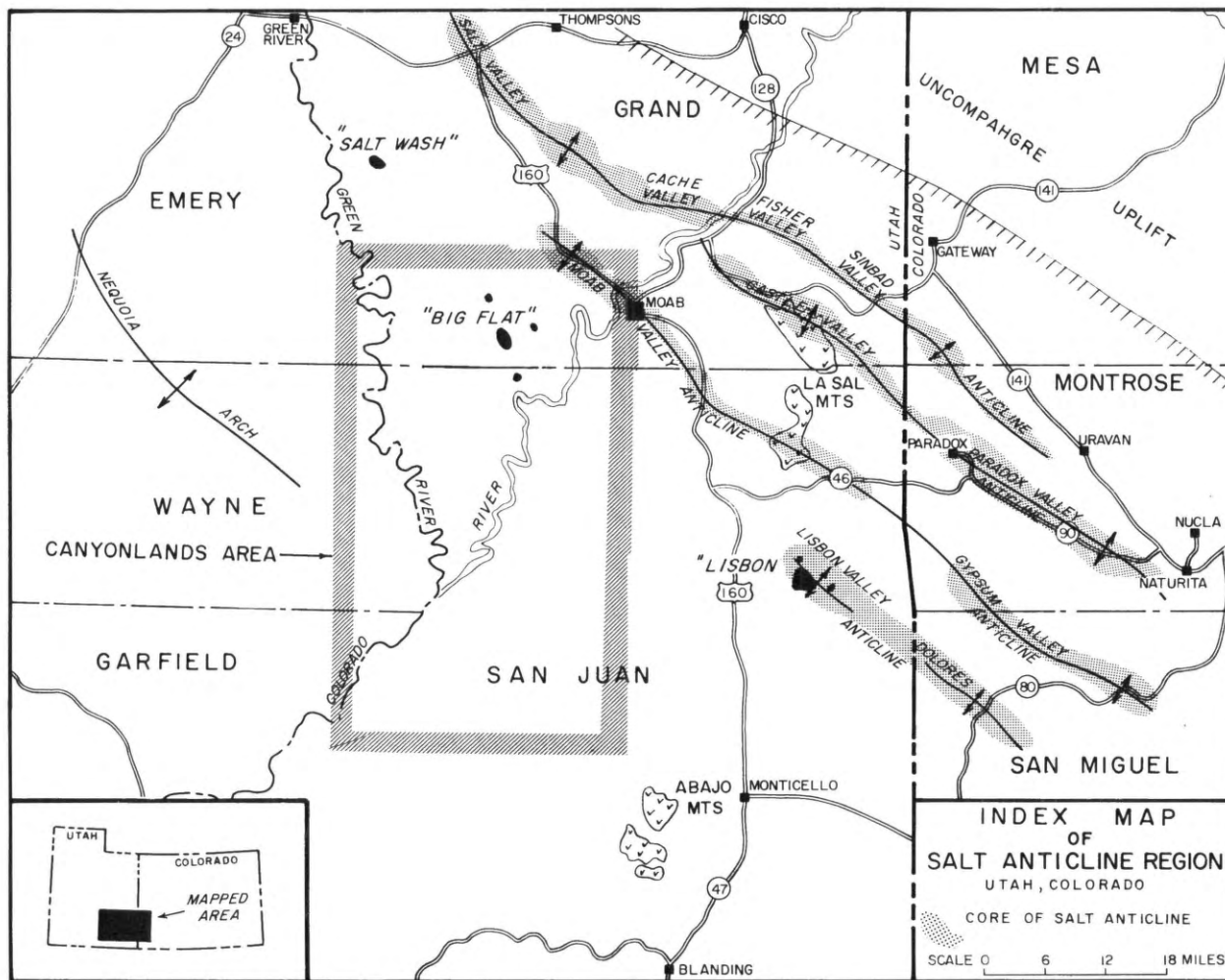
The search for oil in the scenic and rugged Canyonlands area had its start in the mid-twenties. Although numerous wells encountered good oil and gas shows during the intervening years, it was not until 1957 that Mississippian oil production was finally established at the Big Flat field a few miles north of the proposed park. In 1962 the Pennsylvanian Paradox salt section proved to be commercially productive in three separate discoveries--north, south, and east of the Big Flat field.

To date over 60 wells have been completed in the area, and of these, almost one half have had oil and/or gas shows in the Pennsylvanian Honaker Trail, Paradox salt, or in the Mississippian (Table XX). With all of these good shows, why only 4 discoveries? An individual closely involved in the area for many years offers a partial answer by referring to past completion efforts as the "Comedy of Errors". Several of the early wells with apparent commercial production in the Paradox salt were lost by improper completion, or upon deepening the hole. Many possible producing horizons in the salt were probably by-passed with the use of heavy drilling muds. Another problem, prevalent not only in the Canyonlands area but in the entire salt anticline region, is that of interpreting structure underlying the Paradox salt. Since the salt section varies in thickness (Figure 136), it effectively masks the underlying structure. Thus, a hole drilled on a surface high may bottom in a Mississippian low.

1. Adapted from PETROGRAM, July, 1962.

2. Associate Editor, PETROGRAM, Salt Lake City, Utah

Figure 131.



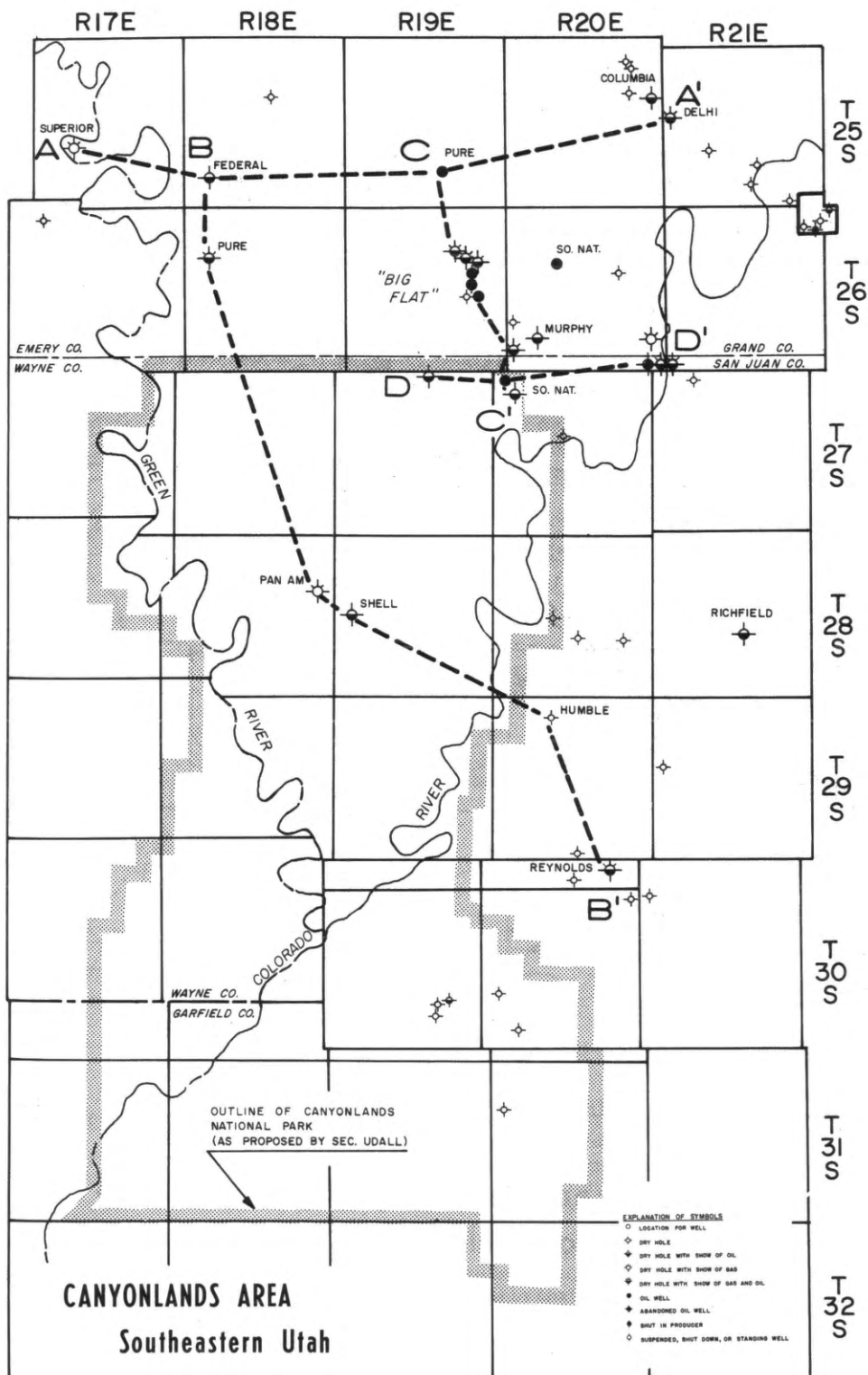


Figure 132.

Essentially, the scope of this paper is to present a compilation of known oil and gas shows in the Canyonlands area, placing emphasis on the occurrences in the salt section of the Pennsylvanian Paradox formation. Although many of the wells discussed are not in the proposed Canyonlands National Park proper, the results of these tests influence oil and gas exploration within the park boundary.

STRATIGRAPHY

Sedimentary rocks ranging in age from the Jurassic to the Pennsylvanian outcrop in the general area. In addition, sections of pre-Pennsylvanian rocks down to the Cambrian have been encountered in several wells. A brief description of these rocks follows:

TRIASSIC-JURASSIC

Glen Canyon Group (includes Navajo, Kayenta, and Wingate formations)

Navajo formation - about 600' of massive highly cross-bedded red to buff sandstone.

Kayenta formation - 250' of continental, red, gray to purple sandstone shale and siltstone.

Wingate sandstone - about 350' of massive red and reddish-brown aeolian sandstone.

TRIASSIC

Chinle formation - about 300' of sandstone, variegated shale, and siltstone, with some calcareous sandstone beds near the base, and underlain by the Shinarump member - 0-50' of continental sandstone and conglomeratic channel deposits. Figure 133 shows a structure contour map on top of the Chinle.

Moenkopi formation - about 500' of red to brown continental shale and siltstone, with some interbedded sandstone.

PERMIAN

Cutler formation - approximately 750' of continental sandstone and shale.

At the top there is 70-80' of White Rim sandstone, and near the base the Cutler grades into marine limestones and sandstones of the underlying Rico formation.

Rico formation - about 600' of marine limestone and sandstone.

PENNSYLVANIAN

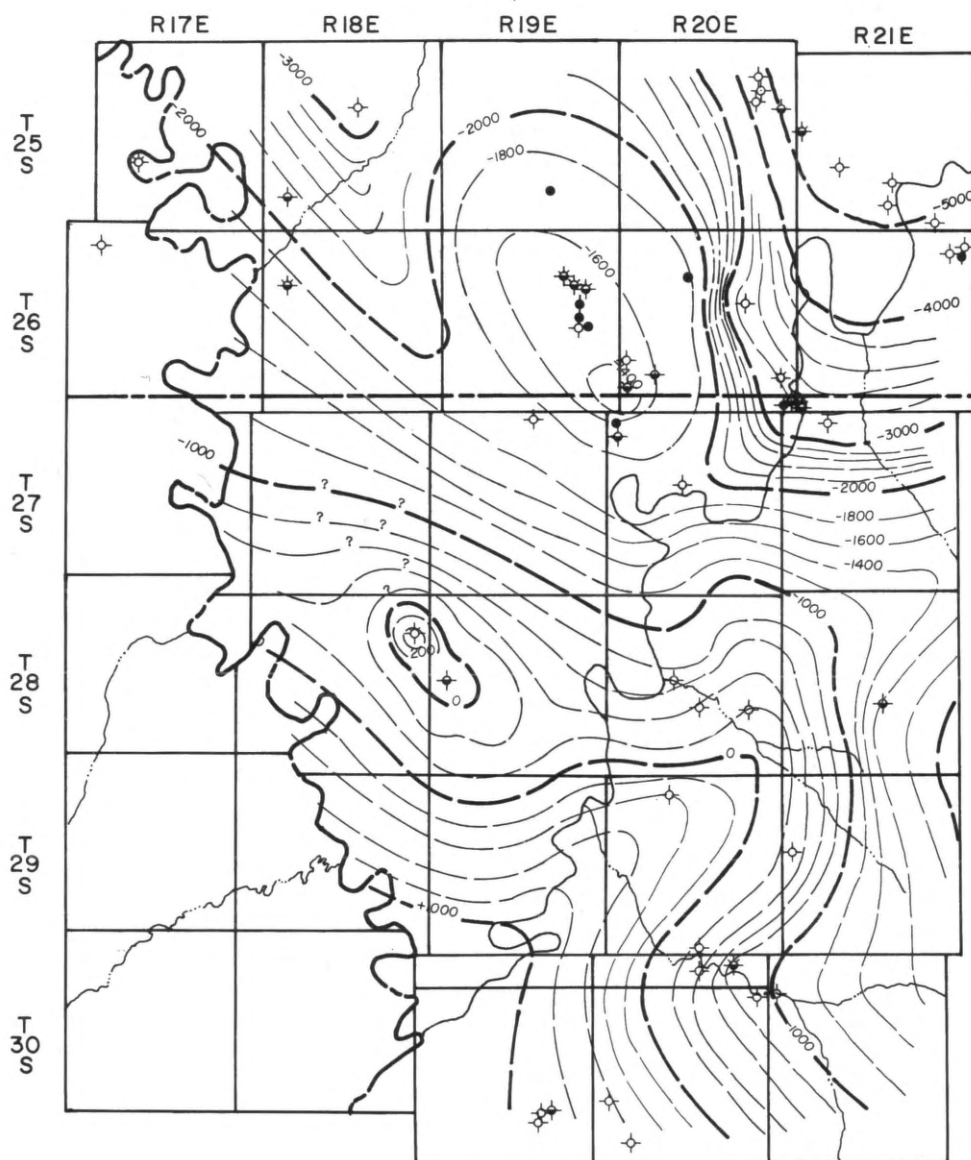
Hermosa Group (includes the Honaker Trail, Paradox, and Pinkerton Trail formations)

Honaker Trail formation (upper Hermosa) - 1100-1600' of light to dark gray limestone with interbedded sandstone, siltstone, shale and sandstone with only thin limestone beds.

Paradox formation - has been divided by Robert J. Hite (1960) into 3 distinct units on the basis of lithology and described as follows:

Upper unit - a penesaline facies, 150-500' thick and consisting of interbedded limestone, dolomite, anhydrite, black shale, and siltstone. The unit grades laterally into normal limestones on the southern and western margins of the salt basin.

Middle unit - referred to by Hite as the "saline facies," consists of 29 known beds of halite separated by clastic and penesaline interbeds of dark gray to black carbonaceous shale, siltstone, anhydrite,



**Generalized Structure Contour Map
on top of Mississippian**

Figure 134.

dolomite and minor amounts of sandstone. Two of these clastic interbeds, locally referred to as the Black Oil zone and the Cane Creek zone, are shown as marker beds in the cross sections A through D. The depositional thickness of the salt unit, absent at the margins of the salt basin, is an estimated 7000' in the basin deep. However, as much as 13,000' of salt is known to occur in the structurally thickened salt anticlines. In the proposed park area, drilling has penetrated as little as 1131' of salt at the Pan American No. 1 Murphy Range Unit (NE NW Sec. 12, T-28-S, R-18-E), where the salt thins out over a Mississippian high, to as much as 7020' of salt at the Delhi Taylor No. 2 Utah (NW SW Sec. 18, T-25-S, R-21-E) well, which was used by Hite for the classification of a type salt section. Mapping of the individual beds indicates that they vary in thickness from 15' to almost 1000'. The thinning or absence of individual beds indicates the presence of pre-salt highs, some of which were present throughout the entire period of salt deposition, and some only during certain intervals. (Figure 135 is a structure contour map on top of the salt; Figure 136 is a salt isopach map; Figure 141 is a correlation of the saline facies with the normal limestone sequence in the Greater Aneth area.)

Lower unit - is similar to the upper unit, and consists of intercalated beds of anhydrite or gypsum, dolomite, siltstone, and radioactive black shale.

Pinkerton Trail formation (lower Hermosa) - a fossiliferous limestone with interbedded gray shale.

Molas formation - 0 to 100' of vari-colored shale, with thin limestone and sandstone beds, wedges out locally over Mississippian highs.

MISSISSIPPIAN

Leadville formation - about 200' of light to dark gray limestone, containing thin discontinuous bands of porosity (Figure 134).

Madison formation - about 250' of dark gray limestone and dolomite with more "massive" porosity.

DEVONIAN

Ouray formation - about 100' of massive limestone.

Elbert formation - about 125' of interbedded dolomite, quartzite, and shale.

Aneth formation - about 175' of dark gray dolomite, with interbedded gray, brown, and black shale.

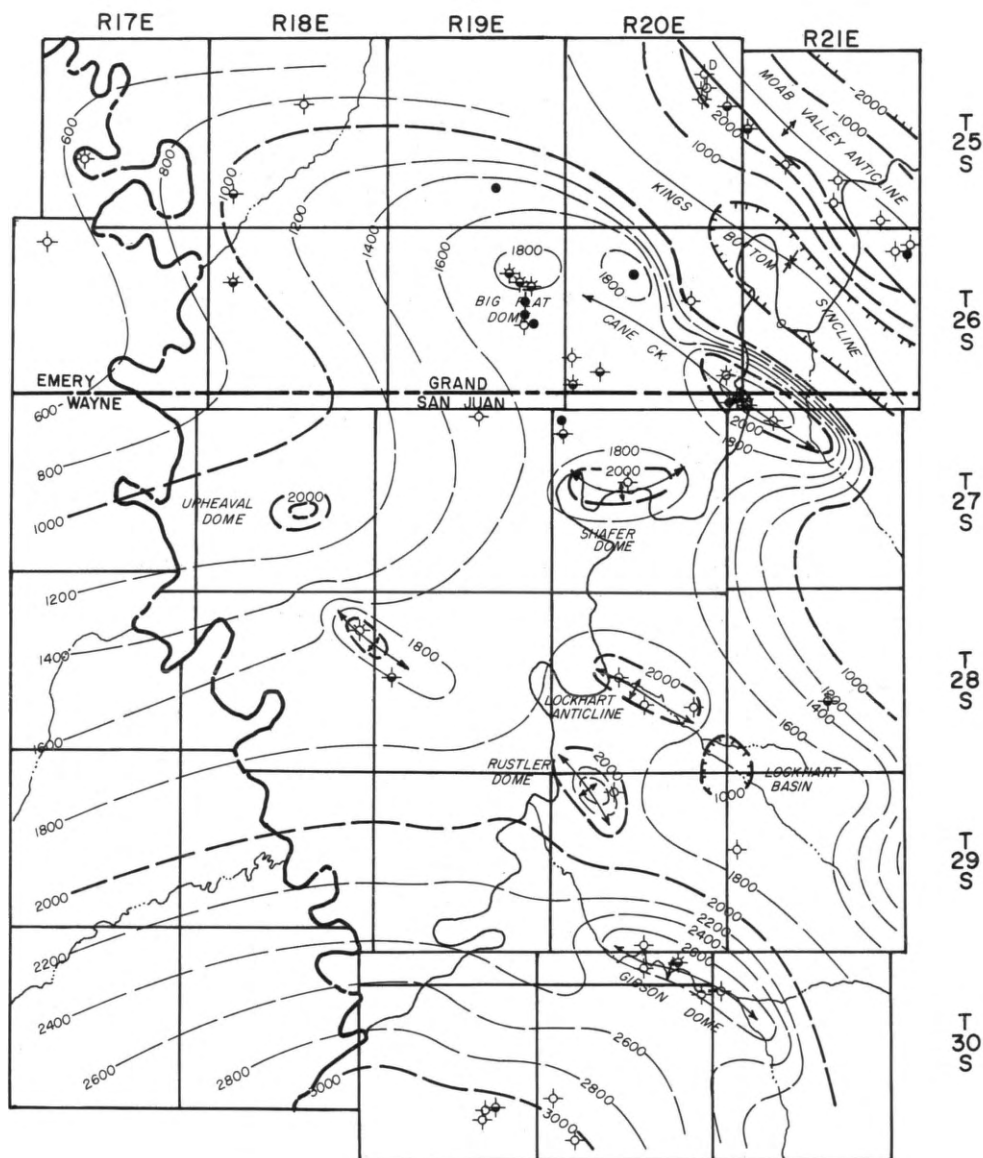
CAMBRIAN

Lynch formation - light to dark gray dolomite.

STRUCTURE

The regional dip of the surface beds is north at the rate of 100-150' per mile. The axial trend of most of the local structural features is northwest, paralleling the major salt anticlines and the Uncompahgre Uplift.

At least one well has been drilled on the surface crests of most of the known anticlines -- a notable exception is Upheaval Dome. These surface structures



**Generalized Structure Contour Map
on top of Penn. Paradox Salt**

Figure 135.

seem to carry through to the top of the Paradox salt; below the salt section a surface high is often underlain by a Mississippian low. According to Robert Hite (1960), mapping of individual salt beds has shown that the surface salt anticlines were actually sedimentary troughs during most of salt deposition time. In addition, drilling has revealed Mississippian highs that are not reflected at the surface (Figures 133, 134, and 135).

Listed below are surface structures that have had at least one significant drill test:

The Big Flat anticline is a broad domal shaped structure with at most 150' of surface closure. The Mississippian high is near the Pure No. 1 discovery, at least 1 mile south of the surface high (Figure 139).

The Cane Creek anticline, an elongate feature with more than 400' of surface closure, is readily observed where the Colorado River cuts across the axis. Drilling has encountered over 5000' of Paradox salt, with the Mississippian at a relatively low position (Figure 140).

Shafer Dome, the only anticlinal feature trending east-west, has over 400' of surface closure. A test to the Mississippian Leadville formation encountered no reported shows.

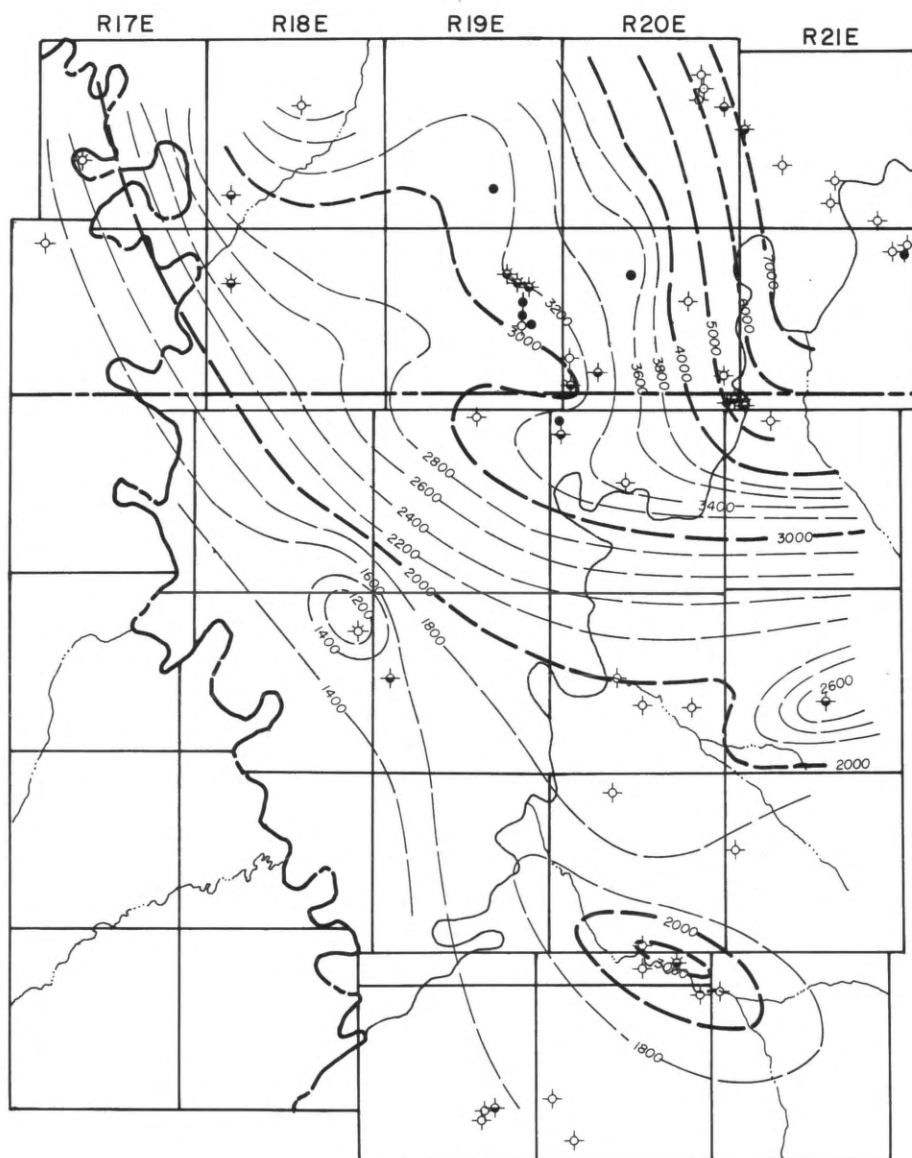
To the south, the Lockhart anticline, and Rustler and Gibson Domes each have over 100' of surface closure. Only Rustler Dome retains a prominent high below the salt section (Figure 138).

DRILLING HIGHLIGHTS

Between the years 1924 and 1929, cable tools were floated down the Colorado River from Moab, and three wells were drilled in the Cane Creek area by Utah Southern Oil Company and Midwest Refining Company. The most significant well was probably Midwest's No. 1 F. Shafer (Sec. 31, T-26-S, R-21-E). While drilling at 2028' in the Paradox salt, the well blew out and flowed gas and green oil (36° gravity) which caught fire and demolished the rig. After the fire was brought under control, the zone was cased off and drilling continued to 3628' in the salt where a second test recovered 800' of oil. This zone was also cased off and the well was drilled to a depth of 5000'. In 1927, after unsuccessful attempts to complete these zones, the well was finally abandoned (Carlton, 1958).

The next period of drilling began in 1948 and has continued somewhat sporadically to the present time. In October 1949, Tidewater Oil completed the No. 74-11 Big Flat (SE NW Sec. 11, T-26-S, R-19-E) near the surface crest of the Big Flat anticline. Slight oil and gas shows were recovered from the Honaker Trail, the Black Oil and Cane Creek zones in the Paradox salt, and from the Upper Mississippian limestone. The well was abandoned at 8389' in the Devonian (?). To follow up these encouraging shows Glen Ruby, a Salt Lake independent, drilled a 40 acre offset which was abandoned in May 1953. The well, No. 1-A Big Flat (NW NW Sec. 11, T-26-S, R-19-E), had oil shows with a good gas blow in the Black Oil zone, and traces of oil were swabbed from the upper Mississippian.

In January 1955, Delhi-Taylor completed a significant, but disheartening deep test a few miles northwest of Moab. The well, No. 2 Utah (NW SW Sec. 18,



Isopach Map of Penn. Paradox Salt

Figure 136.

T-25-S, R-21-E) drilled through more than 7000' of Paradox salt section and was bottomed at 9424' in the lower Paradox. Over 1000' of oil was recovered from the Cane Creek zone, and on subsequent tests the operator swabbed 27 BOPD with a flow of 171 MCFGPD from 7646 to 7672'. As did its predecessors, the well encountered completion problems, and when the casing finally collapsed the operator abandoned the venture.

In the same year another "near miss" was scored on the Cane Creek anticline by Modco, Inc. The well, No. 2 Govt. (NE SE Sec. 36, T-26-S, R-20-E) was drilled to a total depth of 7355', possibly in the upper Mississippian. Reports indicate that 780 BOPD was recovered from the Cane Creek zone (6666-6721'). After several months of delay, completion was attempted--but the well was dead. With prompt completion, the Modco failure might have been the first discovery in the area.

Two additional Mississippian tests were drilled and abandoned during 1955. King Oil drilled the No. 2 Ruby (SW SE Sec. 11, T-26-S, R-19-E) in the Big Flat area about 1/2 mile southeast of the Tidewater failure. A gas blow with up to 80 BOPH was encountered in the Black Oil zone, and a pump test of the upper Mississippian limestone (7778-7840') recovered 15 BOPD. After extensive testing, the well was abandoned at 7860'. Later, Pure Oil deepened the well to 8061' to test the lower Mississippian, but recovered only slight oil shows and water. Reynolds Mining drilled the No. 1 Gibson Dome (SE NE Sec. 35, T-29-1/2-S, R-20-E), and recovered 100' of green gassy oil from the Paradox salt section (3486-3537', between salt No. 13 and 14).

In November 1957, Pure Oil Company made the first successful wildcat completion at the Big Flat field. The discovery, No. 1 Big Flat (SW SE Sec. 14, T-26-S, R-19-E) flowed 319 BOPD from the Mississippian (7694-7728'), climaxing the 30 and some odd years of drilling and repeated disappointment. The producing interval, a light to dark gray dolomite with zones of vugular and fractured porosity, is probably upper Madison in age. The oil is 43° gravity, with a paraffin base and a high sulfur content (Parker, 1960). A drill stem test of the Leadville recovered non-flammable nitrogen gas at an estimated rate of 7000 MCFGPD. Oil and gas were also recovered from two separate intervals in the Paradox salt section. The well blew out in the Black Oil zone (5970-5980') and flowed an estimated 5000 MCFGPD and 10-30 BOPH. A second DST within salt No. 18 (6266-6273') resulted in 500' of gas and oil cut water, and 580' of gas cut water. These zones were cemented to permit deepening of the well, and were never retested. Structurally, Pure's discovery was lower on the surface than any of the previous wells drilled on the anticline, but was about 200' higher in the Mississippian. The well is presently not producing due to waxing problems and a low pumping potential. Production in the well was down to 23.5 BOPD in December 1959 before the well was shut in.

The following year Pure Oil completed the No. 2 Big Flat (SW NE Sec. 14, T-26-S, R-19-E) a 1/2 mile north offset, with a flow of 85 BOPD from limestone beds in the Mississippian Leadville. Although the top of the Mississippian was almost 200' structurally lower than in the No. 1 well, the producing intervals were at about the same elevation. This well was shut down in November 1959, after pumping-potential decreased to less than 10 BOPD. In October, 1962, an attempt to recomplete in the Paradox salt proved to be unsuccessful.

Four other wells, with significant shows were completed in 1958, but none were successful. Cabeen Exploration drilled to the Mississippian at the No. 1

Figure 137.

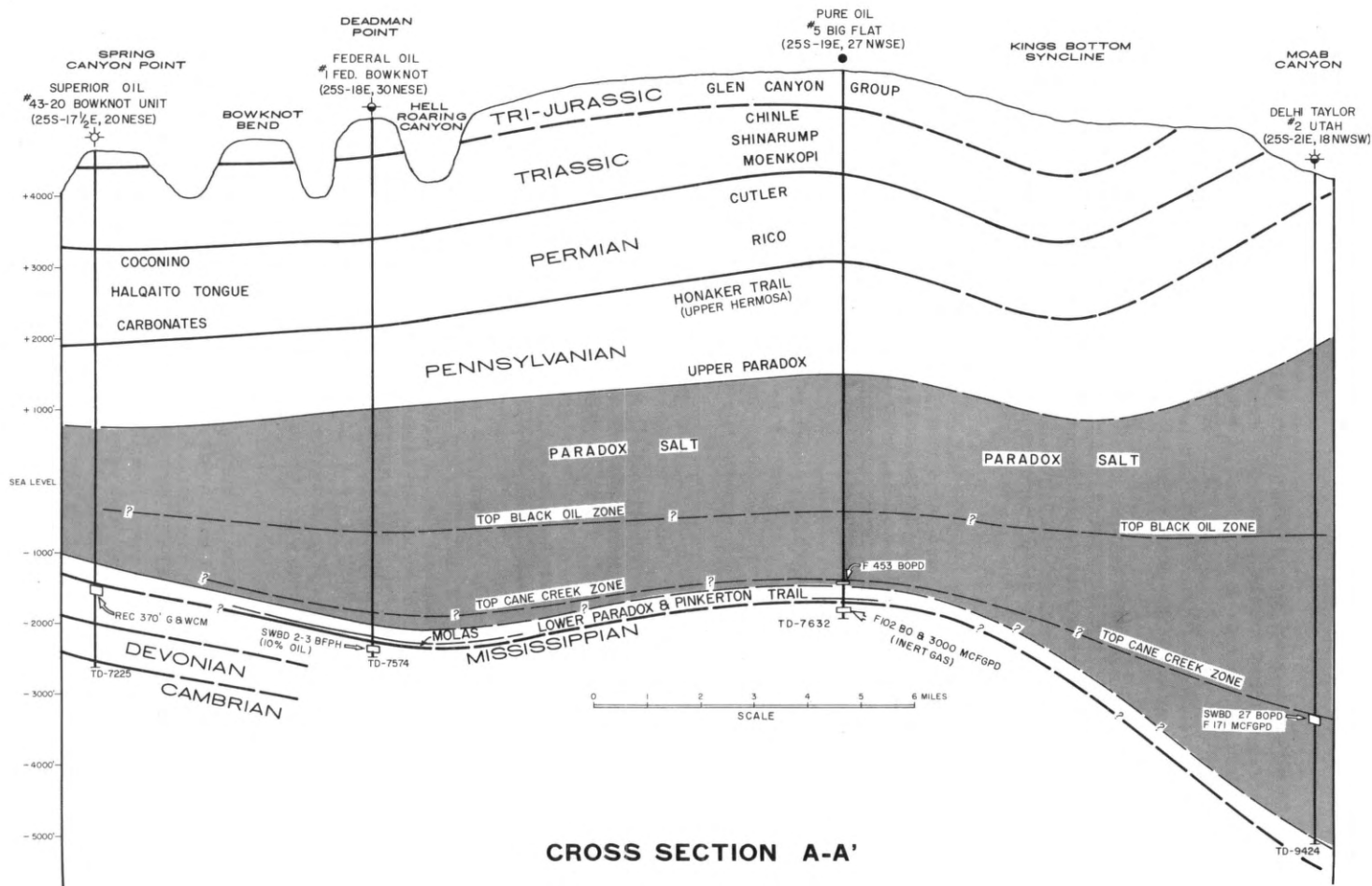
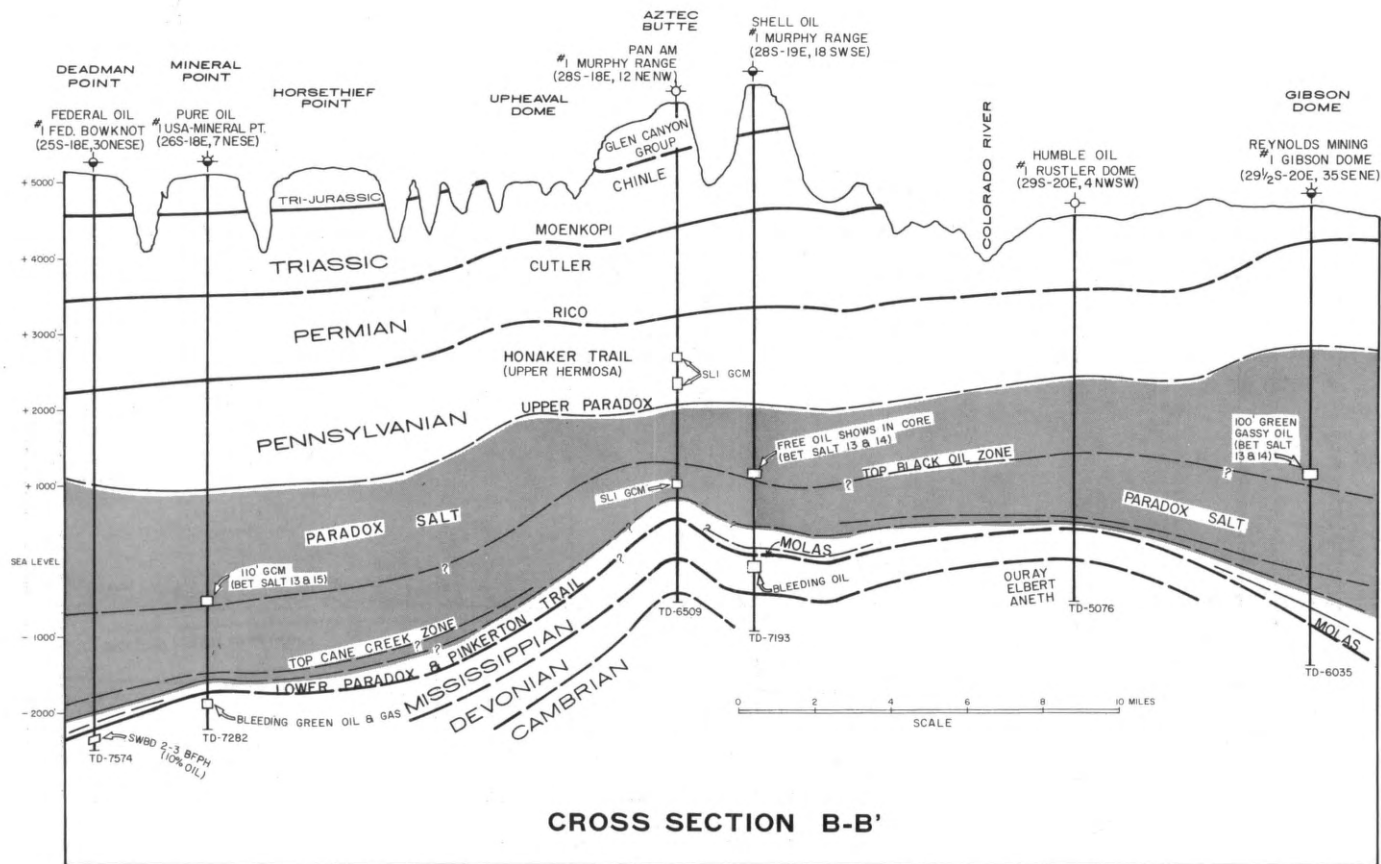


Figure 138.



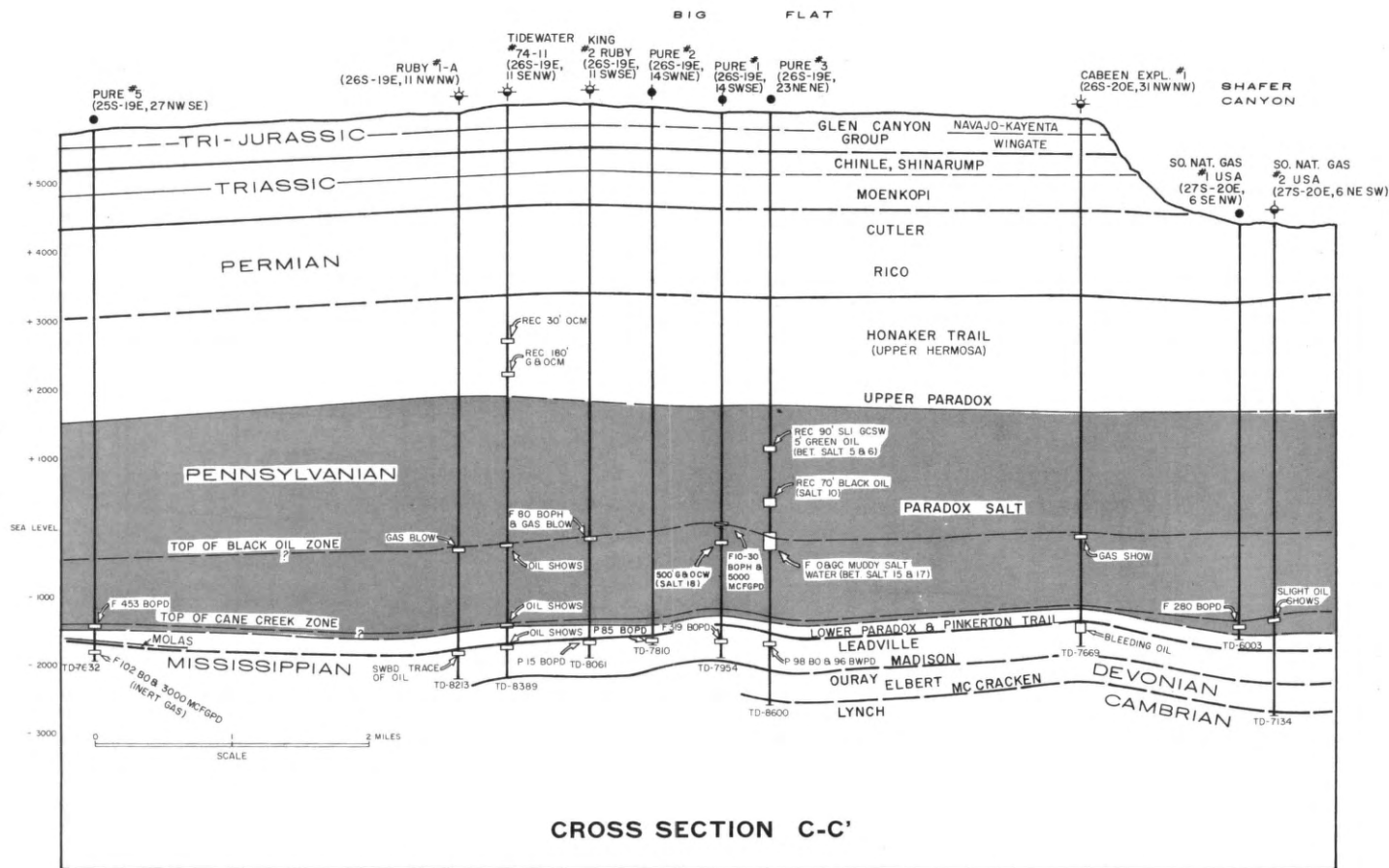
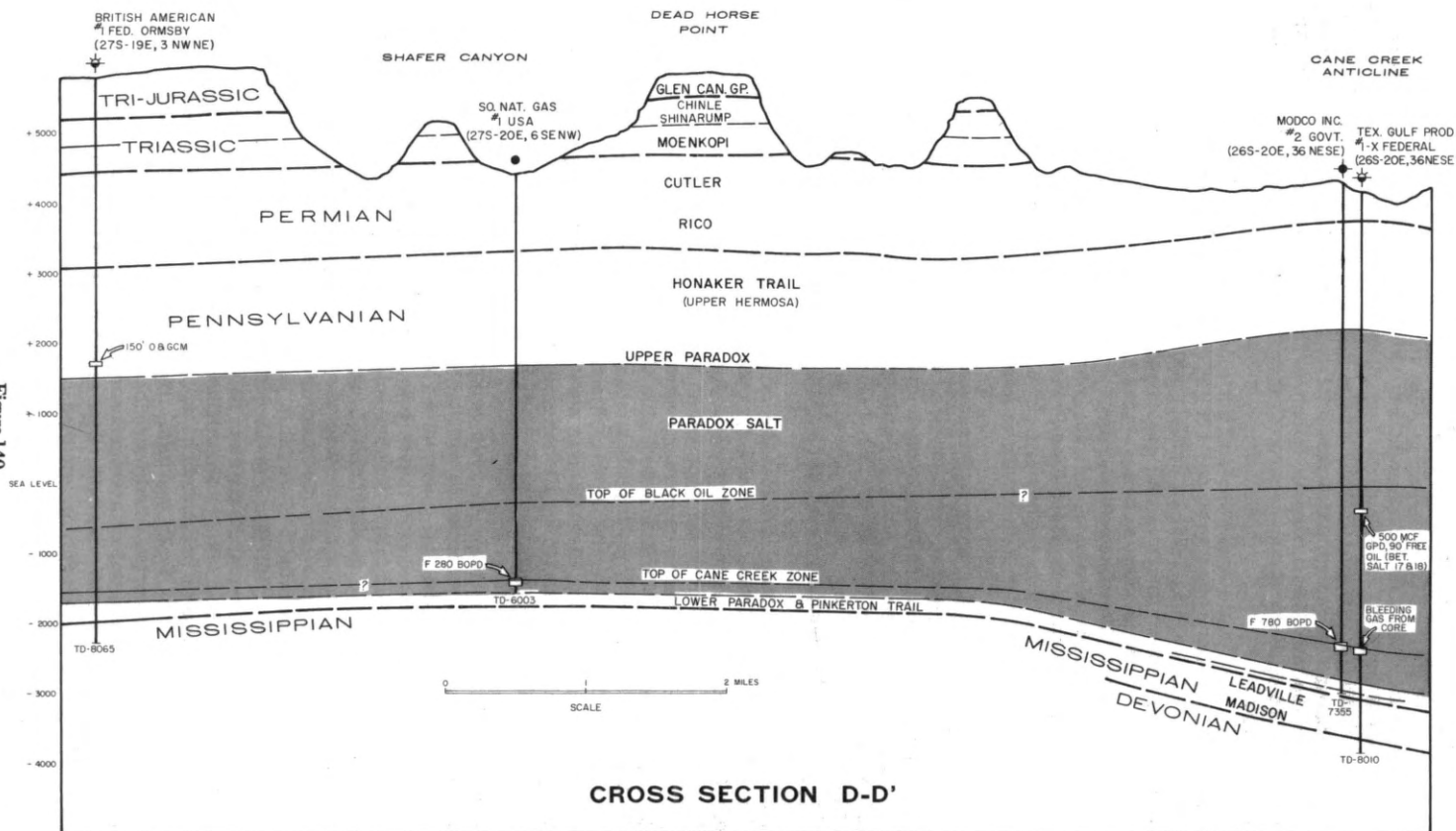


Figure 140.



Big Flat-Govt. (NW NW Sec. 31, T-26-S, R-20-E) and recovered slight gas shows in the Black Oil zone, and bleeding oil from Mississippian cores. Federal Oil abandoned the No. 1 Fed-Bowknot (NE SE Sec. 30, T-25-S, R-18-E) after swabbing non-commercial amounts of oil from the Mississippian. Pure Oil drilled the third Mississippian failure at No. 1 USA-Mineral Point (NE SE Sec. 7, T-26-S, R-18-E) and recovered shows in the Paradox salt and in the Mississippian.

The fourth, a 1/4 mile offset to Modco's 780 BOPD "near miss", was the No. 1-X Federal (NE SE Sec. 36, T-26-S, R-20-E) which Texas-Gulf Producing drilled on the Cane Creek structure, and abandoned at 8010' in the Devonian after recovering oil and gas shows from the Paradox salt. The Cane Creek zone, which was only slightly lower structurally than in the Modco well, had only slight gas shows. The absence of oil in this 1/4 mile offset gives some indication of the elusive nature of the Cane Creek zone as a productive reservoir.

In 1960 Pure Oil completed the third successful well at the Big Flat field. The well, No. 3 Big Flat (NE NE Sec. 23, T-26-S, R-19-E) had an initial pump potential of 98 BO, 81 MCFG, and 96 BWPD from the Mississippian (7714-7726'). Oil and gas shows were also recovered from three separate intervals in the Paradox salt section, and a cumulative total of nearly 6,000 barrels of oil was recovered from the Black Oil zone before the well was deepened. An offset, No. 4 Big Flat (NW NE Sec. 23, T-26-S, R-19-E) was drilled to evaluate these shows but was dry. At the present time the No. 3 is the only producing well in the field, pumping 40-50 BOPD.

Also in 1960, Murphy Corp. completed a dry 8600' Devonian test at the No. 1 Little Valley (NW SW Sec. 29, T-26-S, R-20-E) a few miles southeast of Big Flat. Oil shows were recovered from the Paradox salt and the Mississippian.

In 1961, two more wildcats with shows were abandoned. Superior Oil drilled No. 43-20 Bowknot Unit (NE SE Sec. 20, T-25-S, R-17 1/2 E) to a depth of 7225' in the Cambrian, recovering only slight shows in the Mississippian. About 13 miles southwest of Big Flat, Shell Oil drilled the No. 1 Murphy Range Unit (SW SE Sec. 18, T-28-S, R-19-E) on a seismic Mississippian high. The well was abandoned in the Devonian after encountering slight oil shows in the Paradox salt and in the Mississippian.

During the first nine months of 1962, six additional significant wells were completed -- three as discoveries and three as dry holes. In January of this year, Pure Oil made the first successful Paradox salt completion in the area, a few miles north of Big Flat. The well No. 5 Big Flat unit (NW SE, Sec. 27, T-25-S, R-19-E) had an initial flowing potential of 453 BO and 282 MCFGPD from the Cane Creek zone (7202-7228') at the base of the salt. The only other salt production in Utah at the time was at the Lisbon field in northeastern San Juan County. The new-pay discovery, No. 2 NW Lisbon-C (NE NW Sec. 3, T-30-S, R-24-E) completed by Pure Oil in January 1961 had an initial potential of 103 BO and 129 MCFGPD (46.5° gravity) from the Paradox salt. The producing interval corresponds roughly to the Black Oil zone in the Canyonlands area (Hite personal communication, 1962). Toward the end of April, production at the No. 5 well was killed due to collapsed casing. Prior to this time the well flowed 200-260 BOPD (43.2 to 43.8° gravity). The operator whipstocked and drilled deeper to the Mississippian where up to 102 BO and 3000 MCFGPD (inert gas) was recovered. Because of the increasing ratio between inert gas and oil, completion attempts in the Mississippian were abandoned and the well was plugged back to the Paradox where Pure recompleted in the Cane Creek zone for 450 BOPD, (7210-7250).

In February 1962, Southern Natural Gas made the second Cane Creek zone discovery a few miles south of Big Flat. The well, No. 1 USA (SE NW Sec. 6, T-27-S, R-20-E) was completed flowing 280 BOPD from the 5808-5860' interval. Total depth was 6003' in the lower Paradox. The average production for the month of May was 102.2 BOPD. Southern Natural's confirmation to the discovery was abandoned at 7134' in the Cambrian. The 1/4 mile offset, No. 2 USA (NE SW Sec. 6, T-27-S, R-20-E) recovered only slight oil shows in the Cane Creek zone, although structurally the interval was slightly higher than in the discovery.

The two other dry holes drilled in 1962 were Richfield Oil's No. 1 Hatch Mesa (NW SW Sec. 22, T-28-S, R-21-E) which had slight oil staining in the Mississippian, and Pan American's No. 1 Murphy Range (NE NW Sec. 12, T-28-S, R-18-E) which recovered only slight gas shows in the Honaker Trail formation and in the Paradox salt. The Pan American well, located about two miles northwest of Shell's failure, was about 500' structurally higher in the Mississippian. The Pennsylvanian Molas was absent in this well.

The third Cane Creek zone discovery, located on the Long Canyon Unit about 4 miles east of the Big Flat field, was completed in September, 1962. The well, No. 1 unit (SE NW Sec. 9, T-26-S, R-20-E) flowed 660 BOPD (42° gravity) from the Cane Creek zone (7050-7075').

SUMMARY AND CONCLUSIONS

Although the success ratio in the Canyonlands area is relatively poor, a review of the past drilling activity shows that a better knowledge of salt completion techniques might have resulted in additional discoveries. A tabulation of the shows in all of the wells drilled in the area indicates that there are at least 13 separate intervals with oil and gas occurrences; 2 are in the Pennsylvanian Honaker Trail formation, 9 in the Pennsylvanian Paradox salt section, and 2 in the Mississippian (Figure 141).

The Mississippian, including both the Leadville and Madison formations, has produced oil at the Big Flat field just north of the proposed Canyonlands National Park. Although numerous wells have been drilled to the Mississippian since the field's discovery in 1957, and have recovered shows from this interval -- no additional Mississippian discoveries have been made by mid 1962. Much of the problem thus far has been in interpreting Mississippian structure. A better understanding of the seismic results would help greatly. In addition, waxing has become a problem at Big Flat field, and of the three successfully completed wells, two have been shut down because of decreasing pumping potential and the third is pumping at a reduced rate. This situation, however, is not evident in the Mississippian production at the Lisbon field, about 38 miles to the southeast, and at the Salt Wash field, about 24 miles to the northwest.

High pressure "blowouts" occurring in both salt beds and in the intervening clastics of the Paradox salt section were encountered as early as the mid-twenties. The salt section consists of 29 known beds of halite separated by clastic and penesaline interbeds of dark gray to black carbonaceous shale, light to dark gray siltstone, anhydrite, dolomite and minor amounts of sandstone. Mapping of the Paradox salt towards the margins of the salt basin, shows that the oil producing limestones in the Greater Aneth area to the southeast, are peripheral facies of specific salt beds (Figure 141).

TABLE XX

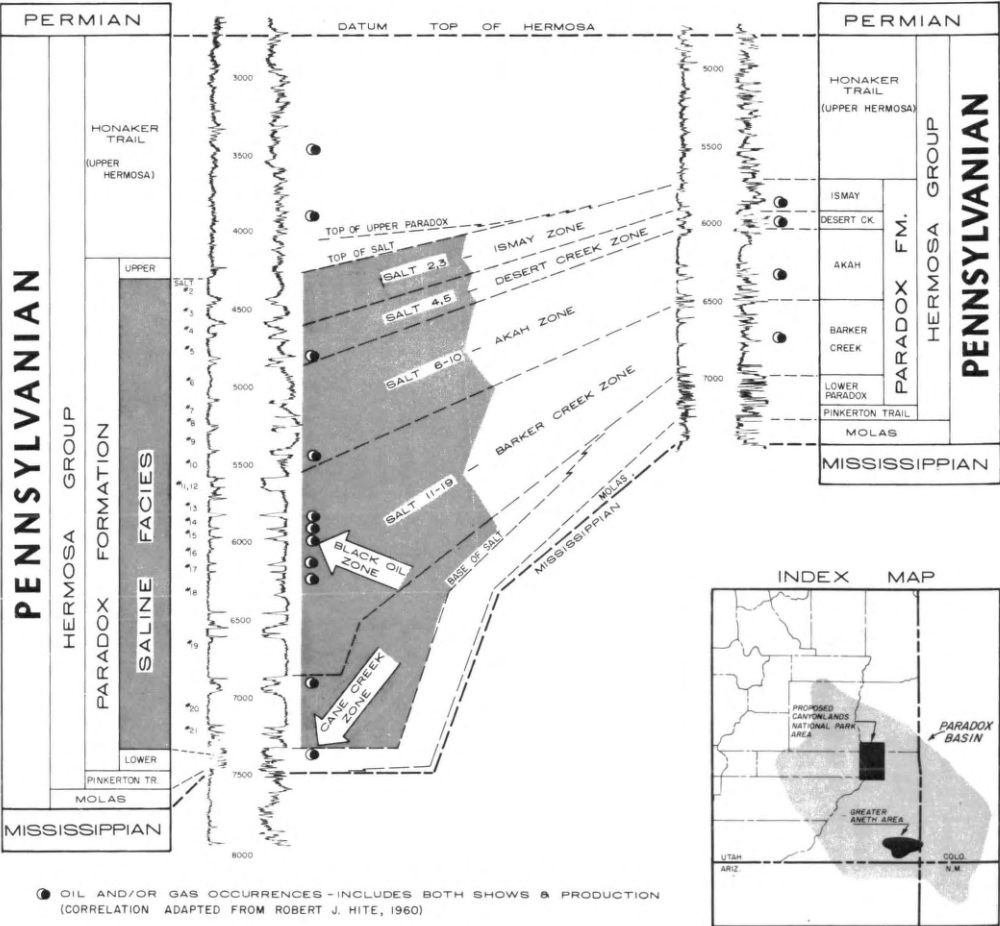
Chart of Completed Wells with IMPORTANT OIL AND GAS SHOWS
in the Proposed Canyonlands National Park Area, Utah

Company	Well Name	Location	Date Compl.	T.D.	Deepest Fm. Drilled	Remarks
Superior Oil	#43-20 Bowknot Unit	25S-17½E, 20 NE SE	2-15-61	7225'	Cambrian	Recovered 370' sli. G & WCM from Mississippian (6070-6206), P & A.
Federal Oil	#1 Fed.-Bowknot	25S-18E, 30 NE SE	9-18-58	7574'	Mississippian	Swabbed 2-3 BFPH (10% oil) from Mississippian (7404-62'), P & A.
Pure Oil	#5 Big Flat Unit	25S-19E, 27 NW SE	1-2-62	7632'	Mississippian	F 453 BOPD from Cane Creek zone (7202-28') at base of Paradox salt, NEW FIELD DISCOVERY, re-drilled to Mississippian and tested up to 102 BO and 3000 MCFGPD (inert gas).
Columbia Crude	#1	25S-20E, 12 SW SE	10-26-38	4243'	Lower Paradox	Slight oil shows in Hermosa (2130-33'), P & A
Delhi-Taylor	#2 Utah	25S-21E, 18 NW SW	1-20-55	9424'	Lower Paradox	Recovered 108 MCFG & 700' oil & water (7611-52'); 171 MCFG & 560' clean oil (7621-82'); swabbed 27 BOPD (7646-72'); recovered 1000' free oil (7706-10') from Cane Creek zone in the salt, casing collapsed, P & A.
Pure Oil	#1 USA - Mineral Pt.	26S-18E, 7 NE SE	11-20-58	7282'	Mississippian	Recovered 110' sli. GCM between salt and 13 & 15 and bleeding gas and green oil from core in Mississippian. (6925-50'), P & A.
Tidewater Oil	#74-11 Big Flat	26S-19E, 11 SE NW	10-10-49	8389'	Devonian	Recovered 30' OCM (3449-80'); and 180' G & OCM (3908-63') from Hermosa; also reported oil shows in Black Oil zone and Cane Creek zone, and Mississippian, P & A.
Glen Ruby	#1-A Big Flat	26S-19E, 11 NW NW	5-26-53	8213'	Devonian	Gas blow and oil shows in Black Oil zone, oil show in Mississippian, P & A.
King Oil	#2 Ruby	26S-19E, 11 SW SE	9-1-55	8061'	Mississippian	Gas blow & 80 BOPH in Black Oil zone, also P 15 BOPD from Mississippian (7778-7840').
Pure Oil	#2 Big Flat Unit	26S-19E, 14 SW NE	9-15-58	7810'	Mississippian	P 85 BOPD (40° gravity) from Miss. (7750-62')
Pure Oil	#1 Big Flat Unit	26S-19E, 14 SW SE	11-1-57	7954'	Mississippian	F 319 BOPD (43° gravity) from Miss. (7694-7728) also flowed 5000 MCFGPD & 10-30 BOPH from Black Oil zone (5970-80'); flow was killed in deepening, NEW MISSISSIPPIAN DISCOVERY.
Pure Oil	#3 Big Flat Unit	26S-19E, 23 NE NE	12-24-60	8600'	Cambrian	Recovered 90' CGSW & 5' green oil between salt #5 & 6 (4882-4950'); 70' black oil from salt 10 (5601-5701'); and 0 & CGSW between salt #15 & 17 (6119-6373'); flowed 6000 BO from Black Oil zone before deepening; also F 98 BO, 81 MCFG & 96 BWPD from Mississippian (7714-26').
Southern Natural Gas	#1 Long Canyon Unit	26S-20E, 9 SE NW	9-62	8134'	Devonian	Flowed 660 BOPD from Cane Creek zone (7050-75') NEW FIELD DISCOVERY

Utah So. Oil	#1-A	26S-20E, 25 SW NE	6-18-29	4107'	Penn. Paradox	Show of gas at 2055' near top of salt.
Murphy Oil	#1 Little Valley	26S-20E, 29 NW SW	8-24-60	8600'	Devonian	Recovered show of oil in Black Oil zone; and 728' green oil & 50 MCFGPD between salt #19 & 20 (6763-6805'); bleeding oil in Mississippian (7630-94'), P & A.
Cabeen Expl.	#1 Big Flat-Govt.	26S-20E, 31 NW NW	7-2-58	7669'	Mississippian	Show of gas in Black Oil zone, bleeding oil from Mississippian (7350-95', 7452-67'), P & A.
Modco, Inc.	#2 Govt.	26S-20E, 36 NE SE	1955	7355'	Mississippian (?)	Unconfirmed reports of 780 BOPD from Cane Creek zone (6666-6721'), was shut in and killed and finally abandoned.
Texas-Gulf Prod.	#1-X Federal	26S-20E, 36 NE SE	7-3-58	8010'	Devonian	Recovered 500 MCFGPD, 780' O & GCM, and 90' free oil (41.8° gravity) between salt #17 & 18 (4520-84'); also gas show in Cane Creek zone (6550-6618').
Midwest Oil	#1-F. Shafer	26S-21E, 31 SW SW	3-21-27	5000'	Penn. Paradox	Recovered green oil (36° gravity) and gas from salt (2028'); 800' of oil (3628') and gas show at 4980' in salt, P & A.
British American	#1 Fed.-Ormsby	27S-19E, 3 NW NE	7-28-58	8065'	Mississippian	150' O & GCM from upper Hermosa (4030-4100'), P & A.
Southern Nat. Gas	#1 USA	27S-20E, 6 SE NW	2-28-62	6003'	Penn. Paradox	P 280 BOPD from Cane Creek zone (5808-60'); recompleted for a flow of 100 BOPD, NEW FIELD DISCOVERY.
Southern Nat. Gas	#2 USA	27S-20E, 6 NE SW	5-20-62	7134'	Cambrian	Recovered slight shows in Cane Creek zone, unsuccessful offset, P & A.
Pan American	#1 Murphy Range	28S-18E, 12 NE NW	6-13-62	6509'	Cambrian	Recovered slightly GCM from upper Hermosa (3255-3365', 3550-3713'), and from salt (4940-5037'), encountered Mississippian about 500' structurally higher than adjacent well, and only 1131' of salt section.
Shell Oil Co.	#1 Murphy Range	28S-19E, 18 SW SE	9-9-61	7193'	Devonian	Recovered free oil shows from core between salt #13 and 14 (5073-5111'); and 4 barrels OGSW from Mississippian (6237-6325'), P & A.
Richfield Oil	#1 Hatch Mesa	28S-21E, 22 NW SW	1-5-62	8518'	Devonian	Slight oil staining in Mississippian.
Reynolds Mining	#1 Gibson Dome	29½S-20E, 35 SE NE	10-16-55	6035'	Mississippian	Recovered 100' green gassy oil between salt #13 & 14 (3486-3537'), P & A.

CANYONLANDS NATIONAL
PARK AREA

GREATER ANETH AREA



COMPARISON OF
PENNSYLVANIAN OIL & GAS OCCURRENCES
in the
CANYONLANDS NATIONAL PARK and GREATER ANETH AREAS
Emery, Wayne, Garfield, Grand, and San Juan Counties, Utah
(Showing type Gamma Ray-Neutron Logs for each area)

Figure 141.

The presence of the carbonaceous interbeds in the Paradox salt indicates a highly favorable environment during salt deposition for preserving organic matter. That most of this organic debris has been converted to hydrocarbons is well illustrated by the drilling results -- almost half of the wells drilled in the area had some shows in the salt section.

Of the 9 intervals having oil and gas shows in the Paradox salt, two clastic interbeds are of notable interest -- they are the Black Oil zone and the Cane Creek zone. The Black Oil zone occurs between salt No. 15 and 16, roughly in the middle of the salt section. Although no sustained commercial production has been attained from this zone in the Canyonlands area, wells have flowed as high as 80 BOPH from the interval. The Black Oil zone is also believed to be the producing interval at Utah's first Paradox salt discovery in the Lisbon field. The Cane Creek zone, thickest clastic interbed in the salt section, is the producing interval in three discoveries in the Canyonlands area completed in 1962. The wells Pure No. 5, and Southern Natural No. 1 USA and No. 1 Long Canyon Unit had initial potential flows of 453, 280, and 660 BOPD. The Cane Creek bed lies between salt No. 21 and 22, and occurs anywhere from at the base of the salt to 1800' or more above the base, depending on the number of underlying salt beds.

Recent study of these clastic interbeds, which are usually very tight reservoir rocks, indicates that fracturing is necessary in developing a favorable environment for oil and gas accumulation. According to Robert Hite (personal communication, 1962) the producing interval in each of the Paradox salt discoveries in Utah is believed to be fractured and/or faulted.

It is quite possible that future drilling in this area will eventually establish sizeable reserves within the Paradox salt, however, past experience indicates that accumulation will likely be erratic and high potential wells will be offset by dry holes -- as has occurred south of Big Flat and in the Cane Creek area. This type of erratic distribution of oil accumulation is characteristic of fracture reservoirs.

Thus far the Mississippian seems to offer the best potential for the development of any large oil reserves in the Canyonlands area. These reserves, however, will never be realized unless forthcoming legislation on the proposed Canyonlands National Park makes definite provision for future oil and gas exploration.

CITED REFERENCES

- Carlton, P. E., 1958, Geology and drilling history of the Big Flat-Cane Creek area, Grand County, Utah: Intermountain Assoc. Petroleum Geologists Guidebook, p. 254-256.
- Hite, Robert J., 1960, Stratigraphy of the saline facies of the Paradox member of the Hermosa formation of southeastern Utah and southwestern Colorado: Four Corners Geol. Soc. Guidebook, p. 86-89.
- Parker, J. W., 1960, Big Flat Field: Four Corners Geological Society Guidebook, p. 127-132.

Paper **39** MEXICAN HAT OIL FIELD
Relation to the Paradox Basin and
an Estimate of Future Possibilities
by Sherman A. Wengerd¹

INTRODUCTION

Geography

The Mexican Hat oil-field is located north of the San Juan River in T-40, 41, and 42-S, R-18 and 19-E, San Juan County, Utah (Figures 142 and 145). Mesas, arroyos, buttes, dry washes, and steep canyons tributary to the master canyon of the San Juan River dominate the topography. Elevations range from 3,900 to 6,200 feet. Rainfall averages about seven inches, and the master stream is snow-fed from the high San Juan Mountains of southwestern Colorado. Uranium roads and air strips have made much of the country available to the geologist, and easy access is provided by Utah State Highway 47.

Regional Geology

Except for Ordovician-Silurian strata, Cambrian to Mississippian sediments originated on the highly irregular, eastern shelf of the Cordilleran geosyncline. Pennsylvanian shelf strata genetically related to the northwest-trending Paradox geosyncline grade upward into the Uncompahgre continental detrital facies of Permian age, with sources far northeast of the Mexican Hat area. Supai deltaic beds were deposited from southerly and westerly directions and interfinger with Pennsylvanian marine carbonates, as well as medium-grained quartzose clastics, distal equivalents of coarse Cutler arkosic clastics. Erosional scarps of Triassic and Jurassic ages flank the Monument upwarp. Upper Cretaceous marine, and perhaps Tertiary non-marine, sediments close to 4,500 feet thick may have once covered this region. Erosion of the San Juan River across the Upwarp has exposed rocks of Pennsylvanian-Desmoinesian-Cherokee age athwart the axes of the Cedar Mesa anticline (Figures 143 and 144).

The dominant structure of the Mexican Hat area is the north-trending Monument upwarp (Figure 142) first named by Gregory (1917, p. 113). It is about 110 miles long and 50 miles wide, extending northward from the Black Mesa Basin in northeastern Arizona, obliquely across the northwest-trending shelf of the Paradox Basin to the vicinity of Beef Basin in southeastern Utah. The Upwarp is bounded by the Paradox Salt Basin on the north and northeast, the Blanding structural basin on the east, the Defiance uplift and Black Mesa structural basin on the south and southwest, and the Circle Cliffs upwarp, and the Kaiparowits structural basin on the west and northwest. The steeply-dipping Navajo and Wingate sandstones of Comb Ridge are near the eastern boundary of the Monument upwarp.

The Mexican Hat oil-field lies on the west flank of the Mexican Hat syncline between the Cedar Mesa anticline on the west and the Raplee anticline on the east, in the southeast central part of the Monument upwarp (Figure 142).

1. Professor of Geology, University of New Mexico

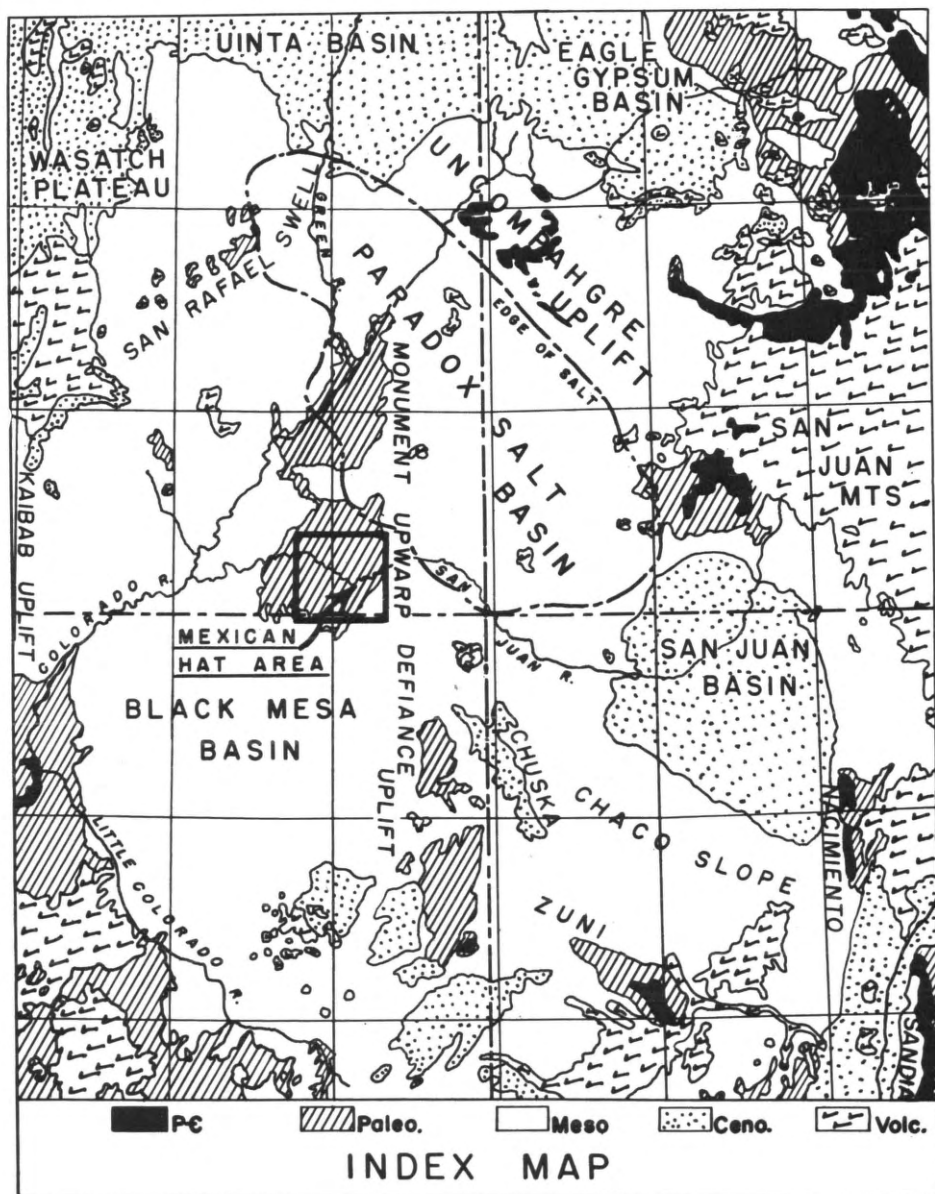


Figure 142. Index map showing Four Corners region with its uplift and basins, generalized extent of Paradox salt, and outline of Mexican Hat area.

STRATIGRAPHY

The Rico facies, highest of the better oil-bearing beds in the Mexican Hat oil field, is conformably overlain by and interfingers with Halgaito red calcareous siltstone and shale. The lower two-thirds (about 235 feet) of the Rico facies, considered to be a transgressive-regressive cyclic upper transition member of the Honaker Trail formation, contains marine lentils closely related genetically with the Honaker Trail formation (Figure 144). The name "Goodridge" formation was applied to Rico and Hermosa strata of the southern Monument Upwarp by earlier geologists--Woodruff, Miser, Bailey.

Regional correlations from type localities indicate that, in the area of Mexican Hat field and Honaker Trail type locality, the upper one-third of the Rico facies, mapped as a lower unit of the Halgaito, is of Pennsylvanian (Virgilian) age, with the lower two-thirds being of Missourian age (Figure 144).

The Rico facies of the Mexican Hat area ranges from 310 to 370 feet. The upper 106 feet (above the Shafer limestone lentil) is placed into the Halgaito shale of the Cutler group, and the lower portion is part of the Honaker Trail formation. The Rico facies comprises red to brown siltstone, red-brown calcareous sandstone which grade laterally and vertically into arenaceous limestones which have been described in detail by Bailey (1955). These calcareous sandstones produced such oil as has been found in quantity in the Mexican Hat oil field.

The canyon of the San Juan River does not expose the entire Pennsylvanian Hermosa group in the Ruplee, Goosenecks, or Honaker Trail areas; hence, no direct surface measurement of its thickness is possible (Figure 143).

The middle part of the Honaker Trail formation exposed on Honaker Trail is predominantly brown to gray, calcareous siltstone and shale, interbedded with gray, massive, cherty, lithographic to fine-grained limestone. The lower part of the Honaker Trail section is predominantly carbonate, or gray, medium-bedded to very massive, fine to coarse grained limestone with interbedded gray calcareous siltstone.

Three biohermal zones, several biostromal layers, two thin jet-black to green-black lentils, several massive dolomite lentils, and several sedimentary limestone breccias characterize the Paradox formation below Horn Point at the Honaker Trail locality (Figure 143). Several lentils of black shale, brown to gray, medium bedded, fine to medium grained dolomite, and several thin gypsum lentils of the Paradox formation correlative with similar but thinner lentils at Honaker Trail, are present in the subsurface of the Mexican Hat oil field area. Following the published work of Wengerd, Strickland, and Matheny, the Rico and Hermosa formations as originally defined by Gregory for the Mexican Hat area can be resubdivided into the Honaker Trail formation above, the Paradox formation in the middle, and the Pinkerton Trail formation at the base, above the Molas shale (Figure 144).

The Hermosa group is around 2,000 feet thick on the southern third of the Monument Upwarp, increasing in thickness northeasterly by the presence of more Paradox lentils toward the axis of the Paradox Basin.

Only four "oil sands" can be recognized on modern logs of the Honaker Trail section. Other "sands" reported to bear oil in the field cannot be identified with certainty in the exposed strata of the San Juan Canyon.

CROSS SECTION-MEXICAN HAT AREA, SAN JUAN COUNTY, UTAH

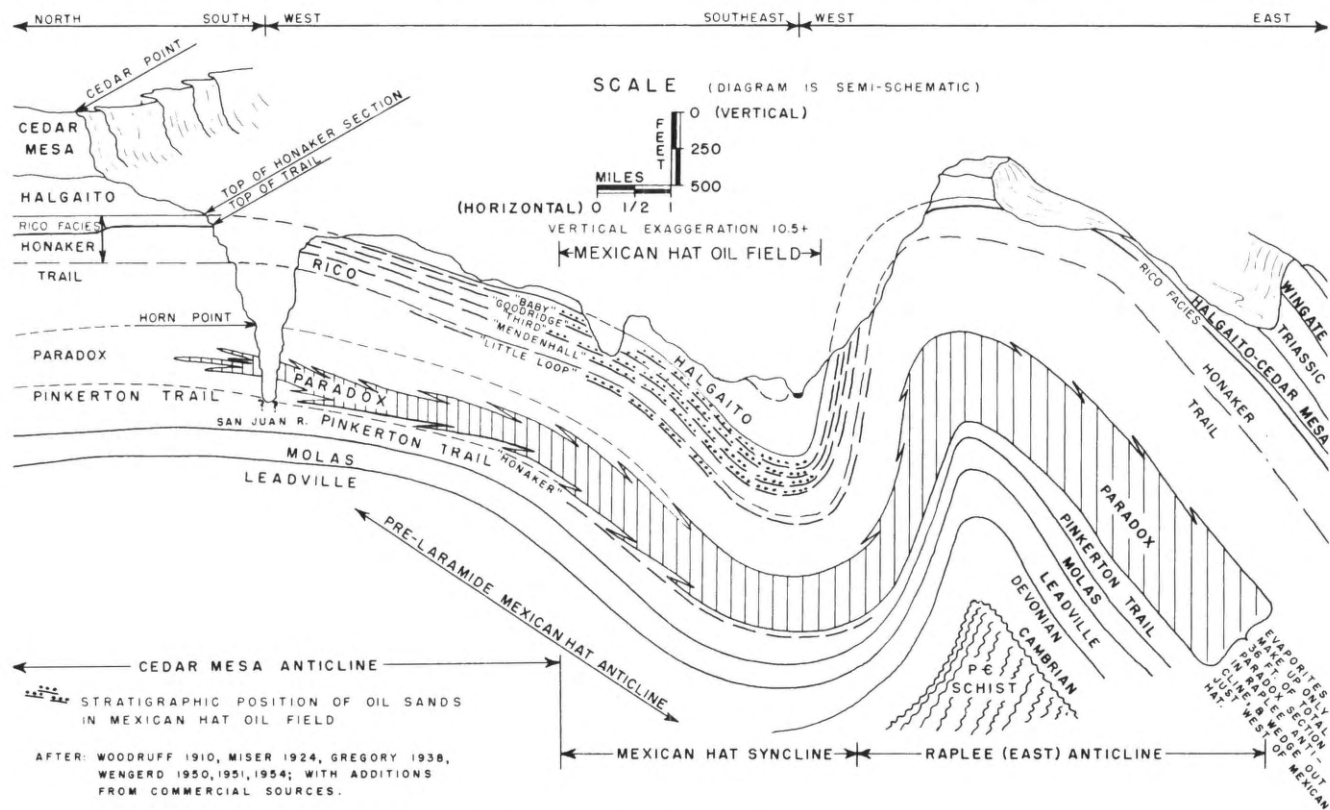


Figure 143. Cross section, Mexican Hat area, San Juan County, Utah. A semi-schematic diagram in great part scalar-controlled to show location of the older Mexican Hat "anticline", now a structural terrace on the west flank of Mexican Hat syncline and east flank of Cedar Mesa anticline. Diagram also shows stratal position of productive oil sands. The canyon at left side of oil field is an abandoned tributary to an older higher-level abandoned San Juan Canyon.

STRUCTURE

Regional Structure

The Monument Upwarp is a vast regional anticlinorium 110 miles long, north-south, and 50 miles wide. Regional structural relief above the Blanding Basin to the east is more than 5,000 feet, and the Upwarp is over 6,900 feet structurally higher than parts of the Kaiparowits Basin far to the west. The Upwarp is furrowed by synclines and anticlines of great length, high relief, and low flank dips (Figure 142). Only along the east side of the Upwarp, where Comb Ridge has easterly dips ranging from 18° to 58° , do the flanks of anticlines such as the Raplee and Lime Ridge have flank and plunge dips greater than 6° .

Good stratigraphic evidence indicates that the Monument Upwarp was the locale of a north or northwest-trending tectonic submarine irregularity or welt in the early Pennsylvanian seas (Figure 143) (Jordan, 1957, and Hinds, 1960). The Mexican Hat area was probably alternately covered by marine waters during parts of Missouri and Virgil time and open to slight subaerial erosion; however, most of the reddish-brown clastic strata are very likely marine deposits. Based on dips in later Mesozoic rocks at some distance, Gregory (1938, p. 85) concluded that the general tectonic pattern of the Upwarp could be attributed to pre-Tertiary regional crustal movement.

Rocks younger than the Wingate sandstone are stripped from the Upwarp, but it appears that the major orogeny of the area began in Laramide and continued into mid-Tertiary time, causing localized folding into anticlines and synclines (Kelley, 1958), and regional uplift to elevations from 8,000 to 15,000 feet accelerating denudation which has continued to the present time.

Local Structure of the Mexican Hat Oil Field

The oil field lies on the west flank of the Mexican Hat syncline between the Raplee anticline on the east, and the Cedar Mesa anticline on the west (Figure 143). The Raplee anticline is the southwesternmost of three prominent anticlines which line en echelon along the east flank of the Monument Upwarp (Figure 142). The San Juan River has trenched 1,325 feet into the Hermosa group of Raplee anticline, exposing black shale and gypsum clearly correlative with the Paradox formation (Figure 143) (Borden, 1952, p. 27) (Wengerd and Matheny, 1958, p. 2060-2061). This anticline is 15 miles long, 4 to 6 miles wide; the Rico facies on its crest stand about 1,400 feet above the Rico at river level on both flanks. The top of the Rico facies lies at depths from 200 to 400 feet in the deeper parts of the Mexican Hat syncline so the total structural relief is at least 1,600 feet (Figure 143).

The Mexican Hat syncline is approximately 16 miles long and 5 miles wide, with a steeply west-dipping east limb (24° - 48°) and a gently east-dipping west limb (3° - 6°). A large area of Halgaito red beds and some Cedar Mesa sandstone equivalents are preserved along the axis of the syncline. Most of the west flank of the syncline is underlain by the thin McKim limestone (Wengerd, 1950, p. 778), the mappable top of the Rico facies. The rim of some of the deeper canyons on the east flank of the Cedar Mesa anticline is upheld by the Shafer limestone, which forms the rim at Honaker Trail, is the mappable top of the Honaker Trail formation, and is found 106 feet below the Rico facies top. The mappable top of the Paradox formation in the inner gorges of the San Juan Canyon is the Hornpoint limestone (Figure 143).

PENNSYLVANIAN CORRELATIONS—FOUR CORNERS REGION

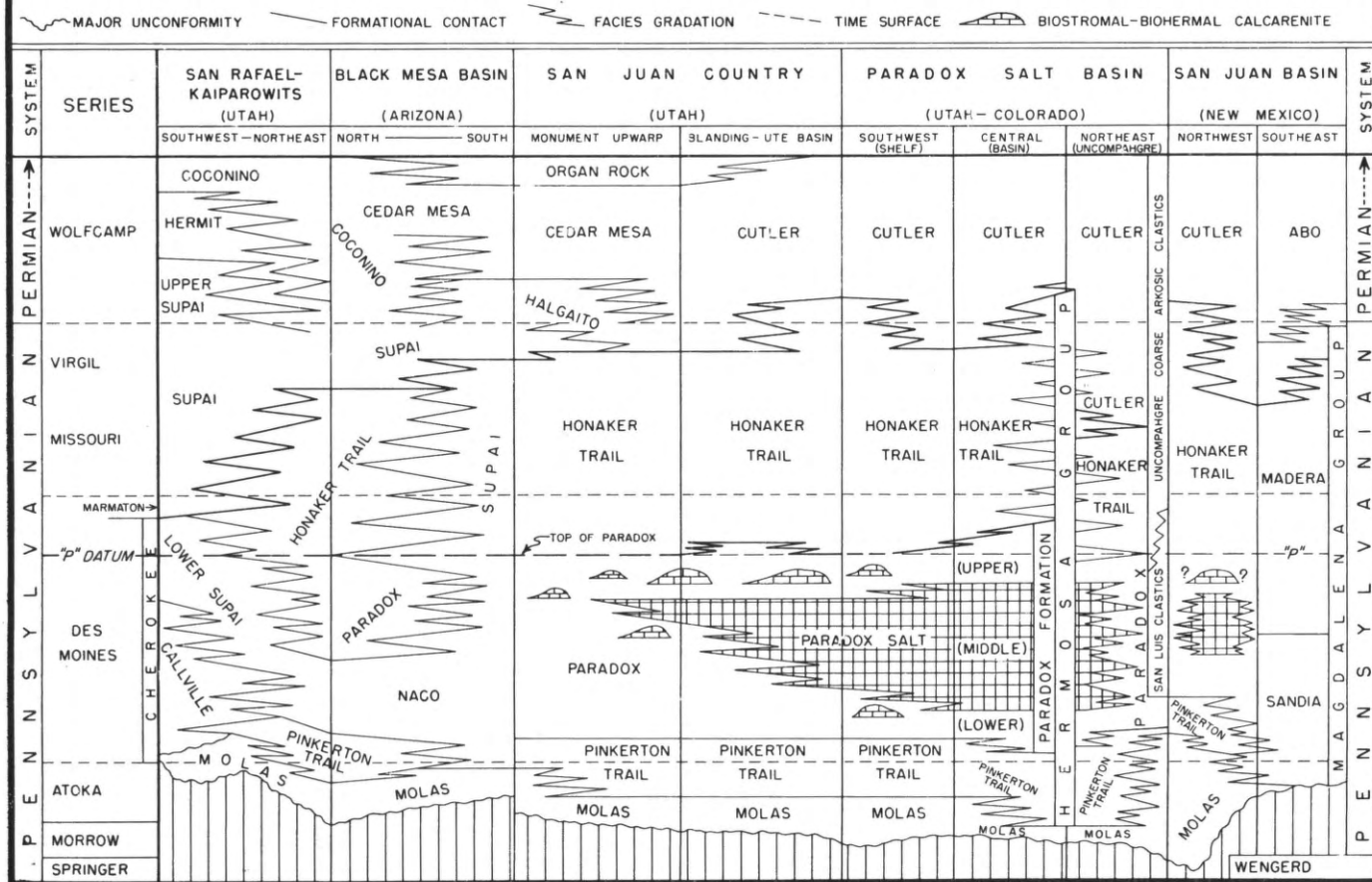


Figure 144. Pennsylvanian correlations, Four Corners region. The higher irregular facies intertonguing of the Upper Honaker Trail formation (containing associated marine Rico facies) suggests that an important part of the reason for existence of the Mexican Hat field involves facies-stratigraphic entrapment (from A.A.P.G. Symposium, "Pennsylvanian System in the United States").

Close examination of the surface structure of the oil-field reveals the presence of a sharp increase in Rico dips from 3° to 6° and 8° on the east flank of the Cedar Mesa anticline. This structural terrace may have existed as a closed anticline with a suggested northeasterly trend prior to the folding which created the prominent north-trending Cedar Mesa-Mexican Hat-Raplee structures.

The crest of the Cedar Mesa anticline is a north-trending six-mile segment of one of the longest anticlinal trends in the Colorado Plateau with "highs" which have been named Halgaito, West, Cedar Mesa, Bullet Springs, Bears Ears, and Elk Ridge.

The strongest folds show diverse-trending noses, terraces, and sinuous axes. Based on the lack of Virgil strata in many locales, and the existence of notable disconformities and peculiar variations of thickness in the upper Hermosa group and Cutler strata of the region (Wengerd-Matheny, 1958), the writer suggests that minor, though diverse-trend, critical, low-closure tectonic (non-drape) folding took place in the Monument Upwarp-Blanding Basin area as early as late Pennsylvanian-Missouri time when the Uncompahgre positive element began its rise on the northeast flank of the presently defined Paradox Salt basin.

If the above is a correct appraisal of the structural history of the Mexican Hat area, the oil field is not a synclinal one in the genetic sense, and the later synclinal structure had little control on the original oil accumulation.

OIL DEVELOPMENT

History

The history of drilling for oil in the Mexican Hat area may be divided into three parts; 1907 to 1912, 1920 to 1930, 1947 to 1960.

The maximum drilling development was from 1907 to 1912, and, according to A. L. Raplee, twenty-seven drilling rigs were actively drilling in the field on February 1, 1911. Early discovery history of the field was recounted by Woodruff (1910, p. 98-99).

The formerly active area of the oil field is shown in Figure 142; however, as pointed out by Gregory:

"The only notable production has been obtained from a few wells of small individual capacity, near Mexican Hat and Goodridge. These wells, which are named below, are all in T. 42 S., R. 19 E., within a radius of $1\frac{1}{4}$ miles of the common corner of Sections 5, 6, 7, and 8:

Hudson well, Section 5
Bryce No. 1 well, Section 6
Bryce No. 2 well, Section 6
Mexican Hat well, Section 6
Arcola well, Section 6
Crossing No. 1 well, Section 7
Monticello well, Section 7

Other wells within the same radius have bailed small quantities of oil or furnished showings of oil and north of that locality, showings of oil have been reported at various depths from scattered wells in

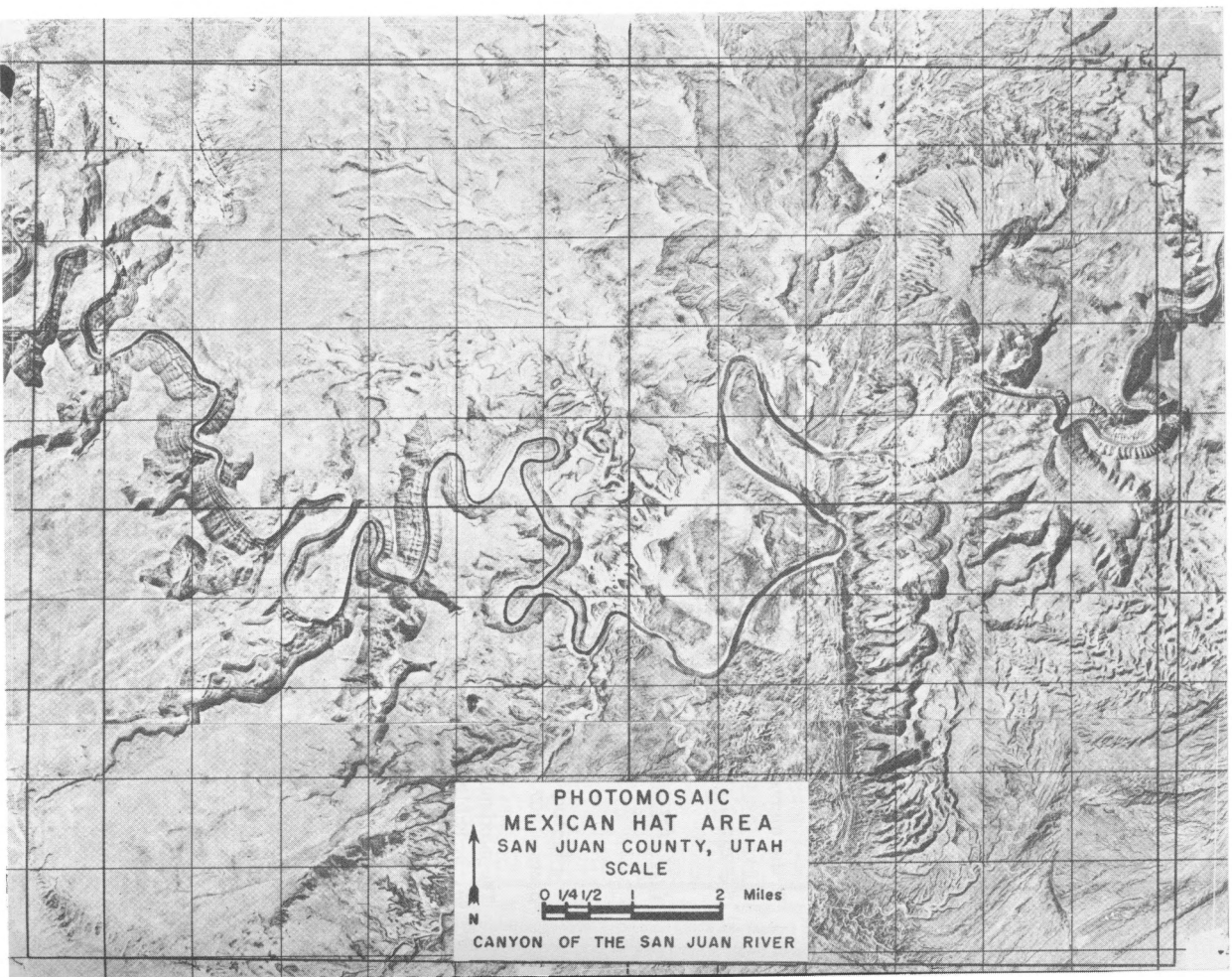


Figure 145. Photomosaic, Mexican Hat area, San Juan County, Utah. Note excellent exposures of Pennsylvanian rocks along San Juan River in Raplee anticline on right and Cedar Mesa anticline on left.

T-40-S, R-18-E; T-41-S, R-18 and 19-E. Showings of oil are also reported from wells as far west as Johns Canyon and the mouth of Slickhorn Gulch.

The production of the field has all been consumed locally. No reliable estimate of the output of the field in the period of activity is available, though records of sales from the Bryce No. 2 well show that some 5,000 barrels of oil were disposed of for field use in 1910 and 1911, in addition to many barrels of oil either wasted or consumed in drilling by the owners of the well." (Gregory, 1938, p. 112-113) (Miser, 1924, p. 142-143).

No wells drilled after the early period found commercial quantities of oil or gas, although significant shows are reported in virtually all of the wells which penetrated to the Molas shale or as deep as the Precambrian schist.

Oil Production

At least 13 wells produced commercial quantities of oil; of these, the breakdown shown in the following tabulation is believed approximately correct.

Tabulation of Production

Formational Position of Strata	Oil "Sands"	Thickness	Number of Producers	Estimate of Cumulative Oil Production
Hal- gaito	"Baby"	2'-12'	0	-----
	"Goodridge"	12'-53'?	3	10,000 bbls.
Honaker Trail	Rico Facies	"Third"	5'-6'	500 bbls.
		"Mendenhall"*	24'-40'	25,000 bbls.
		"Little Loop"***	3 1/2'	18,000 bbls.
		"Goosenecks"	35' ?	-----
Para- dox	"Blue Shale"	2'	0	-----
	"Honaker"*** (upper bioherm?)	73'	1	500 bbls.
TOTALS			13	54,000 bbls.

*also believed to be the "Arcola" and "Amber" sands.

**mainly from the Mexican Hat No. 1 well in Sec. 6, T-41-S, R-19-E, which may have found oil in fractures.

***not the "Honaker" sand as originally defined (Figure 146).

Several barrels of oil were found in all of the eight "sands" named in the field. Figures 143 and 146 show the known and inferred stratigraphic correlations of the "Arcola", "Amber", and "Goosenecks" oil zones.

An analysis of depths in relation to the measured Honaker Trail section reveals some difficulty concerning the "Honaker" oil sand which is said to "...occur just below water level at the foot of Honaker Trail" (Miser, 1924, p. 145). The Anderson, Hudson No. 1, in Sec. 5, T-42-S, R-19-E, was originally thought to be productive from the "Honaker" sand, (Mrs. Ellis Neville, personal communication, June, 1951) yet the depth of the Hudson well indicates that this production may have been obtained from the upper Bioherm (Figure 146) as recorded from Honaker Trail section measured by Wengerd and Strickland for the Continental Oil Company in June, 1951. If such is the case, the "Honaker"

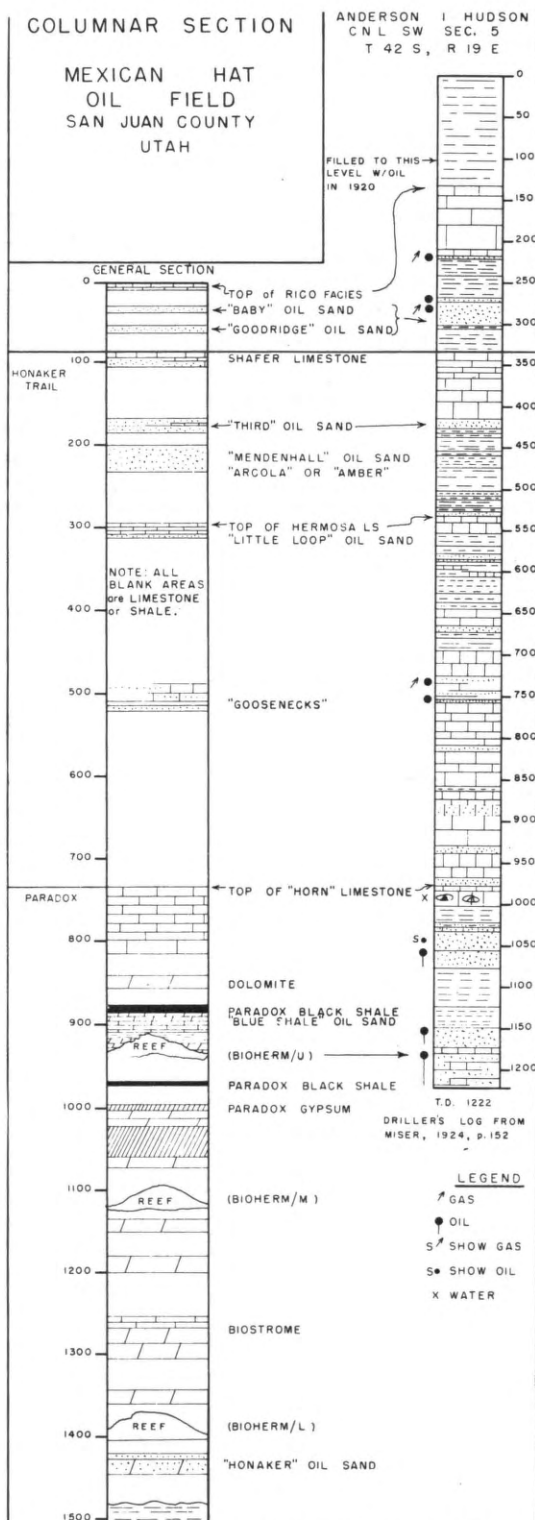


Figure 146. Columnar section, Mexican Hat field, San Juan County, Utah; shows the excellent drillers log of the Anderson Hudson No. 1 compared with a generalized log of the Honaker Trail section. Names in quotes are, or were, productive of oil in Mexican Hat field. Note that top of the Rico marine facies is higher stratigraphically in Mexican Hatfield than in outcrops at Honaker Trail. For mapping purposes the top of the Honaker Trail formation, Hermosa group, is chosen as top of Shafer limestone, a local name used by early surface geologists who worked in southeastern Utah.

oil sand was defined from Honaker Trail where it was never seen but where it was inferred from an oil seep discovered in sand bars of the San Juan River 1 1/2 miles southeast of the head of Honaker Trail (Miser, 1924, p. 140). Data available indicate that the "Honaker" oil sand was not tested by any well drilled in the main productive part of the Mexican Hat oil field.

Cumulative oil production seems not to have exceeded 60,000 barrels, although the statements ascribed to "old-timers" placed the total oil production to 1950 at "over 75,000 barrels of oil." The field could not be considered an economical producer. As late as 1950, two shallow wells were being drilled, and a few barrels of oil were being produced from three other shallow wells.

Below is a tabulation of the gravities of oil obtained from the oil field:

<u>Well</u>	<u>Formation</u>	<u>Gravity Be</u>	<u>Source of Data</u>
Not given	Not given	29.9°	Gregory, 1909, p. 24.
Oil City	"Baby"	38.0°	"
*Bryce 2	"Mendenhall"	35.5°	" p. 25.
Goodridge 4	"Goodridge"	39.4°	Woodruff, 1910, p. 94.
Jackson 5	"Little Loop"	38.4°	" " "
Hudson 1	"Goodridge"	40.7°	" " "
*Bryce 2	"Mendenhall"	36.9°	" " "
Mexican Hat 1	"Little Loop"	47.0°	" " "

*appear to be two different measurements of oil from the same well.

The first entry in the above tabulation probably represents "weathered" oil analyzed some time after its collection. Variations in gravity among the various "sands" are not great, and could be expected to represent differences in reservoir conditions. The differences between the oils from the "Little Loop" oil sand in the Jackson 5 (38.4° Be) and the Mexican Hat (47.0° Be) are not easily explained. Correlations prove that the "Little Loop" oil sand lies in a sandy phase directly below the top of a massive limestone in the upper part of the Honaker Trail formation. The productive history of these two wells, located only one and one-half miles apart, is greatly dissimilar. The Mexican Hat No. 1 accounts for 90% or more of all commercial oil produced from the "Little Loop". This very thin, discontinuous reservoir is a porosity-variation trap; however, both the gravity and production differences suggest a possible increase of porosity by fracturing at the "crest" of the terrace-flexure on which the Mexican Hat No. 1 was drilled. Further conjecture might suggest vertical migration of oil into the "Little Loop" fracture-reservoir from deeper Honaker Trail sandstones, Paradox dolomite, or biohermal-biostromal lentils.

Character of Reservoir Strata

The porosities and permeabilities of the calcareous sandstones vary greatly. Oil distribution is "patchy," ranging from oil in fractures to intergranular oil whose distribution is controlled by differences in the calcite-cement distribution. The reservoirs in the Rico facies are predominantly buff to brown and brownish-gray calcareous sandstones, whereas the reservoirs below the Rico facies are arenaceous limestones, and calcarenite or sedimentary reef breccias. The "Mendenhall" sandstone is the best oil producer in the Rico section, whereas the anomalous "Little Loop" sandy limestone is the best reservoir in the Honaker Trail formation of the Mexican Hat field. Although the productive layers, despite lithologic variation, can be correlated over a rather wide area from the

Honaker Trail exposures on Cedar Mesa anticline to the subsurface section in the Lime Ridge anticline, the production from these strata vary from well to well. Obviously, all of the reservoirs vary greatly in porosities and permeabilities. It appears that the greatest single factor in oil entrapment is a series of discontinuous, variable porosity traps, unrelated to present structural disposition, but possibly genetically related to marine winnowing of sediments of an old late Pennsylvanian fold (Figure 143).

Origin of Mexican Hat Oil

Fossil content and the discontinuity of porous sections in these upper Pennsylvanian sandstone and limestone lentils suggest an in-place origin of the oil, with some possibility of vertical migration of oil through fractures related to the pre-Laramide Mexican Hat anticline. Original depositional and diagenetic variations related to westward wedging of the Rico Facies sandstones, whose sources lay in the Uncompahgre and Defiance uplifts, are responsible for entrapment of the oil seemingly unrelated to the prominent Laramide and Tertiary structures of the region. That some relief of original compactional and hydrostatic pressures in these oil accumulations occurred as a result of breaching of later Laramide and Tertiary anticlines by the entrenching San Juan River and its tributaries, cannot be doubted. This factor was first mentioned by Gregory (1909, p. 23), elucidated by Woodruff (1910, p. 96-97), mentioned by Miser (1924, p. 146), further detailed by Gregory (1938, p. 113), and finally analyzed by Storm (1949, p. 62), as a regional control in all above-river-level oil accumulation in the region of southeast Utah.

Despite the fact that the numerous extinct oil seeps in the San Juan Canyon virtually prove that an entrenching river will release oil from a reservoir by direct breaching, or by crossing minor faults which cut a reservoir, the relatively discontinuous nature of effective porosity in these high-shelf reservoir strata militate against a regional draining of all reservoirs which stand above the present level of the San Juan River. There can be little doubt that intake of meteoric and river water on the west limb of Raplee anticline and the east limb of Cedar Mesa anticline resulted in holding oil in hydrodynamic balance on a structural terrace west of the deepest part of the Mexican Hat syncline (Figure 143).

Future Developments

In 1910 Woodruff stated that:

"... all the wells containing more than a good 'showing' of oil are in the syncline, (hence) it is believed that the basin structure probably contains most of the oil." (p. 103).

He noted that very little gas was present with the oil, and other reports state that only the first well, Crossing No. 1, was a "gusher". Woodruff (1910, p. 104) suggested that the following area had the most favorable conditions for developing added reserves:

T-42-S, R-18-E, Secs. 23*, 23*, 25*, 26, 35, 36*
T-41-S, R-19-E, Secs. 19*, 20*, 21, 28, 29, 30*, 31*, 32
T-42-S, R-18-E, Secs. 1*, 2, 11, 12, 13, 14, 24
T-42-S, R-19-E, Secs. 5*, 6*, 7*, 8*, 17, 18, 19, 20

The sections marked with an asterisk have been partly or wholly tested since 1909 in one or more of the oil sands, and the underlined sections have been found productive of some additional oil.

According to Miser (1924, p. 147):

"... (because of) the extensive prospecting, the small production and the deep trenching of the oil field by San Juan Canyon, only small flowing wells, or perhaps fairly good pumping wells may be expected in the prospected sands within the limits of the present field. No large producing wells may be expected in the field unless they are discovered by drilling deeper into the Goodridge (Rico and Hermosa), whose entire thickness is not known, or by drilling in adjoining areas."

A southernmost part of the Mexican Hat oil field was sold to Ellis and Conway interests in 1953. Several additional shallow wells were drilled in 1954, one of which, the Ellis No. 2, was completed for two barrels of oil per day from the "Goodridge". Completion data on this well, and behavior of all other wells on which data could be assembled, leave no doubt that the present reservoir pressures are a combination of gravity drainage and some hydrodynamic pressure.

If this analysis of the structural history is correct, small oil producers might be economically and successfully completed in Sections 7, 8, 18, and 19, T-42-S, R-19-E, and possibly in Sections 13 and 14, T-42-S, R-18-E, south of the San Juan River.

With new completion techniques involving sand-oil-frac or acid-frac, any one or all of the Mexican Hat "oil sands" in the sections listed above might yield commercial quantities of oil south of the San Juan River. Additional engineering studies are necessary before conclusions can be reached along these lines.

Also, possibilities favor encountering deeper reef zones correlative with the Paradox bioherms exposed in the San Juan Canyon to the west of the oil field (Wengerd, 1951). Shows in pre-Pennsylvanian strata in the deep well drilled in the heart of Raplee anticline ("Soda Basin") just north of San Juan River suggest oil and gas possibilities in those strata within the Mexican Hat field.

CONCLUSIONS

The Mexican Hat oil field has produced small quantities of oil, under low pressure, without appreciable quantities of gas, in at least eight lentils within the upper Pennsylvanian section.

The structure of the oil field is a north-trending terrace-steepening on the gentle west flank of the sharply folded asymmetric Mexican Hat syncline. Reservoirs of variable porosities within calcareous sandstone, biostromal and biohermal limestone, and dolomite may lie athwart a pre-Laramide Mexican Hat anticline, later tilted into a steepened structural terrace. This terrace was breached by the San Juan Canyon during Tertiary time which released some of the original reservoir pressure and allowed some gravity drainage (eastward shift) of oil from the reservoir beds. Oil within these beds is thought to have originated in place. Hydrodynamic pressures from the outcrops in the west flank of Raplee anticline probably aided in holding the oil on the east flank of the Cedar Mesa anticline.

Drilling south of the San Juan River may result in the discovery of small commercial quantities of oil if the wells are carefully located, drilled, and brought in with modern completion techniques.

CITED REFERENCES

- Bailey, J. S., 1955, A stratigraphic analysis of Rico strata in the Four Corners Region: Univ. of Arizona, Ph.D. thesis.
- Baker, A. A., 1935, Geologic structure of southeastern Utah: *Am. Assoc. Petrol. Geol.*, v. 19, p. 1472-1507.
- _____, 1936, Geology of the Monument Valley-Navajo Mountain region, San Juan County, Utah: U.S. Geol. Survey Bull. 865, 106 p.
- Borden, J. L., 1952, Paradox Member of the Hermosa formation: *Geol. Symposium of Four Corners Region*, Four Corners Geol. Society, p. 27-35.
- Gregory, H. E., (1909) 1911, The San Juan oil field, San Juan County, Utah: U.S. Geol. Survey Bull. 43, p. 11-25.
- _____, 1917, Geology of the Navajo country: U.S. Geol. Survey Prof. Paper 93, 161 p.
- _____, 1918, The San Juan Country: U.S. Geol. Survey Prof. Paper 188, 123 p.
- Hauptman, C. A., et al., 1949, Location plots of wells drilled in Utah: Oil and Gas Possibilities of Utah, Utah Geol. and Mineralog. Survey, p. 127-128.
- Hinds, J. S., 1960, Controls for Paradox Salt deposition in the area of Comb Monocline, San Juan County, Utah: Univ. of New Mexico, M.S. thesis.
- Jordan, Jack, 1957, Correlation of reef calcarenites of the Pennsylvanian Paradox formation, San Juan County, Utah: Univ. of New Mexico, M.S. thesis.
- Kelley, V. C., 1958, Tectonics of the region of the Paradox Basin: *Intermountain Assoc. Petroleum Geologists 9th Ann. Field Conf.*, p. 31-38.
- _____, 1961, Mexican Hat field, San Juan County, Utah: *Intermountain Assoc. Petroleum Geologists, Symposium of Oil and Gas fields of Utah*.
- McCoy, A. W., Sielaff, R. L., Downs, G. R., Bass, N. W., and Maxon, J. H., 1951, Types of oil and gas traps in Rocky Mountain region: *Am. Assoc. Petroleum Geologists Bull.*, v. 35, p. 1000-1037.
- Miser, H. D., 1924a, Geologic structure of the San Juan Canyon and adjacent country, Utah: U.S. Geol. Survey Bull. 751-B, p. 115-155.
- Quigley, W. D., 1958, Aneth field and surrounding area: *Intermountain Assoc. Petroleum Geologists 9th Ann. Field Conf., Guidebook*, p. 247-253.
- Storm, L. W., 1949, Oil and Ground Water in High Rocky Mountain structures: *Mines Magazine*, v. 39, no. 12, p. 62-64.
- Wengerd, S. A., 1950, Photogeologic characteristics of Paleozoic rocks in the Monument upwarp: *Photogram. Eng.* v. 16, p. 770-781.
- _____, 1951, Reef limestones of Hermosa formation, Utah: *Am. Assoc. Petroleum Geologists Bull.*, v. 35, p. 1038-1051.
- _____, 1955, Biohermal trends in Pennsylvanian strata of San Juan Canyon, Utah: *Four Corners Geol. Soc. Field Conf. Guidebook*, p. 70-77.
- _____, 1962, Pennsylvanian sedimentation in Paradox Basin, Four Corners Region: *Am. Assoc. Petroleum Geologists Pennsylvanian system in the United States*, p. 264-330.
- Wengerd, S. A., and Matheny, M. L., 1958, Pennsylvanian system of Four Corners region: *Am. Assoc. Petroleum Geologists Bull.*, v. 42, p. 2048-2106.
- Wengerd, S. A., and Strickland, J. W., 1954, Pennsylvanian Stratigraphy of Paradox Salt Basin, Four Corners region, Colorado and Utah: *Am. Assoc. Petroleum Geologists Bull.*, v. 38, p. 2157-2199.
- Woodruff, E. G., 1910, Geology of the San Juan oil field, Utah: U.S. Geol. Survey Bull. 471, p. 76-104.

Paper 40 OIL AND GAS OBJECTIVES WORTHY OF EXPLORATION IN SAN JUAN COUNTY (not covered by previous papers in this volume)

by Dorsey Hager

East of the Colorado River and south of T-30-S, SLB & M, there lies a considerable area beyond the limits of the Lisbon Dome, the Greater Aneth area, and the Old Mexican Hat oil field, discussed in the papers of this volume by Kunkel (Paper 37), Carter (Paper 35), Hafeman (Paper 36), Wengerd (Paper 39), Welsh (Paper 41), and Quigley (Paper 34). Carter has confined his discussion largely to the Desert Creek zone of the six townships square in the southeast corner of Utah. Hafeman, while covering the entire Paradox Basin, treats only the Ismay zone of the Pennsylvanian. Welsh focuses attention on the character, extent, and significance in oil finding of the salt disconformities in the Paradox. Kunkel discusses the Lisbon-Big Flat trend, and Wengerd discusses the Mexican Hat area. Quigley discusses the broad features developed through geophysics and geology. Also, Quigley's paper should be carefully studied for its implications of unconformities in the Pre-Pennsylvanian beds. It is a fruitful paper, deserving much consideration. Beyond these areas and below the Post-Mississippian zones discussed by others in detail, are other objectives worthy of consideration. This paper is designed to give a general summary of some of these objectives in San Juan County that have thus far not been discussed in this symposium.

A hundred or more test holes have been drilled in the area under discussion into and through the Mississippian beds. Some thirty of these tests have penetrated the Devonian beds (Figure 147) and a number have penetrated Cambrian and Precambrian rocks. Some of these tests were situated on surface structural features, others on seismic highs. In the main, most of the holes could be classed as combinations of structural and stratigraphic tests.

Aside from the Lisbon-Big Flat fields, the only production from the Mississippian beds occurs far to the south in Texaco's A.E. Navajo in Sec. 19, T-43-S, R-21-E, San Juan County. This well produces from the Leadville limestone at 6,910-6,922 feet. Initial production was given as 47 bbls. of oil, 105 bbls. water per day, A.P.I. gravity 39.3. The hole penetrated the Elbert formation (Devonian), but no McCracken sandstone production was found. This test is well down the southwest flank of the Chinle Wash Field.

Texaco Inc. also drilled a deep test on a high in the producing area in the Aneth field, No. D-30 Navajo, in Sec. 20, T-40-S, R-24-E. This test penetrated the Mississippian, the Devonian, and the Cambrian, and ended in Precambrian rocks, but found no oil below the Pennsylvanian beds, although non-inflammable gas was encountered in the Leadville at 6,666-6,840 feet, also some water deeper in the Leadville, and water in the Devonian 7,204-7,428. The Aneth was topped at 7,455, the Tapeats sandstone at 7,616, and the Precambrian 7,870-7,885. This test is an especially interesting one, and at once raises the question of whether the structural high in Pennsylvanian beds is reflected in the Pre-Pennsylvanian beds, or whether there is a marked discordance. Additional tests will, no doubt, be made, or old holes deepened later as the Pennsylvanian production declines.

1. Consultant, Salt Lake City, Utah.

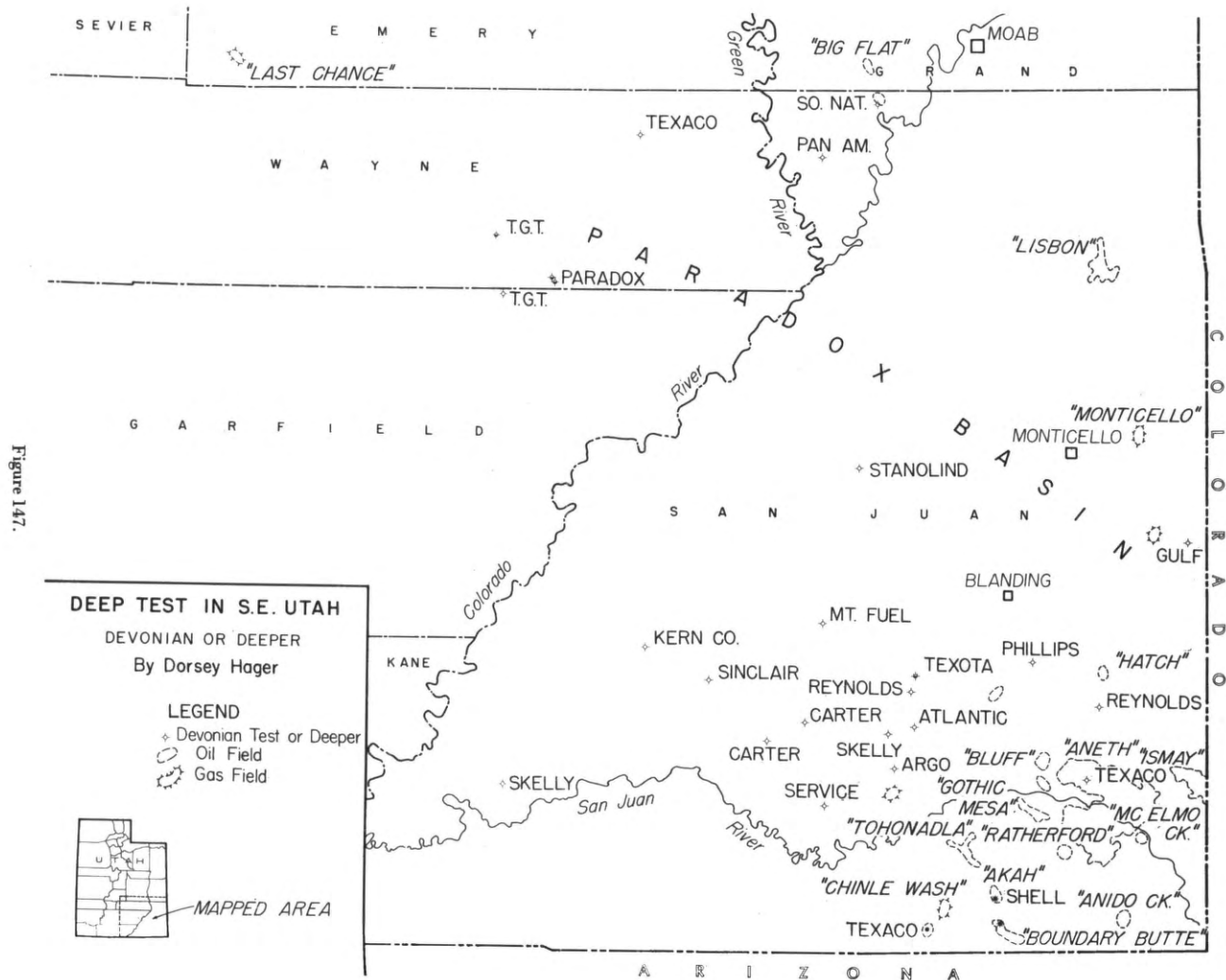


Table XXI. Stratigraphic Table.

PERIOD	SERIES		CHARACTER	THICKNESS	REMARKS
PENNSYLVANIAN	Des Moines	Unconformity	White to tan l.s.; oolitic cherty	375-450'	
MISSISSIPPIAN	Meramec	Leadville (Redwall Madison)	Finely crystalline l.s., dolomite, gray and brown bright green, sandy, waxy shale	370-500'	Correlates with Redwall of Grand Canyon which carries oil in Garfield Co., Big Flat, and Lisbon, and good shows in San Juan County
DEVONIAN	Upper	Ourray l.s.	Gray and brown argillaceous l.s. some glauconitic, green, waxy sh.	0-250'	
		Upper member	Dol. gray-green shale red shale	0-300'	
		McCracken s.s.	Massive dol. glauc. some siltstone and dk. shale glauc. s.s.	0-500'	Sandstone productive at Lisbon
		Ignacio			
		Aneth	Limestone, dol. shale	0-300'	
SILURIAN AND ORDOVICIAN		Absent?			
		MAJOR UNCONFORMITY			
	Upper	Lynch Dol.	Mass. dol., dns. suc., glauc., sm. xln., minor thin micac. sh.; small siltst. and s.s. locally	0-1500'	might carry porous pay streaks
	Middle	Bowman Hartman l.s. (undiff)	Mass. ls., gr. dense, arg., locally glauc., w/minor stks. micac., glauc. sh. and dol.	0-800'	might carry porous pay streaks
		Ophir FM	Bedded sh., gr-grn. red micac., commonly sdy. w/stks. dol., ls., and s.s.	0-375'	
	Lower	Tintic s.s. (Tapeats)	Mass. s.s., wh., grn. mar., red, fn., dn. tovy. crs., sm. glauc. locally basal 50-70', feldspathic	0-550'	Possible resevoir
		MAJOR UNCONFORMITY			
PRE-CAMBRIAN			Schists, shales, s.s. and granitics		Possible but not likely

Cambrian beds cannot be ruled out. First, oil might be indigenous to them at places, and, second, they could act as reservoirs for migratory gas or oil from Mississippian and Devonian beds. Porosity and permeability are known to be present in the dolomites and sandstones of Cambrian age, which necessarily forces the conclusion that, given proper structural or stratigraphic traps, gas and oil could be found. The Cambrian shales and limestones interfinger towards the east with the Tapeats sandstone, which latter is a transition zone from Lower Cambrian through the Upper Cambrian, and is even correlated by some stratigraphers as equivalent to the Ignacio quartzitic sand of Colorado. This interfingering forms a good channel for lateral migration from west to east.

Tests on the Nequoya arch in the northwest part of the area shown on Figure 147 penetrated Precambrian beds. Quigley's paper deals with several of these penetrations where soft shales and porous sandstones were surprisingly encountered in the stratigraphic section. Drilling time in those rocks was little different from rocks higher in the geologic column. (See Table XXI) However, tests to Precambrian or other metamorphosed rocks should not be undertaken unless a favorable geological section that has a gas or oil producing history overlies the lower rocks. It is also possible, but not likely, that oil could originate from organic matter in Precambrian beds, especially those of the Belt Series (Upper Precambrian) if they are not metamorphosed. Such rocks in places do contain fossil algae and other simple forms of past life, although so far, little fossil evidence of such nature has been found in the Belt Series in Utah.

Testing to Precambrian rocks is not at all revolutionary, as some large oil companies, at present, consider such tests routine procedure. In eastern Kansas, a number of oil fields have been found in Precambrian beds, and in California in Jurassic schists.

In conclusion, possibilities for gas and oil for three series and the Precambrian rocks are classed in order of importance as follows:

Series	Chances of Production	Remarks
1. Mississippian	Good	Lisbon-Big Flat, Southern San Juan County.
2. Devonian	Fair	Only Utah production so far at Lisbon
3. Cambrian	Slight	None so far
4. Precambrian	Very slight	None so far

This is an arbitrary evaluation. However, all four classifications are within the range of possibilities, although the third and fourth are given little weight. It is sufficient to state that the area discussed in this brief paper justifies far more testing below the Pennsylvanian beds, and that numerous new gas and oil fields should be found in those deeper Paleozoic rocks.

Paper 41 PARADOX BASIN SALT DISCONFORMITIES (AND THEIR RELATIONSHIP TO OIL PRODUCTION)

by John E. Welsh¹

THEORIES OF SALT DEPOSITION

Several mechanisms and physical situations have been suggested by different writers to explain the occurrence of evaporites in the Paradox Basin. This paper reviews two widely held concepts and, in the light of detailed stratigraphic data accumulated by the writer, proposes a new concept to explain the Paradox evaporites.

Lateral Facies Concept

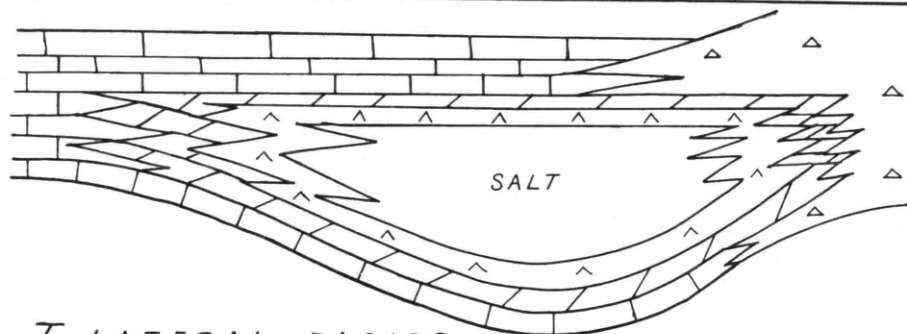
Herman and Barkell (1957, p. 868) state, "The individual evaporite sequences extend not only vertically through time, but horizontally at any one time. Hence, it may be expected that halite will grade toward less restricted conditions near entrance or entrances to the basin, into anhydrite, dolomite, and finally limestone." This relationship is shown diagrammatically in Figure 148. Carbonates around the Paradox Basin margin were shown by these writers to grade laterally into evaporites toward the center of the basin. Using their lateral facies concept, Herman and Barkell correlated the Desert Creek and Ismay intervals at the southern end of the basin with salt beds in the center of the basin.

Reef Barrier Concept

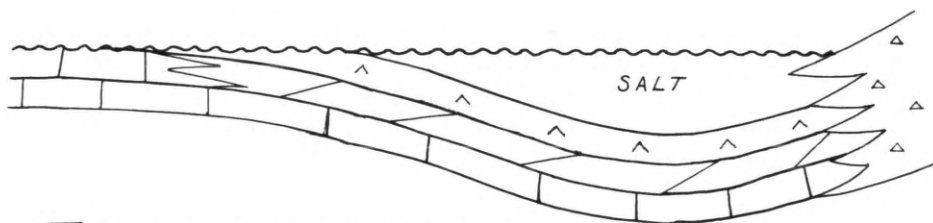
Clair (1958, p. 44) discusses the presence of a barrier reef along the margin of the Paradox Basin: "This (reef) continued to grow and finally reached such proportions that it created a barrier, causing interruption of normal marine circulation. This caused the basin behind the reef to become evaporitic, thus triggering the formation of the Paradox evaporite basin." Clair proposes the existence of two reef trends with a maximum thickness of over one hundred feet in the Four Corners area. To this writer's knowledge, no such formidable reef structure (Figure 148) has ever been encountered in the subsurface of this area. The few reefs that are known are only a few feet thick and at most a few tens-of-feet long.

Both of these concepts rely on considerable imaginative interpretation. If either concept is tested by faunal, lithologic, and radioactive correlative data, immediate problems are encountered. The lateral facies concept requires a mechanism by which calcium carbonate, calcium magnesium carbonate, calcium sulphate, and sodium chloride may be extracted from the same body of sea water at differing positions within the confined basin. This process necessitates density stratification of the sea water and assumes the existence of a deep basin. None of the sediments in the basin, however, suggest deep water. The euxinic black shales interbedded with the salt beds contain phosphatic brachiopods, conodonts, fish remains, plant imprints, and coal, which are not indicative of deep water. The writer's interpretation of the salt basin is one of shallow water in which the concentration reached and remained at saturation for the particular salt until the observed thickness of the individual evaporite unit was deposited.

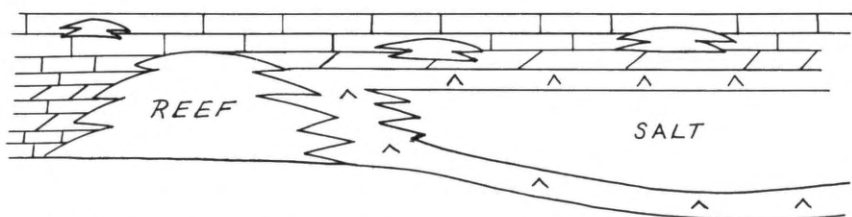
1. Ph.D., Colorado State University, Fort Collins, Colorado.



I. LATERAL FACIES
CONCEPT



II. SALT UNCONFORMITY
SUBSIDENCE CONCEPT



III. REEF BARRIER
CONCEPT

Figure 148. Three concepts used by various authors to explain the occurrence of the evaporites of the Paradox basin.

Faunal correlation of fusulinid zones in the limestones across the supposed reef barrier of Clair (1958) does not show appreciable variation in stratigraphic thicknesses from well to well. The separate zones show remarkable parallelism, and the variation in stratigraphic intervals that occurs does not seem to warrant an interpretation of reef growth. Certainly reef-building organisms are encountered in the subsurface limestones, but not in such proportions to suggest a reef barrier rimming the basin.

Salt Unconformity Subsidence Concept

Figure 148 illustrates a disconformity which the writer believes exists above each salt bed in the Paradox basin. According to this interpretation, there is no major lateral facies change. The sequence of limestone, dolomite, anhydrite, and salt exists only in the vertical dimension. Of the sequence, salt has the smallest aerial extent and is represented on the margins of the basin by a hiatus or a minor disconformity. Each salt bed then represents a period of minimum contraction of the area receiving sediments. The only lithologic type that interfingers with the salt is clastic arkose and silt from the eastern margin that was eroded from the Uncompahgre uplift.

Subsidence of the area along the axis of the basin and parallel to the Uncompahgre is paramount in allowing the thick salt beds to accumulate. Subsidence along this linear trend draws in sea water to replenish the salt which is precipitating from the saturated solution. The only possible direction from which this sea water could come is the southeast. A barrier does not have to be imagined, since the basin is a linear trough surrounded by an essentially horizontal plane along the southwest and west and by the land mass of the Uncompahgre to the northeast.

Through the use of fusulinid zones, it is possible to sub-divide the lower Des Moinesian rocks into those sediments deposited before and those deposited immediately after the evaporite deposition (Welsh, 1958). Figure 149 shows this correlation from near the center of the basin at the Reynolds Gibson Dome well, Sec. 35, T-29 1/2-S, R-20-E, to the Paradox Production well, Sec. 34, T-30-S, R-13-E, then to the Amerada Blue Mesa well, Sec. 8, T-29-S, R-10-E. This cross section is approximately perpendicular to the lithofacies boundaries and should show lateral interfingering if it exists. As the faunal correlation shows, the entire evaporite sequence, which reaches over 4,000 feet in the center of the basin, is represented by less than 100 feet of section in the Amerada Blue Mesa well. Within this 100 feet of section, the salt disconformities exist. Most of the western shelf margin from the Paradox basin to the Wasatch hinge line must have lain exposed while salt precipitated in the subsiding trough. If isopachous maps are used to define highs, it is easy to understand why Herman and Sharps (1956) postulated the "Emery Uplift" at the site of the present San Rafael uplift. The writer believes the "Emery Uplift" to be part of the non-depositional area of the western shelf of the Paradox basin and not a high during Des Moinesian time.

These salt disconformities are more than subsurface interpretation. At Honaker Trail the salt disconformities may be observed in the outcrops of the canyon walls. To observe these minor disconformities, it is important to correlate the surface section at Honaker Trail with the subsurface oil-producing intervals. The top of the Desert Creek interval is located at the top of "Horn Point" limestone (Welsh, p. 155). Below the black shale and argillaceous limestone that lie immediately beneath the Desert Creek interval, there are many conspicuous

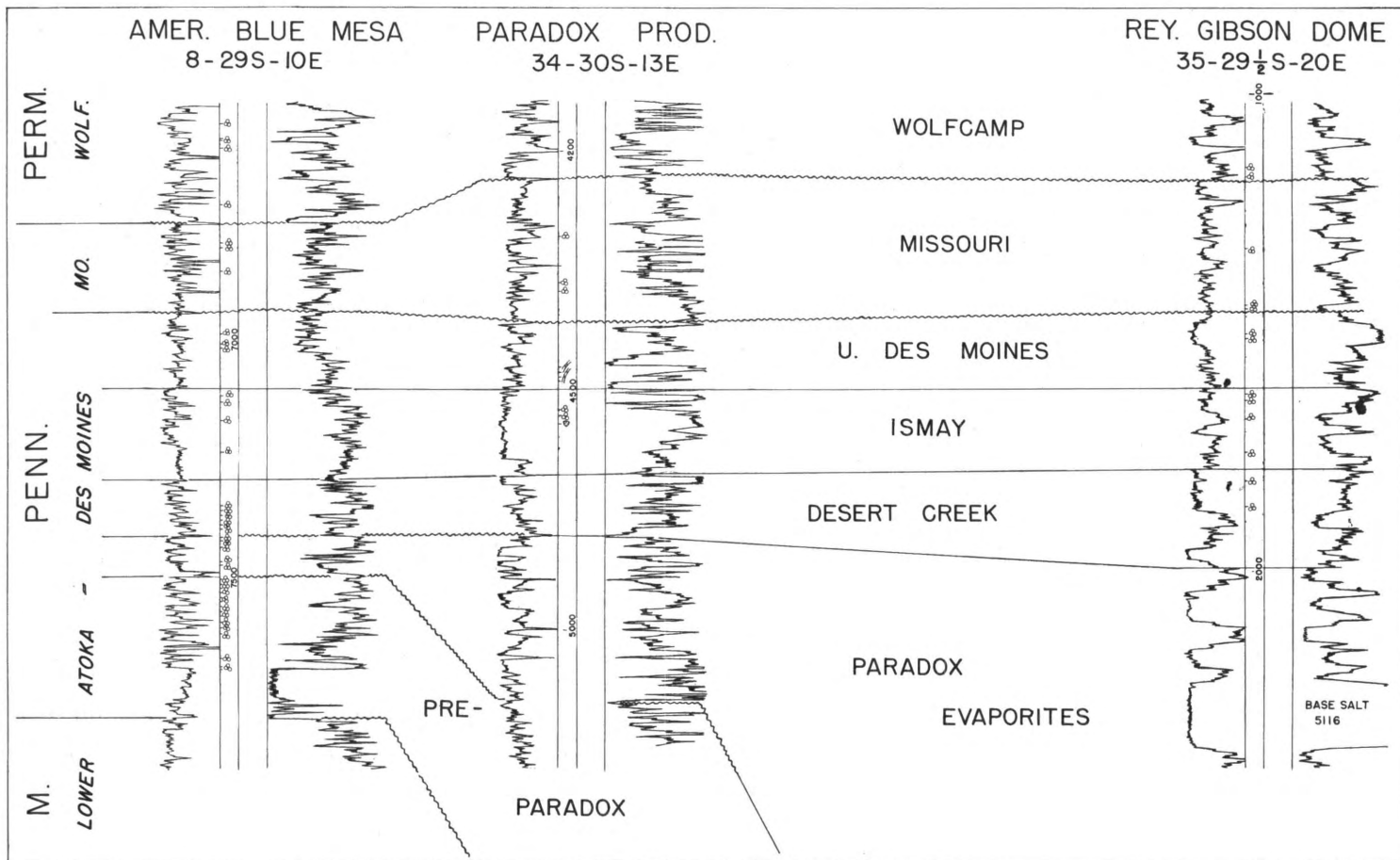


Figure 149. Correlation of the sediments deposited immediately before and after the deposition of the evaporites of the Paradox basin.

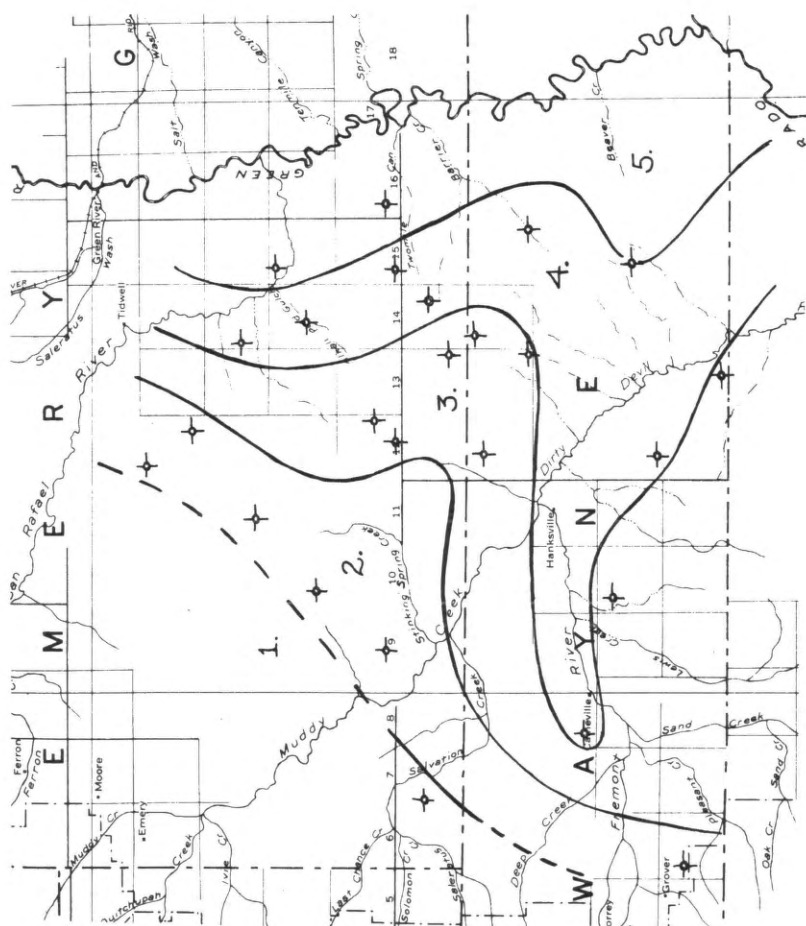


Figure 150. That part of the Paradox Basin adjacent to the San Rafael Swell.

sedimentary structures which suggest disconformities. Channeling, truncated bedding, slump and controlled bedding, and intraformational breccia are common in these limestones. Nodular-weathered limestone intervals suggest possible "B" horizons of soil profiles which formed on the emergent limestone beds while salt was being deposited nearer the center of the basin.

Of the three idealized concepts illustrated in Figure 148, the salt unconformity subsidence concept appears to be the sequence which most nearly fits the Paradox basin salt deposition.

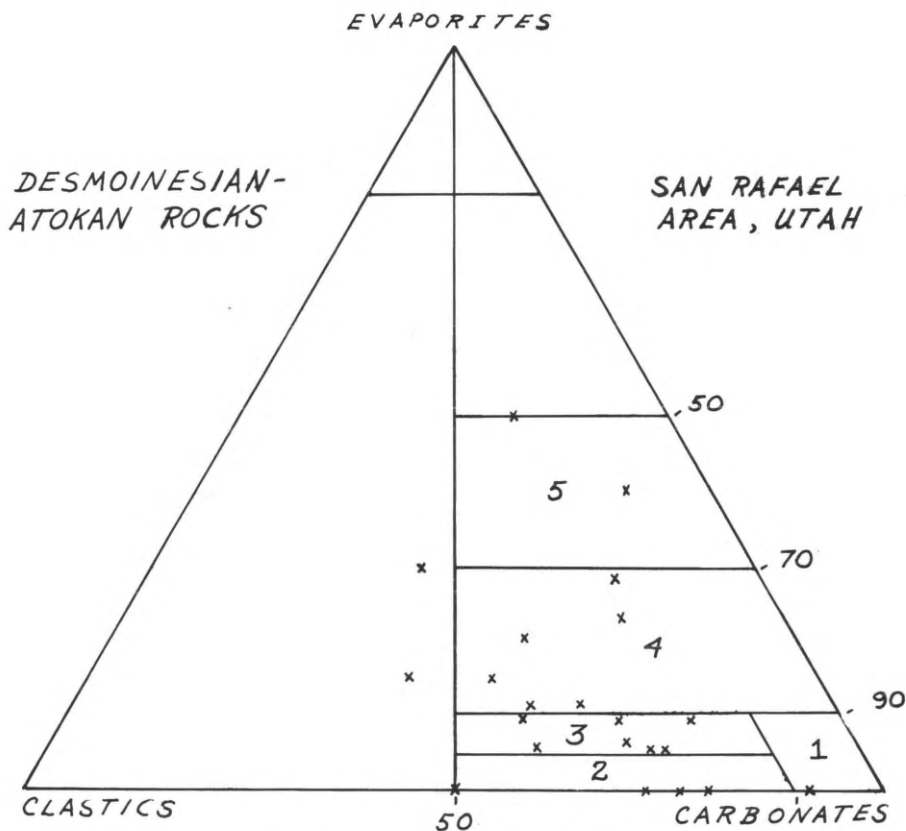


Figure 151. Evaporite-Clastic-Carbonate Triangle, showing statistical trends of the Atokan-Desmoinesian rocks in Emery, and Wayne Counties, Utah.

LITHOFACIES INTERPRETATION

Figure 150 illustrates the area of the Paradox basin adjacent to the present San Rafael uplift. By using the evaporite-clastic-carbonate triangle, definite statistical trends may be mapped for the Atokan-DesMoinesian rocks in Emery

and Wayne Counties, Utah. However, the use of this large stratigraphic interval ignores the detailed relationship which the salt disconformities play in selecting areas for potential oil production.

This area shows an embayment or east-west evaporite arm of the main basin in the Hanksville-Caineville area. According to the lateral facies concept, area 3 would appear to be most attractive for oil exploration; however, according to the salt disconformity concept, both the pre-Paradox carbonates and the Desert Creek-Ismay intervals have widespread shallow shelf or shoal lithology and do not undergo rapid lateral facies changes. These limestones are generally very fine grained, sandy, and lithographic, with low porosities and permeabilities. Bioclastic limestones are in the minority and occur in thin beds, usually less than ten feet thick. Oolitic limestones are usually well cemented. *Chaetetes* coral mounds found in the Tennessee Gas Poison Springs unit No. 1 have been mistaken for reef trends. The Desert Creek and Ismay limestones do not show the prolific organic fossil development in this area that they do in the vicinity of the Four Corners area, located on the southeast accessway into the basin.

A more satisfactory analysis could be made by dealing with only one interval, such as the Desert Creek, and studying the aerial distribution of these limestone components. The widespread uniform thickness of the Desert Creek and Ismay intervals above the evaporite sequence is attributed to uniform sedimentation. This uniformity of tight dense limestones is not and has not been encouraging.

DIRECTIONS FOR EXPLORATION

The area under the High Plateaus of Utah in Kane, Garfield, Piute, Sevier and San Pete Counties should still have shelf-type Pennsylvanian rocks in the subsurface, but these may be thin to locally missing as a result of erosion.

Shell Oil Company, in 1960, drilled the Sunset Canyon Unit No. 1, Sec. 21, T-22-S, R-4-W, which is located east of Meadow, Utah, on the westernmost edge of the High Plateaus. This well penetrated a very thin section of Pennsylvanian rocks. The thin Pennsylvanian sequence in this well and thin outcrop sections of Pennsylvanian rocks west of the High Plateaus are evidence against the existence of the Fremont accessway during middle Pennsylvanian time. In the Pavant, Mineral, and Star ranges the Pennsylvanian rocks are thin, usually less than three hundred feet. This evidence suggests that Pennsylvanian rocks are also thin under the High Plateaus and that the units of middle Pennsylvanian age, of greatest thickness in the Paradox basin, are scarcely represented.

The transitional hinge line area from Nevada to central Utah, an area of shelf-type Pennsylvanian rocks to the east and miogeosynclinal-type rocks to the west in the Great Basin Province, is the intriguing area of future exploration in Pennsylvanian rocks. Unfortunately, erosion during the Mesozoic removed these rocks over a large area in the eastern Great Basin. This eroded area is known as the Sevier Arch.

In conclusion, the limestones along the western margin and north of the Four Corners area in the Paradox basin are shallow shelf-type limestones with low porosities and permeabilities. The carbonates do not undergo rapid facies changes as previously proposed by Herman and Barkell (1957). Areas of varied biofacies changes or truncation by unconformities must be explored by drilling if further important discoveries are to be made in the Pennsylvanian rocks of Utah.

CITED REFERENCES

- Clair, J. R., 1958, Pennsylvanian rocks of Colorado and adjacent areas: Rocky Mountain Assoc. Geologists, Colorado Symposium of Pennsylvanian rocks.
- Herman, George, and Barkell, Clifford, 1957, Pennsylvanian stratigraphy and productive zones, Paradox salt basin: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 861-881.
- Herman, George, and Sharps, Seymour, 1956, Pennsylvanian and Permian stratigraphy of the Paradox salt embayment: Intermountain Assoc. Petroleum Geologists Guidebook, 7th Ann. Field Conf., p. 77-84.
- Welsh, J. E., 1958, Faunizones of the Pennsylvanian and Permian rocks in the Paradox Basin: Intermountain Assoc. Petroleum Geologists Guidebook, 9th Ann. Field Conf., p. 153-162.

PART IV
PAPERS OF GENERAL CONCERN
TO THE
PETROLEUM INDUSTRY

INDEX

<u>Paper</u>		<u>Page</u>
42	CHARACTERISTICS OF CRUDE OILS FROM UTAH, by W. J. Wenger and J. S. Ball _____	497
	Introduction _____	497
	Characteristics of Petroleum _____	499
	Correlation Index _____	503
	Utilization _____	504
	Future Prospects _____	510
	Addendum _____	510
	Cited References _____	510
43	OIL AND GAS LEASING IN UTAH, by N. G. Morgan, Sr., and Virgil V. Peterson _____	511
	Government-Owned Lands _____	511
	State-Owned Lands _____	516
	Oil Shale, Asphalt, Bitumen and Bituminous Rock Leases _____	518
44	PROBLEMS OF JOINT DEVELOPMENT OF POTASH AND OIL AND GAS IN THE PARADOX BASIN, by R. J. Hite _____	519
	Introduction and History of Development _____	519
	Geology of the Potash Deposits _____	521
	Problems in Simultaneous Development of Deposits of Potash and Oil and Gas _____	524
	Summary _____	525
	Cited References _____	525

Paper 42 CHARACTERISTICS OF CRUDE OILS FROM UTAH

by W. J. Wenger² and J. S. Ball³

INTRODUCTION

Considerable attention has been drawn to the oil possibilities of Utah in recent years. Although Utah is not yet a major producing state, annual output has climbed from 638,885 barrels in 1949 to 33,072,000 barrels in 1961.

The Federal Bureau of Mines Experiment Station at Laramie, Wyoming, has studied oils from fifteen Utah fields (Figure 1)⁴. For about 40 years the Bureau has analyzed crude petroleum by a standardized method (Smith, et al., 1950). This permits analyses of new oils to be compared with more than 8,000 analyses already on file. Table XXII, an unabridged report of the analysis for Weber sandstone oil from Ashley Creek, illustrates the data obtained by the Bureau's method of analysis. Through correlations, conclusions can be drawn regarding the refining characteristics of the oils. Geological correlations also have been developed for predicting the character of an oil from a particular formation. This paper presents the abridged analyses of 18 oils⁴ from Utah and suggests the types of petroleum likely to be found in future exploration.

In addition to petroleum, Utah has numerous deposits of hydrocarbons related to, but not generally classified as petroleum. A variety of asphaltite known as gilsonite or uintaite occurs in large veins in the Uinta Basin. It is being mined on a commercial scale for processing into metallurgical-grade coke and liquid fuels. Other natural asphalts have been exploited for many years on a small scale and are being considered for large-scale exploitation. Two of the larger deposits that have been studied (Shea, et al., 1952) are the bituminous sandstones at Vernal and Sunnyside. Recently, discovery of a deposit of bituminous rock of unknown extent in southern Emery County⁵ was reported. Detailed discussion of these materials is beyond the scope of this report. They will have more future significance with the increasing demand for fuels and special products.

1. This report results from work done under a cooperative agreement between the Bureau of Mines and the University of Wyoming. Samples and field data for the study were obtained by H. J. Hyden, U.S. Geological Survey, and J. Fry, R. F. Zaffarano, Paul Biggs, and C. Q. Cupps of the Bureau of Mines. The work was conducted under the general supervision of H. P. Rue, Chief, Division of Petroleum Technology, Region III.

2. Petroleum chemist, Bureau of Mines, Region III, Laramie, Wyoming.

3. Chief, Branch of Petroleum, Region III, Laramie, Wyoming.

4. Plus others represented by the 20 samples discussed in the Addendum.

5. A brief examination by the Bureau of Mines showed it to consist of a sandstone breccia with asphaltite and selenite (gypsum) crystals between sandstone fragments. Yield of asphaltite was 5.7 per cent. Properties of the asphaltite were as follows: Color, black; streak, brown; fracture, conchoidal; fusion point, about 250°C. with decomposition; sulfur, 5.21 per cent; nitrogen, 0.64 per cent; ash, 0.86 per cent; carbon residue, 40.1 per cent; and specific gravity, 1.111 at 60/60° F.

Table XXII. Routine analysis of crude oil from Weber Sandstone,
Ashley Creek Field, Uintah County, Utah

Identification				General characteristics						
Sample PC-50-341				Specific gravity. 0.872						
Ashley Creek field				API gravity 30.8°						
Weber sandstone, Pennsylvanian				Sulfur, percent83						
4181-4308 feet				Pour point, ° F. 15						
Uintah County, Utah				Color Brownish-black						
				Viscosity, S. U. S. at 100°F. . . 61						
Distillation, Bureau of Mines routine method										
Stage 1 - Distillation at standard pressure, 760 mm. Hg absolute. First drop, 29°C. (84°F.)										
Frac. no.	Cut at		Per- cent	Sum, percent	Specific gravity, 60/60°F.	API gravity, 60°F.	C. I.	Aniline point, °C.	Viscosity 100° F. S. U. sec.	Cloud test, °F.
1	50	122	0.7	0.7	0.651	85.9				
2	75	167	1.6	2.3	.661	82.6	3.2			
3	100	212	3.2	5.5	.710	67.8	17	57.8		
4	125	257	4.5	10.0	.735	61.0	19	58.2		
5	150	302	4.2	14.2	.753	56.4	20	59.6		
6	175	347	4.1	18.3	.773	51.5	23	60.2		
7	200	392	4.0	22.3	.791	47.4	25	61.8		
8	225	437	4.8	27.1	.808	43.6	28	64.1		
9	250	482	5.5	32.6	.824	40.2	30	66.7		
10	275	527	6.8	39.4	.839	37.1	32	69.3		
Stage 2 - Distillation continued at 40 mm. Hg absolute										
11	200	392	2.6	42.0	.860	33.0	38	72.4	41	20
12	225	437	7.4	49.4	.865	32.1	37	74.7	46	40
13	250	482	5.7	55.1	.878	29.7	40	78.6	58	55
14	275	527	5.2	60.3	.895	26.6	45	80.9	84	70
15	300	572	7.4	67.7	.907	24.5	47	84.6	155	85
Residuum			31.3	99.0	.983	12.4	too dark			
Carbon residue of residuum, 12.9% - carbon residue of crude, 4.5%										
Approximate summary										
	Percent				Specific gravity		API gravity		Viscosity	
Light gasoline				5.5	0.688		74.2			
Total gasoline and naphtha				22.3	.744		58.7			
Kerosene distillate.				10.3	.817		41.7			
Gas oil				15.3	.851		34.8			
Nonviscous lubricating oil				11.2	.863-.898		32.5-26.1		50-100	
Medium lubricating oil				8.6	.898-.914		26.1-23.3		100-200	
Viscous lubricating oil				0.0					Above 200	
Residuum				31.3	.983		12.4			
Distillation loss				1.0						

CHARACTERISTICS OF PETROLEUMS

Tables XXIII, XXIV, and XXV show selected data from analyses of 18 oils. These oils originate from formations of six geological time periods -- Tertiary, Cretaceous, Jurassic, Triassic, Permian, and Pennsylvanian. Oil is being produced at present from two major structural basins -- the Uinta and the Paradox in the eastern part of the state. The Tertiary and Cretaceous samples were obtained from fields in the Uinta Basin of northeastern Utah. Oils from older formations having a more widespread distribution were obtained from fields in the Uinta Basin, the Paradox Basin in southeastern Utah, and Virgin field in the southwestern part of the state.

In most areas of the Rocky Mountain region, low-sulfur oils (less than 0.5 per cent) are found in the Tertiary and Cretaceous formations, whereas the high-sulfur oils are in older formations (Ball, et al., 1950; Wenger and Lanum, 1952a, 1952b, and 1954; Wenger, et al., 1957). Oils from the Uinta Basin conform to this general pattern with the exception of Jurassic oil at Ashley Creek, which has a sulfur content of 0.12 per cent. All Tertiary and Cretaceous oils listed in tables XXIII and XXV, XXIV have low-sulfur contents and are waxy. Seiber Nose oil from the Jurassic formation and oils from Triassic, Permian, and Pennsylvanian formations, both in the Virgin field and in the Uinta Basin, have high-sulfur contents and are asphaltic, with corresponding dark color. Oils from the Paradox Basin do not conform to this pattern. These Permian and Pennsylvanian oils have low-sulfur content, light color, and most of them are waxy. When samples from Cane Creek, Boundary Butte, and Dove Creek, Colo. were studied some years ago, they were assumed to be exceptions, as they were not the high-sulfur oils expected from Permian and Pennsylvanian formations of the Rocky Mountain area. Since then, additional samples from recent discoveries in the Paradox Basin have established that oils from that Basin may be expected to have low-sulfur contents.

Most Utah oils are waxy, but only those from the Tertiary formations in the Uinta Basin have abnormally high wax contents. This is illustrated by the pourpoint data, which serve as a relative measure of wax content. The sample from Duchesne (item 1, Table XXIV) heads the list with a value of 130°F., the highest value ever observed at the Bureau of Mines Laramie laboratories. Next is the oil from Gusher, with a value of 95°F., followed by Roosevelt with 85°F. Other Utah oils have values ranging from 45°F to less than 5°F.

The yield of 100-penetration asphalt that may be obtained from an oil can be estimated by multiplying percentage of Conradson carbon residue by 4.9 (Smith, et al., 1950). Normally, waxy oils tend to have low carbon-residue values; thus, the oil from Duchesne has only a trace of asphalt. Oil from the Gusher field is exceptional, containing both wax and asphalt. Carbon-residue values for the Utah oils indicate a range from less than 1 per cent 100-penetration asphalt to as much as 34 per cent (item 8, Table XXIV).

API gravities usually reflect the amount of gasoline or "light ends" present. The highest value of 54.0° API (item 4, Table XXIV) is for oil from the Chapita Wells field, which has a total gasoline and naphtha content of 63.3 volume-per cent. The lowest value of 21.8° API (item 8) is for one of the oils from the Virgin field which has a total gasoline and naphtha content of only 5.9 volume-per cent.

Table XXIII. Summary of data showing sources of Utah oil samples, arranged according to geological time periods.

Item	Field	County	Structural basin	Productive formation	Discovery date	Depth, feet
				<u>Tertiary period</u>		
1	Duchesne	Duchesne	Uinta	Wasatch ss	1951	7,518
2	Gusher	Uintah	do.	Basal Green River sh	1950	8,711
3	Roosevelt	do.	do.	do	1949	9,350
				<u>Cretaceous period</u>		
4	Chapita Wells	do.	do.	Mesaverde ss	1952	8,275
				<u>Jurassic period</u>		
5	Ashley Creek	do.	do.	Entrada ss	1948	2,003
6	Seiber Nose	Grand	do.	Morrison ss	1955	1,430
				<u>Triassic period</u>		
7	Virgin	Washington	*	Moenkopi ss	1907	557
8	Virgin	do.	*	do.	1907	550
				<u>Permian period</u>		
9	Ashley Creek	Uintah	Uinta	Phosphoria ls	1948	4,212
10	Boundary Butte	San Juan	Paradox	Coconino ss	1948	1,498
				<u>Pennsylvanian period</u>		
11	Aneth	do.	do.	Paradox ls	1956	5,828
12	Ashley Creek	Uintah	Uinta	Weber ss	1948	4,181
13	Bluff	San Juan	Paradox	U. Hermosa ls	1956	5,470
14	Cane Creek	Grand	do.	Paradox ls	1926	2,025
15	Desert Creek	San Juan	do.	do.	1954	5,244
16	Ismay	do.	do.	do.	1956	5,585
17	Ratherford	do.	do.	do.	1956	5,578
18	Recapture Creek	do.	do.	U. Hermosa ls	1956	5,354

* Virgin field is on the Kaibab Upwarp in southwestern Utah.

Table XXIV. Summary of data -- some characteristics of Utah oils.

Item	Field	Gravity, °API	Color*	Viscosity at 100°F. S.U. secs.	Pour- point, °F.	Sulfur, weight- percent	Nitrogen, weight- percent	Carbon residue, weight- percent **	Ratio, nitrogen to carbon residue
<u>Tertiary period</u>									
1	Duchesne	36.0	Br. gr. ***	125	130	0.01	0.002	0.2	0.010
2	Gusher	20.2	Br. blk.	330	95	.08	.25	4.1	.061
3	Roosevelt	30.0	Gr. blk.	145	85	.07	.169	2.7	.063
<u>Cretaceous period</u>									
4	Chapita Wells	54.0	NPA 1-1/2	<32	40	.02	.005	.0	----
<u>Jurassic period</u>									
5	Ashley Creek	31.5	Gr. blk.	52	45	.12	.012	2.0	.006
6	Seiber Nose	34.8	Br. blk.	44	30	.96	.055	3.7	.015
<u>Triassic period</u>									
7	Virgin	31.7	do.	57	40	.82	.085	4.2	.020
8	Virgin	21.8	Black	270	30	2.21	.158	7.0	.023
<u>Permian period</u>									
9	Ashley Creek	30.0	Br. blk.	66	15	.89	.13	4.8	.027
10	Boundary Butte	42.5	Br. gr.	36	15	.11	.00	1.0	.00
<u>Pennsylvanian period</u>									
11	Aneth	41.3	do.	37	10	.11	.042	.8	.052
12	Ashley Creek	30.8	Br. blk.	61	15	.83	.134	4.5	.030
13	Bluff	39.8	Green	40	30	.08	.052	.8	.065
14	Cane Creek	38.4	NPA 5	46	< 5	<.10	----	.4	----
15	Desert Creek	39.4	Green	40	50	.11	.037	.8	.046
16	Ismay	44.1	Br. gr.	33	10	.05	.022	.5	.044
17	Ratherford	39.8	Green	38	35	.15	.047	.8	.059
18	Recapture Creek	41.9	do.	35	20	.10	.031	.4	.078

*Colors of crude oils in this table are designated as follows: Brownish green, br. gr.; greenish black, gr. blk.; brownish black, br. blk.; green; black; and NPA numbers.

**Carbon residue values are equivalent to those obtained by the Conradson method, ASTM Designation D189-46.

***Value determined by extrapolation from viscosities at temperatures above the pour point of 130°F.

Table XXV. Summary of data -- distillation yields of Utah oils.

Item	Field	Distillation yield, volume-percent				Residuum
		Fractions (1-3) (light gasoline)	Fractions (4-7) (naphtha)	Fractions (8-12) (kerosene and gas oil)	Fractions (13-15) (lubricating oil)	
<u>Tertiary period</u>						
1	Duchesne	0.0	10.2	26.0	23.7	40.2
2	Gusher	1.5	9.1	18.1	21.5	50.2
3	Roosevelt	2.7	11.9	18.7	21.4	44.6
<u>Cretaceous period</u>						
4	Chapita Wells	21.6	41.7	26.0	5.8	3.4
<u>Jurassic period</u>						
5	Ashley Creek	4.1	14.6	34.5	23.2	23.6
6	Seiber Nose	5.3	21.8	29.5	17.8	25.4
<u>Triassic period</u>						
7	Virgin	4.6	18.9	25.2	18.5	32.4
8	do.	.5	5.4	27.7	23.8	41.7
<u>Permian period</u>						
9	Ashley Creek	5.2	16.1	24.8	18.5	34.3
10	Boundary Butte	12.2	26.5	27.4	15.8	16.3
<u>Pennsylvanian period</u>						
11	Aneth	11.0	22.5	29.8	19.0	15.2
12	Ashley Creek	5.5	16.8	27.1	18.3	31.3
13	Bluff	12.8	16.3	29.8	17.3	19.4
14	Cane Creek	6.5	22.5	26.8	18.9	25.1
15	Desert Creek	10.0	21.2	23.3	18.2	22.0
16	Ismay	15.3	26.9	25.8	14.8	14.0
17	Ratherford	12.8	21.1	28.3	15.7	21.1
18	Recapture Creek	14.2	23.6	34.2	11.0	15.1

High percentages of nitrogen are associated with the higher percentages of carbon residue or asphalt content. Nitrogen ranges from 0.002 per cent in the Duchesne oil to 0.25 per cent in the Gusher oil. The ratio of nitrogen to carbon residue seems to have some geological and geographical significance. Oils from younger formations normally have higher ratios than those from older formations. The ratios for Gusher and Roosevelt, 0.061 and 0.063, are normal for oils from younger formations. The lower values for Jurassic, Triassic, Permian, and the Pennsylvanian oil in the Uinta Basin and at Virgin field are also normal. However, most Permian and Pennsylvanian oils from the Paradox Basin have considerably higher ratios than normal, in line with their other unusual qualities.

CORRELATION INDEX

The correlation index (C.I.) (Smith, 1940), a function of specific gravity and boiling range, indicates the structure of the hydrocarbons contained in the analysis fraction. The C.I. scale is arranged so that straight-chain paraffins have values of 0 and benzene has a value of 100. Branched paraffins, cycloparaffins (naphthenes), and monocyclic aromatics other than benzene have intermediate values. Distillation fractions that are mixtures of these hydrocarbon types have, therefore, C.I. values in the range of 0 to 100.

A correlation-index curve can be obtained for each crude oil by plotting C.I. values against fraction numbers. Such curves for each of the Utah oils are plotted in Figures 156, 157, and 158, in which the numbers of the curves correspond to item numbers in Tables XXIII, XXIV, and XXV. These curves indicate differences among the oils based on composition and can be used to show geological and geographical relationships.

Curves for the Tertiary and Cretaceous oils from Utah are generally horizontal over the central portion of the curve (Figure 156). The oils from Permian and Pennsylvanian formations can be divided into two groups on the basis of their C.I. curves. One group consists of oils with C.I. curves having a decided positive slope; the other group more closely resembles the younger oils. The first group contains oils that have high-sulfur contents, while the second contains oils with low-sulfur contents. The latter are shown as a "band" (Figure 158) where the individual curves have essentially the shape of the band and are contained in it. The oils from Jurassic and Triassic formations (Figure 157) show both the low-sulfur pattern (item 5) and the high-sulfur pattern (items 6, 7, and 8). Thus the curves for Utah oils appear to group according to the sulfur content of the oil. Although sulfur compounds have high specific gravities and, thus, could contribute to raising the correlation index, the major effect probably is due to high-specific-gravity naphthenic and aromatic hydrocarbons in the high-sulfur oils.

The Utah oils are, in general, of two types: low-sulfur oil, having a horizontal C.I. curve, and high-sulfur oil, having an upward sloping C.I. curve. The first type, except those from the Paradox Basin, are found in younger formations, whereas those of the latter type are found in older formations.

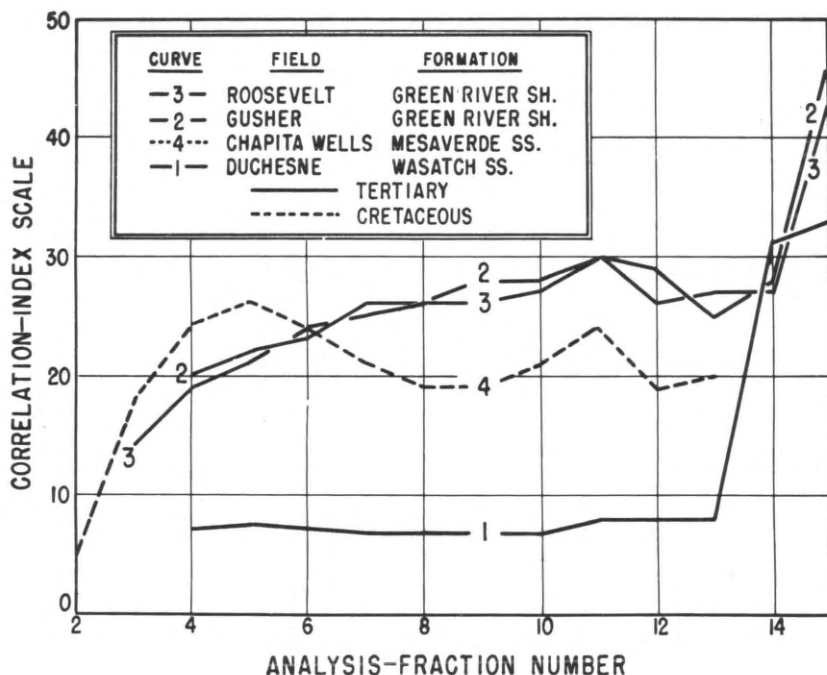


Figure 152. Correlation-Index Curves, of Utah Oils from Tertiary and Cretaceous Formations

UTILIZATION

Suitability of oils as a source of specific products can be predicted by a study of the C.I. curves (Smith, 1940). For example, high values in the gasoline range (analysis fractions 1-7) indicate sources of high-octane motor fuel or blending stock. For oils to have much interest for this purpose, the key fraction (number 4) should have a C.I. value of at least 28. A curve with a high value, 30 or more for fraction 4 or 5 followed by a decline, indicates a source of toluene (Smith, et al., 1950). Thus, oil from the Entrada sandstone at Ashley Creek (item 5, Figure 157) with a C.I. value of 34 at fraction 4, should be a suitable source of high-octane motor fuel. As there is no decline between fractions 5 and 7, toluene is not specifically indicated in that region of the distillation. Oil from the Duchesne field (item 1, Figure 156) has a very low C.I. value of 7.1 at fraction 4, as well as low values over almost the entire distillation range. This curve illustrates a very paraffinic oil.

Saturated hydrocarbons are desirable in products such as cleaning solvents, kerosene, diesel fuels, and lubricants. Oils from the Paradox Basin (band of curves, Figure 158) would be especially suitable for manufacturing these products. A large yield of paraffin wax could be obtained from the oil at Duchesne. Although a number of such products could be obtained with a minimum of processing, full utilization of Utah oils generally will require such processing as cracking and reforming, especially if reasonable yields of high-quality gasoline are desired.

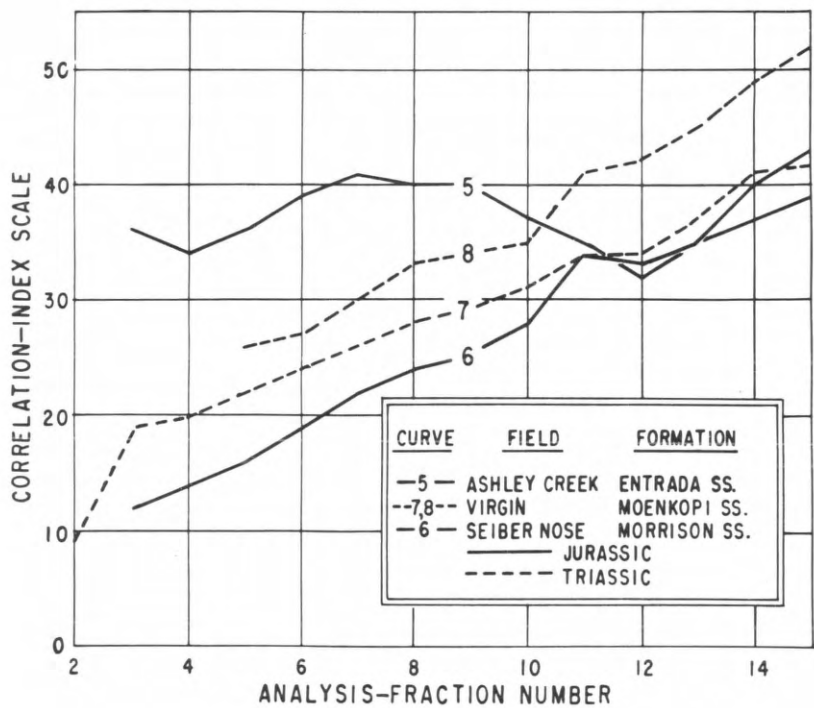
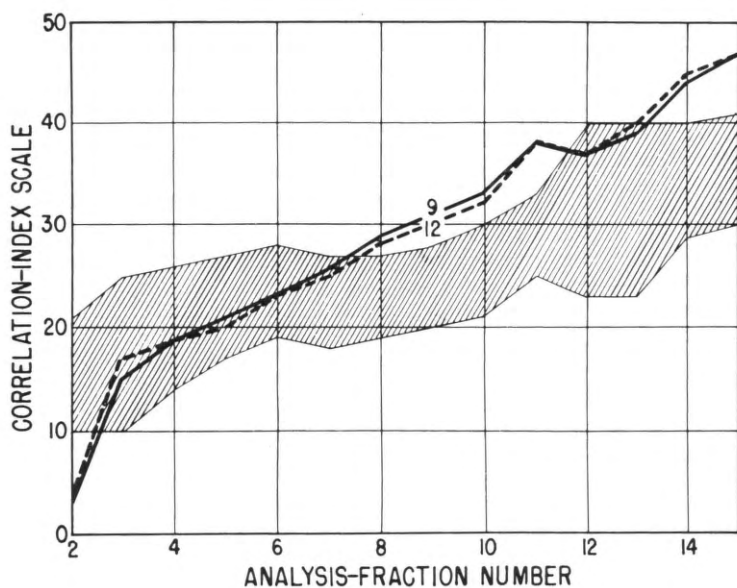


Figure 153. Correlation-Index Curves of Utah Oils from Jurassic and Triassic Formations



<u>CURVE</u>	<u>FIELD</u>	<u>FORMATION</u>
— 9 —	ASHLEY CREEK	PHOSPHORIA LS.
- - - 12 - - -	Do.	WEBER SS.
— BAND —	ANETH	PARADOX LS.
	BLUFF	HERMOSA LS.
	CANE CREEK	PARADOX LS.
	DESERT CREEK	Do.
	ISMAY	Do.
	RATHERFORD	Do.
	RECAPTURE CREEK	HERMOSA LS.
	BOUNDARY BUTTE	COCONINO SS.

Figure 154. Correlation-Index Curves of Utah Oils from Permian and Pennsylvanian Formations

FUTURE PROSPECTS

Oils from the Uinta Basin and the southwestern portion of Utah are similar to those produced from corresponding formations in the Rocky Mountain region. Oils from the Paradox Basin are of better quality than is usual from Permian and Pennsylvanian formations in the Rocky Mountain region. Based on past experience, future fields in the Uinta Basin and southwestern Utah generally will produce low-sulfur, paraffinic oil from formations above the Jurassic and high-sulfur asphaltic oil from formations below Cretaceous. Only high-quality, low-sulfur oil is expected to occur in the Paradox Basin.

ADDENDUM

Many additional oil fields have been discovered in Utah since January 1958. This addendum gives properties of the 20 crude oils analyzed by the Bureau of Mines since that time. Selected properties of these oils are presented in supplementary tables numbered XXIIIa, XXIVa, and XXVa.

Both Mississippian and Devonian formations in the Paradox Basin have been found to be oil productive. Two samples from Mississippian formations and one from a Devonian formation were analyzed. Although the data are sketchy, they indicate that the pre-Pennsylvanian oils in the Paradox Basin are similar to the Pennsylvanian oils. Seventeen other oil samples from both the Paradox and Uinta Basins were analyzed. They are similar to the oils that were studied previously.

CITED REFERENCES

- Ball, J. S., Wenger, W. J., and Whisman, M. L., 1950, Refining properties of new crudes: Oils from 20 new discoveries in the Rocky Mountain Region analyzed, pt. 3, *Petrol. Processing*, v. 5, no. 8, p. 842-846.
- Shea, G. D., Higgins, R. V., Wenger, W. J., Hubbard, R. L., and Whisman, M. L., 1952, Separation and utilization studies of bitumens from bituminous sandstones of the Vernal and Sunnyside, Utah deposits: Bureau of Mines Rept. of Inv. 4871, 28 p.
- Smith, H. M., 1940, Correlation index to aid in interpreting crude-oil analyses: Bureau of Mines Tech. Paper 610, 34 p.
- Smith, N. A. C., Smith, H. M., Blade, O. C., and Garton, E. L., 1950, The Bureau of Mines routine method for the analysis of crude petroleum: Part I, The analytical method, Bureau of Mines Bull. 490, 82 p.
- Smith, N. A. C., Smith, H. M., and McKinney, C. M., 1950, Refining properties of new crudes: Part I, Significance and interpretation of Bureau of Mines routine crude oil analysis: *Petrol. Processing*, v. 5, no. 6, p. 609-614.
- Wenger, W. J., and Lanum, W. J., 1952a, Characteristics of crude oils from the Powder River Basin: *Petrol. Eng.*, v. 24, no. 10, p. A60-71.
- _____, 1952b, Refining properties of new crudes: Part VI, Crude oils from the Julesburg Basin, Colorado, Nebraska, and Wyoming, *Petrol. Processing*, v. 7, no. 6, p. 821-825.
- _____, 1954, Characteristics of crude oils from Big Horn Basin fields: *Petrol. Eng.*, v. 26, no. 2, p. A52-60.
- Wenger, W. J., Whisman, M. L., Lanum, W. J., and Ball, J. S., 1957, Characteristics and analyses of ninety-two Colorado crude oils: Bureau of Mines Rept. of Inv. 5309, 60 p.

Table XXIIIa*. Summary of data showing sources of Utah oil samples arranged according to geological time periods.

Item	Field	County	Structural basin	Productive formation	Discovery date	Depth, feet
<u>Tertiary period</u>						
19	Brennan Bottom	Uintah	Uinta	Wasatch ss. and Green River sh.	1954	6, 635
20	Red Wash	Uintah	Uinta	Green River sh.	1951	5, 550
21	Walker Hollow	Uintah	Uinta	Green River sh.	1952	5, 520
22	Wells Draw	Duchesne	Uinta	Basal Green River ss.	1962	5, 204
23	Wonsits Unit	Uintah	Uinta	Green River sh.	1959	5, 820
<u>Jurassic period</u>						
24	Bar-X	Grand	Uinta	Morrison fm.	1948	2, 714
25	Cisco Townsite	Grand	Uinta	Morrison ss.	1954	565
26	Agate	Grand	Uinta	Brushy Basin ss., sh.	1961	1, 562
<u>Triassic period</u>						
27	Grassy Trail	Emery	Uinta	Moenkopi ss.	1961	3, 872
<u>Pennsylvanian period</u>						
28	Akah	San Juan	Paradox	Paradox ls.	1955	4, 688
29	Big Flat	Grand	Paradox	Paradox salt	1955	5, 730
30	Gothic Mesa	San Juan	Paradox	Desert Creek ls.	1956	5, 768
31	Hatch	San Juan	Paradox	Paradox ls.	1957	5, 967
32	Lisbon, N. W.	San Juan	Paradox	Paradox salt	1960	5, 934
33	McElmo Creek	San Juan	Paradox	Paradox ls.	1957	5, 350
34	Tohonadla	San Juan	Paradox	Paradox ls.	1957	5, 050
35	White Mesa	San Juan	Paradox	Paradox ls.	1957	5, 445
<u>Mississippian period</u>						
36	Cane Creek	Grand	Paradox	Mississippian ls.	1959	6, 605
37	Lisbon, N. W.	San Juan	Paradox	Mississippian ls.	1960	8, 738
<u>Devonian period</u>						
38	Lisbon, N. W.	San Juan	Paradox	McCracken ss.	1960	8, 905

* Oils studied since 1958 are listed in tables XXIIIa, XXIVa, and XXVa.

Table XXIVa. Summary of data showing some characteristics of Utah oils.

Item	Field	Gravity, °API	Color 1/	Viscosity at 100° F., S.U. secs.	Pour point, °F.	Sulfur, weight- percent	Nitrogen, weight- percent	Carbon residue, weight- percent 2/	Ratio, nitrogen- to carbon residue
<u>Tertiary period</u>									
19	Brennan Bottom	27.1	br. gr.	200	95	0.13	0.146	3.6	0.041
20	Red Wash	22.6	br. blk.	700	30	.15	.303	5.2	.058
21	Walker Hollow	24.2	br. blk.	360	60	.11	.255	4.8	.053
22	Wells Draw	32.7	br. gr.	105	95	.03	.063	.5	.126
23	Wonsits Unit	25.2	br. blk.	400	85	.19	.291	4.0	.073
<u>Jurassic period</u>									
24	Bar-X	40.9	br. gr.	40	55	.12	.013	1.0	.013
25	Cisco Townsite	33.8	br. blk.	48	< 5	1.07	.070	5.7	.012
26	Agate	40.4	gr. blk.	38	< 5	.61	.034	3.0	.011
<u>Triassic period</u>									
27	Grassy Trail	40.4	NPA 7-1/2	38	< 5	.18	.012	.5	.024
<u>Pennsylvanian period</u>									
28	Akah	39.0	br. gr.	36	5	.16	.062	1.6	.039
29	Big Flat	32.8	br. gr.	79	< 5	.16	.069	3.1	.022
30	Gothic Mesa	40.4	green	37	25	.05	.034	.8	.043
31	Hatch	40.4	NPA 8	37	< 5	.09	.023	.7	.033
32	Lisbon, N.W.	45.2	NPA 2	37	< 5	.01	.002	.3	.007
33	McElmo Creek	40.0	d. green	37	20	.09	.041	.8	.051
34	Tohonadla	38.8	br. gr.	40	20	.09	.069	1.4	.049
35	White Mesa	41.1	green	36	15	.10	.039	.7	.056
<u>Mississippian period</u>									
36	Cane Creek	40.9	NPA 6	37	20	.09	.011	.3	.037
37	Lisbon, N. W.	62.6	NPA 2	32	< 5	.21	.001	.0	----
<u>Devonian period</u>									
38	Lisbon, N. W.	46.7	NPA 5	34	40	.03	.003	.0	----

1/ Colors of crude oils in this table are designated as follows: Brownish green, br. gr.; greenish black, gr. blk.; brownish black, br. blk.; dark green, d. green; green; and NPA numbers.

2/ Carbon residue values are equivalent to those obtained by the Conradson method, ASTM Designation D189-46.

Table XXVa. Summary of data showing distillation yields of Utah oils.

Item	Field	Distillation yield, volume percent				
		Fractions (1-3) (light gasoline)	Fractions (4-7) (naphtha)	Fractions (8-12) (kerosene and gas oil)	Fractions (13-15) (lubricating oil)	Residuum
<u>Tertiary period</u>						
19	Brennan Bottom	0.9	9.6	18.7	18.9	48.4
20	Red Wash	.5	7.1	14.1	16.0	62.3
21	Walker Hollow	.0	7.8	15.5	16.8	59.7
22	Wells Draw	1.6	8.3	20.5	17.3	51.8
23	Wonsits Unit	.8	7.7	13.8	18.0	59.1
<u>Jurassic period</u>						
24	Bar-X	6.8	19.8	32.5	19.7	19.8
25	Cisco Townsite	5.3	20.7	26.5	16.9	29.9
26	Agate	8.9	23.6	27.8	14.8	23.3
<u>Triassic period</u>						
27	Grassy Trail	5.0	20.9	34.7	17.5	20.4
<u>Pennsylvanian period</u>						
28	Akah	9.9	25.9	24.9	16.6	22.0
29	Big Flat	3.2	12.7	25.8	18.2	39.3
30	Gothic Mesa	8.9	24.2	27.3	16.4	21.4
31	Hatch	7.6	24.4	26.0	16.5	24.2
32	Lisbon, N. W.	12.8	23.7	24.7	16.1	22.5
33	McElmo Creek	11.3	25.9	22.7	15.0	24.0
34	Tohonadla	8.7	22.0	25.2	17.5	25.1
35	White Mesa	12.7	22.5	25.5	15.5	21.5
<u>Mississippian period</u>						
36	Cane Creek	6.5	16.2	27.9	13.6	33.8
37	Lisbon, N. W.	41.5	37.7	14.7	2.3	1.8
<u>Devonian period</u>						
38	Lisbon, N. W.	13.8	23.3	25.7	17.6	19.1

Paper 43 OIL AND GAS LEASING IN UTAH

by N. G. Morgan, Sr.¹ and Virgil V. Peterson

GOVERNMENT-OWNED LANDS

Evidence of the tremendous activity in the leasing of Federal lands in Utah is found in the records of the Land Office of the Bureau of Land Management, Department of Interior, which office is located in the Darling Building, Salt Lake City, Utah. The Land office manager reports that during the period July 1, 1951, to June 30, 1961, there were 74,350 offers for oil and gas leases received by that office, from which more than 30,000 leases issued. He further reports that the income for oil and gas leases for that same period was \$46,924,770.00. The fiscal year ending June 30, 1961, exceeded all other like periods, showing a total income of \$7,392,536.00. On that date there were 29,500 oil and gas leases in effect, covering 17,526,000 acres of public domain. There are in the State of Utah, about 32,000,000 acres of public land which are subject to oil and gas leasing.

The accomplishment of this tremendous task has been made possible by the Bureau of Land Management's decentralization program which has eliminated much of the departmental red tape in evidence when leases were issued out of the Bureau of Land Management in Washington, D. C.

With all this additional work, the Land Office has operated on a very conservative budget, the ratio of increase between budget and business handled for the years 1944 and 1961 being about ten to one.

Under present regulations, 37 1/2 per cent of all rentals and royalties paid by lessees and oil and gas operators on Federal lands in Utah goes to the Utah State Treasury. Since July 1951 the amount paid the State would aggregate about \$17,596,864.00. This division of rentals and royalties derived from oil and gas leases was made effective under the Mineral Leasing Act of Feb. 1920. That law also provides that 52 1/2 per cent of all rentals and royalties derived from oil and gas leases and production be paid to the U.S. Bureau of Reclamation, to be spent by that Bureau in accordance with its own discretionary powers.

Under the Enabling Act, which empowered the people of Utah to form a Constitution and State Government and to be admitted into the Union on an equal basis with the original states, it is provided:

The people inhabiting said proposed States do agree that they forever disclaim all right and title to the unappropriated public lands lying within the boundaries hereof; and to all lands lying within said limits owned or held by an Indian or Indian Tribes; and that, until the title thereto shall have been extinguished by the United States, the same shall be and remain subject to the disposition of the United States, and said Indian lands shall remain under the absolute jurisdiction and control of Congress of the United States...

1. Morgan-Peterson Enterprises, Inc., Salt Lake City, Utah

Prior to 1914, practically all land patents granted by the government to patentees included everything of mineral value in the lands involved, including all oil, gas, and other hydrocarbons. Subsequent to 1914, however, on public lands which the Secretary of the Interior considered as having oil, gas, or other hydrocarbon possibilities, there was inserted in the patent granted a provision reserving to the government the oil, gas, and other hydrocarbons that might therein be found.

Prior to February 25, 1920, in order for a qualified citizen of the United States to acquire patent to government-owned lands having oil, gas, or other hydrocarbon possibilities, it was necessary for a locator to file an oil placer location in accordance with the rules and regulations of the Department of the Interior. If a discovery of oil was made as a result of drilling, the applicant could then take the placer claim to patent and acquire the fee simple title to the lands covered in his filing.

On February 25, 1920, legislation previously enacted by Congress became a law, which, since that time, has been known as the Act of February 25, 1920 (41 Stat. 437), as amended. Oil and gas and other mineral leases under the Mineral Leasing Act until recently stood as a barrier to entry, under the mining laws of the United States, to the same land. This condition has been largely corrected in the Act of August 13, 1954 (68 Stat. 708), which amends the mining laws and the mineral leasing laws to the extent that multiple mineral development can be carried on simultaneously on public lands.

All Federal oil and gas leases, competitive and non-competitive, are issued in accordance with the aforementioned Act of February 25, 1920, and subsequent amendatory acts relating thereto. The Federal Code of Regulations as pertaining to oil and gas leasing makes the following provisions:

1. Acreage limitations on leases - The maximum leasable acreage, as provided by law, for any one individual is 246,080 acres in each state of which not more than 200,000 may be held by option. All interests in leases, whether by royalties on producing leases, by options, by undivided interests in record titles of leases, or through associations or corporations, directly or indirectly, are accountable. Each application must not exceed 2,560 acres nor be less than 640 acres, except where the lands are in an approved unit or isolated land parcels constitute less than the stipulated 640 acres. There is no limit on the number of applications filed by any one individual, except as controlled by the maximum acreage limitation. Should it be shown that any party has exceeded his limit, the leases, offers, or interests creating his excess holdings will be cancelled in their entirety although only a part of the lease or interest may constitute the overage, "unless it can be shown to the satisfaction of the Director of the Bureau of Land Management that the holding or control of excess acreage is not the result of negligence or willful intent." In the event a lessee's holdings are increased by the termination or contraction of a unit creating an excess, he is given 90 days in which to comply with the prescribed limitation.

2. Acreage limitations on options - No individual, corporation, or association may hold options on oil and gas leases in excess of 200,000 acres in any one state, except as provided by the Act of August 8, 1946. Options shall not exceed three years, except by the prior approval of the Secretary of the Interior. Optioned acreage is chargeable both to optionor and optionee. Optionees are required to file under oath at the local land office the extent of their holdings by option within ninety days after June 30 and December 31 of each year.

3. Leases on lands in reserves, parks, refuges, etc. - Leases may issue on:

- a. Naval oil shale and helium reserves only as authorized by the Secretary of the Interior and then on a basis of competitive bidding. (Helium reserves in Utah have lease authorization).
- b. Indian lands on a competitive bid basis as approved by the Indian Agency and the Tribal Council concerned. (Some Indian lands do not carry reservation of minerals).
- c. Wildlife refuge lands in accordance with specific regulations of the Secretary of the Interior which are designed to protect the wildlife.
- d. National parks and monument areas only if the economic value is considered more important than the aesthetic value and in accordance with Department of the Interior directives.
- e. Acquired lands through the local offices of the Bureau of Land Management.

4. Noncompetitive leases - Application for noncompetitive leases must be submitted in quintuplicate on form No. 4-1158 Offer to Lease and Lease for Oil and Gas, or a facsimile reproduction thereof. A filing fee of \$10.00, which is considered earned and not returnable as soon as the application is filed, and rental for the first year at fifty cents per acre must accompany the application. All leases which expire by law or are terminated otherwise become subject to simultaneous filing. Each offer or application must be filled out in ink or type-written, and the applicant must furnish all information requested. Description of lands should be given by legal subdivision, as far as practical to do so. All unsurveyed lands must be described by section, township and range as indicated on approved protracted surveys.

An applicant may file by power-of-attorney, provided evidence of such power is filed with the offer. Partnerships, associations, or corporations must show evidence of authority to do business under the name of a given entity in order to qualify as an offeror. An applicant is required to show citizenship and to show that oil and gas lease holdings are within the prescribed limitations. Within 15 days after filing the lease offer, the applicant must file a signed statement indicating that he is the sole party in interest in the offer, and if he is not, he must set forth the names of the other interested parties who in turn are required to file a statement signed by all interested parties including the offer or indicating the nature and extent of the interest of each party. A copy of any written agreement between parties must be included. All parties must present evidence of qualification to hold a lease interest.

If errors are made in application or if regulations are not compiled with, the offer is returned to the applicant, or he is notified of any insufficiency which he may cure. Priority to the land involved under these conditions is not guaranteed.

5. Leases on patented or entered lands - Preference right to oil and gas leases on patented lands is allowed the patentee as provided by Interior Department regulations. To quote from circular 2037 dated Jan. 28, 1960, "An entryman or patentee who made entry prior to February 25, 1920, or an assignee of such entryman, or a vendee of such patentee if the assignment or conveyance was

made prior to January 1, 1918, for lands not withdrawn or classified or known to be valuable for oil and gas at date of entry, shall be entitled, if the entry or patent is impressed with a reservation of the oil or gas, to a preference right to a lease for the land. A settler whose settlement was made prior to February 25, 1920, on land in the same status, but which has since been withdrawn, classified, or is known to contain oil or gas, also has such a preference right.

"Any offeror for a lease to lands owned, entered, or settled upon as stated above must notify the person entitled to a preference right of the filing of the offer and of the latter's preference right for 30 days after notice to apply for a lease. If the party entitled to a preference right files a proper offer within the 30-day period, he will be awarded a lease; however, if he fails to do so, his rights will be considered to have terminated."

A bond of \$1,000.00 to protect the surface owner's rights is required from oil and gas lessees on lands patented under the Act of July 17, 1914, with reservation of oil and gas to the United States.

6. Rentals and royalties - All rentals on non-competitive leases are due in advance, and, if wholly outside a known geologic structure or producing oil or gas field, the rate is fifty cents per acre of fraction thereof per year. When a lease or any part thereof is declared to be within a known geologic structure, the entire lease at its next anniversary will carry a rental of \$1.00 per acres per year until offset by royalties through production. On all leases issued subsequent to September 2, 1960, the rental is \$2.00 per acre per year. Leases in known geologic structures require the posting of a corporate surety bond in a sum equal to double the amount of the annual rental with a minimum of \$1,000 and a maximum of \$5,000.

Rentals are payable on or before the anniversary of the lease. Failure to pay rentals will cause the lease, unless it is producing, to terminate automatically by operation of law.

Standard royalties under noncompetitive leases are 12 1/2% of production. If production is limited, a minimum royalty of \$1.00 per acre (\$2.00 on leases issued after September 2, 1960) may be applied, and, if royalty from actual production does not equal this amount, the difference must be paid by the lessee. Special royalty provisions are applicable where warranted by conditions. The total maximum allowable overriding royalty on a noncompetitive lease is five per cent, unless production exceeds 15 barrels of oil per day.

7. Term of lease - The primary term of a non-competitive lease is ten years, or as long thereafter as oil and/or gas are being produced in commercial quantities. A lease in its tenth year may be extended an additional two years by making an assignment of a divided interest, except on leases carrying a date of issue subsequent to September 2, 1960.

8. Availability of lands to further lease - Lands which are covered by leases that have terminated by operation of law or that have been cancelled or relinquished shall be subject to lease offers again only on the basis of simultaneous filing. On the third Monday of each month a description of the lands embraced in all leases which have expired or otherwise terminated is posted in the Land Office. Such lands are immediately thereafter subject to leasing. All offers filed on said lands within the succeeding five-day period are considered simultaneously filed. If more than one offer is filed on any given acreage, priority is established by public drawing.

Every offer to lease must be accompanied by separate checks, covering the \$10.00 filing fee and the advance rental payment. The rental check must be certified or any other guaranteed form of remittance may be used.

9. Assignment of leases - Subject to the approval of the Bureau of Land Management, leases may be assigned wholly, or in part, as to divided or undivided interest to any qualified person. Qualifications are the same as for an oil and gas lease applicant. A transfer affecting the record title of a lease may be filed on form 4-1175, Assignment Affecting Record Title of Oil and Gas Lease or any other acceptable assignment form and accompanied by a filing fee of \$10.00. Assignee must show citizenship and extent of lease holdings and file transfer in triplicate.

Transfer of record title of each oil and gas lease requires separate instruments. If a new lease is created by partial assignment, the assigned part becomes a new lease and carries an "a", "b", or "c" designation following the original lease number. Under such conditions the assignee becomes a lessee of the assigned portion and is bound by the terms of the lease. Leasehold assignments must be filed within 90 days after date of execution.

Assignment of royalty interests should be filed for the record, but are not acted upon for approval. If royalty interests assigned are identical in a number of leases, multiple assignments are permissible in one document. The filing fee is \$10.00.

10. Termination of leases - Leases may be terminated by filing in triplicate an instrument of relinquishment. Evidence of freedom from obligation pertaining to lease operations and rentals must be shown. When leases are terminated by relinquishment or cancellation, or by operation of law, the lands affected thereby are considered available for leasing when notation of termination is made on the tract book and when monthly descriptions of land are posted in the Land Office preparatory to simultaneous filing. Such notation is not necessary if a lease expires at the end of its five-year period or at the end of any extension thereof.

Leases are cancellable for default of lease terms.

11. Competitive Leases - Open lands in a known geologic structure of a producing oil and/or gas field are subject to competitive bidding. Notice of offer of lands to lease will be by publication in a newspaper of general circulation in the county in which the lands are located. The notice specifying the rental and royalty required must be published once per week for five consecutive weeks. The Land Office may circulate notice by other means also.

Leasing blocks are divided into compact units not exceeding 640 acres each which are available to the qualified person offering the highest bonus in competitive bidding either by sealed bid or public auction. Any or all bids are subject to right of rejection.

All sealed bids must be accompanied by a certified check, money order, or cash in the amount of one-fifth of the bonus bid and a statement declaring citizenship and other oil and gas interests held. If bidding is by public auction, the same requirements are exacted of the successful bidder. When the lease is awarded, three copies of the lease will be sent to the successful bidder, allowing 30 days during which time the bidder must submit the balance of his bonus bid and the rental of \$2.00 per acre for the first year.

A bond in the amount of double the annual rental, for not less than \$1,000 nor more than \$5,000 must also be filed.

12. Drilling bonds - Prior to beginning drilling operations an operator must furnish surety or personal bonds in the amount of \$10,000 on each lease drilled. If the operator does not hold record title of the lease he must show evidence of an operating agreement approved by the Land Office. This bond obligation is fully satisfied by an operator's nation-wide bond in the amount of \$150,000 or in any one state by a state-wide bond in the amount of \$25,000.

STATE-OWNED LANDS

The State of Utah owns the fee simple title to Sections 2, 16, 32, and 36 in each township where public lands have been surveyed, the revenue from which is applied to the support of schools. Title to these school sections vest in the state upon approval of survey by the Department of the Interior, unless some previous disposition by the United States prevents title from vesting such as creation or expansion of National Forests, Power Sites, Indian Reservations, National Parks or Monuments, and Reclamation Projects. To compensate the State in such instances, the federal government permits lieu lands to be selected by the State in exchange for the school sections, often resulting in the State owning lands other than the four sections specified. In the past special land grants, totaling approximately 1,750,000 acres, have also been made to State institutions. The State also owns the beds of navigable rivers and lakes.

Minerals have been reserved to the State by law, since May 12, 1919, although surface rights to State lands may have been conveyed. Previous to this date minerals were sold with the surface rights on nearly all tracts. The State does not warrant its title to any land, but the Land Board will not knowingly issue an oil and gas lease on lands the State does not own.

All State lands are under the direction of the Utah State Land Board, which has its offices in the Capitol Building, Salt Lake City, Utah. Oil and gas leases are issued under and pursuant to Title 65, Chap. 1, Utah Code Annotated 1953, as amended. Records of the Land Office are open to public inspection during regular office hours.

By law, any qualified United States citizen may acquire oil and gas leases on State-owned lands with no acreage limitation or chargeability. An application may contain 640 acres or one section, whichever ever is the larger. Where lands are non-contiguous, separate leases are issued for each parcel. A filing fee of \$2.00 is charged for each lease issued. Leases run for a primary term of five years and shall continue as long thereafter as oil and/or gas are produced in commercial quantities from lands leased.

If at the end of the primary term drilling operations are being prosecuted on the leased premises, the entire lease shall be extended automatically on application for a period of two years. The Land Board is empowered to grant an extension of five years on any oil and gas lease upon payment of a sixth year rental, assuming that the lease has no encumbrances and provided that the lands embraced therein do not lie within four sections in any direction from a section having commercial production, which production was discovered subsequent to the date of issue of the lease to be extended.

The rental on State lands is \$1.00 per acre per year, payable in advance. Individual leases issued on a fiscal basis and rentals for the second and subsequent years are due and payable on or before the annual anniversary of the effective date of the lease.

Lease applications are considered in the order filed. If simultaneously filed, the applicant willing to pay the highest rental is awarded a lease. When lands become available for leasing through new acquisition by the State, or through cancellation or termination of a previous lease, the Land Board will within 60 days following such acquisition, cancellation, or termination post a notice of availability for lease of such lands. All applications filed within a 15-day period following such notice will be considered simultaneously filed. Submittals must be made in sealed envelopes which will be opened the day following the last day bids are receivable. Leases are awarded to the qualified bidder who offers the highest bonus in addition to the rental for the first year. In the event of identical bids the successful bidder will be determined by public drawing.

Under Chapter 27, Laws of Utah, 1945, the State of Utah may consent to lessees holding oil and gas leases on State lands joining federal government unit plans or agreements for the development of said lands.

In the event other valuable minerals not encompassed in the oil and gas lease are discovered in the course of the drilling for oil and gas, the Utah State Land Board, on application, will grant to lessee priority for a lease on other minerals of value so encountered.

The lessor's royalty is 12 1/2% on the value of all oil and gas production at the well head, except (1) where the leased premises lie within four sections in any direction from a section in which is located a commercially productive well discovered prior to the issuance of the lease, and (2) when lands under lease "lie within four sections in any direction from the section in which a commercially productive well is first discovered after the lease is issued, and the lessee from the State has less than a twenty-five per cent (25%) working interest in such first discovered well at the time of discovery." When these exceptions obtain, the royalty on gas shall be 16 2/3% if the average production per well per day exceeds 5,000,000 cubic feet for a calendar month. Under those same exceptions the royalty on oil operates on a sliding scale. When the average daily production per well for a calendar month does not exceed 100 barrels, the royalty is 12 1/2%. As this average production increases, the royalty increases; the maximum being 25% when 400 barrels per day is reached. A further provision decreases the royalty rate by "one-half of one per cent for each 1,000 feet or fraction thereof that the lowest point of production from a pay zone is below 5,000 feet; provided further that no royalty rate shall be reduced below 12 1/2 per cent."

There are approximately 5,000,000 acres of State land in Utah subject to oil and gas leasing, inclusive of navigable streams and water bodies. As of June 30, 1961, there were 1,672,795 acres of State land under oil and gas lease. Rental income to the state on oil and gas leases for the fiscal year ending June 30, 1961, was approximately \$1,110,000 as compared with about \$1,000,000, a year earlier. Income from royalties for the same period totaled \$290,774. The increased rental income, however, does not necessarily indicate increased activity in leasing. In May 1960, basic rentals increased from \$.50 to \$1.00 per acre and competitive bidding was introduced.

The 1955 State Legislature enacted a regulation to conserve the oil and gas resources of the State. Designed to prevent wasteful practices and protect the rights of the producers and owners, it is the first such legislative act in the State. It became operative July 1, 1955.

OIL SHALE, ASPHALT, BITUMEN AND BITUMINOUS ROCK LEASES

On April 15, 1930 all oil shale deposits on federal lands were withdrawn for study and evaluation by Executive Order 5327. These oil shale deposits have not been restored to mineral leasing, but in August 1962 a regulation became effective providing for the leasing of deposits of bituminous rock, native asphalt, and solid and semisolid bitumen inclusive of gilsonite and oil impregnated sands and rock.

No specific form is provided for an application for lease, but name, address and citizenship qualifications are required of the applicant. Description of lands is the same as for oil and gas leasing. No applicant, (person, corporation or association) may acquire or hold more than 7,680 acres in any one state. A \$10.00 filing fee must be filed with each application which is considered earned when paid. Leases are issued only by competitive bidding in the same manner provided for oil and gas lease competitive bidding.

Royalty rates are determined on an individual lease basis and are set out in the publication inviting bids. The annual rental is fifty cents per acre. Term of the lease is 10 years and as long thereafter as the terms and conditions of the lease are observed.

Leases are issued on a modified form of 47LD which is the oil shale lease form in use prior to the oil shale withdrawal. A corporate surety bond is required as stipulated in the bid invitation. The principle of multiple use of public lands is operative.

Leases for oil shale or any asphaltic or bituminous deposits on State of Utah lands may be issued to any qualified United States citizen. Leases may not be larger than 640 acres and lands must be contiguous in a given lease. There is no total acreage limitation. Term of the lease is determined by the Utah State Land Board, but in no instance is it for less than 10 years. Royalties are also specified by the Board. The rental is \$.50 per acre per year. Bonds may be required. Multiple use is operative.

Paper 44 PROBLEMS OF JOINT DEVELOPMENT OF POTASH AND OIL AND GAS IN THE PARADOX BASIN¹

by Robert J. Hite²

INTRODUCTION AND HISTORY OF DEVELOPMENT

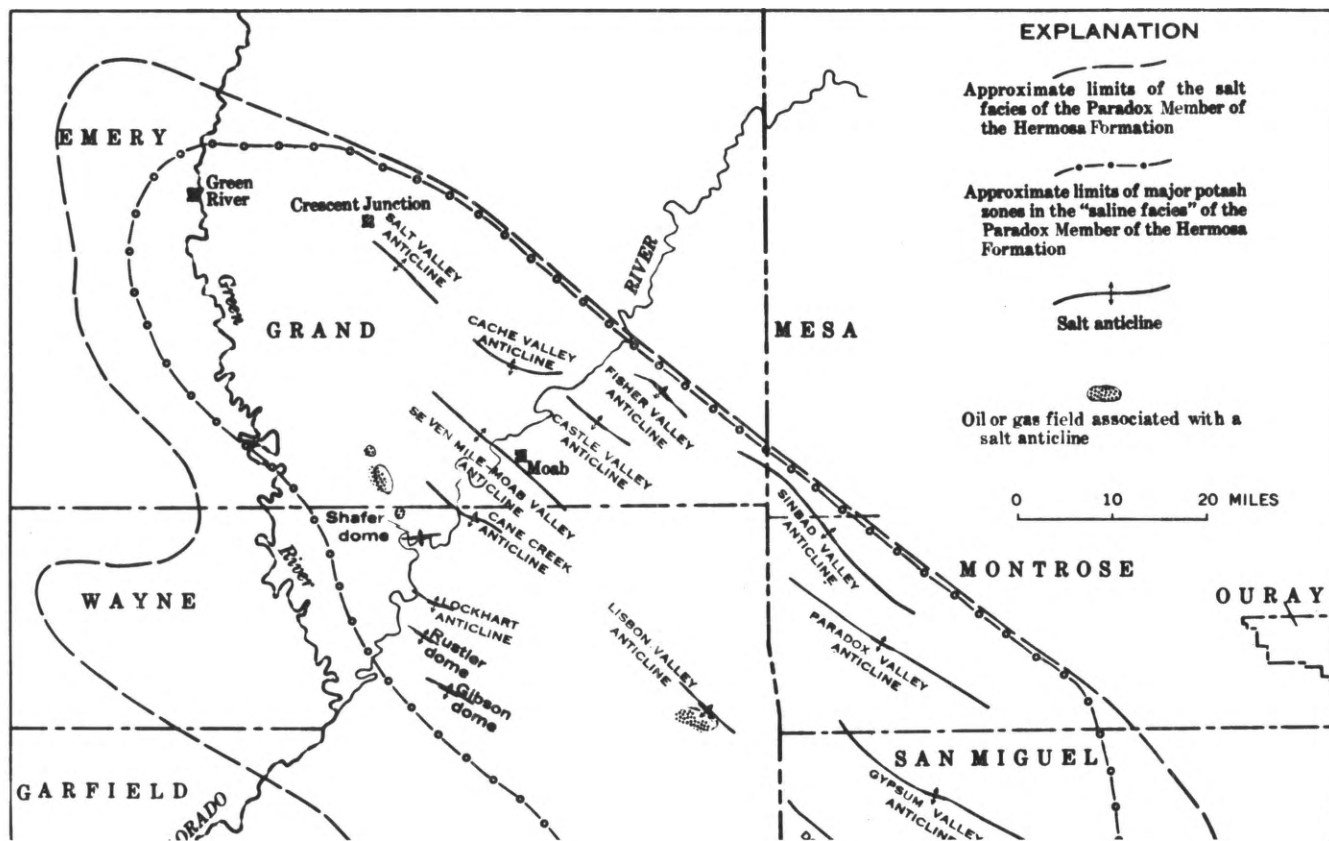
The juxtaposition of potash deposits and oil and gas in the Paradox basin of southeast Utah and southwest Colorado leads to serious problems in any anticipated development, or exploration and development, of these commodities. To avoid serious conflict of interest and loss of mineral resources, the Department of the Interior temporarily withdrew from oil and gas leasing two areas of public lands known to contain valuable deposits of potash in the Paradox Basin. This withdrawal was made for the purpose of preservation and development of the potash deposits. As the withdrawals have led to some misunderstanding, the purpose of this paper is to discuss the geologic significance of the problems that led to this action, and it is hoped thereby to create a better understanding between the potash and petroleum producers.

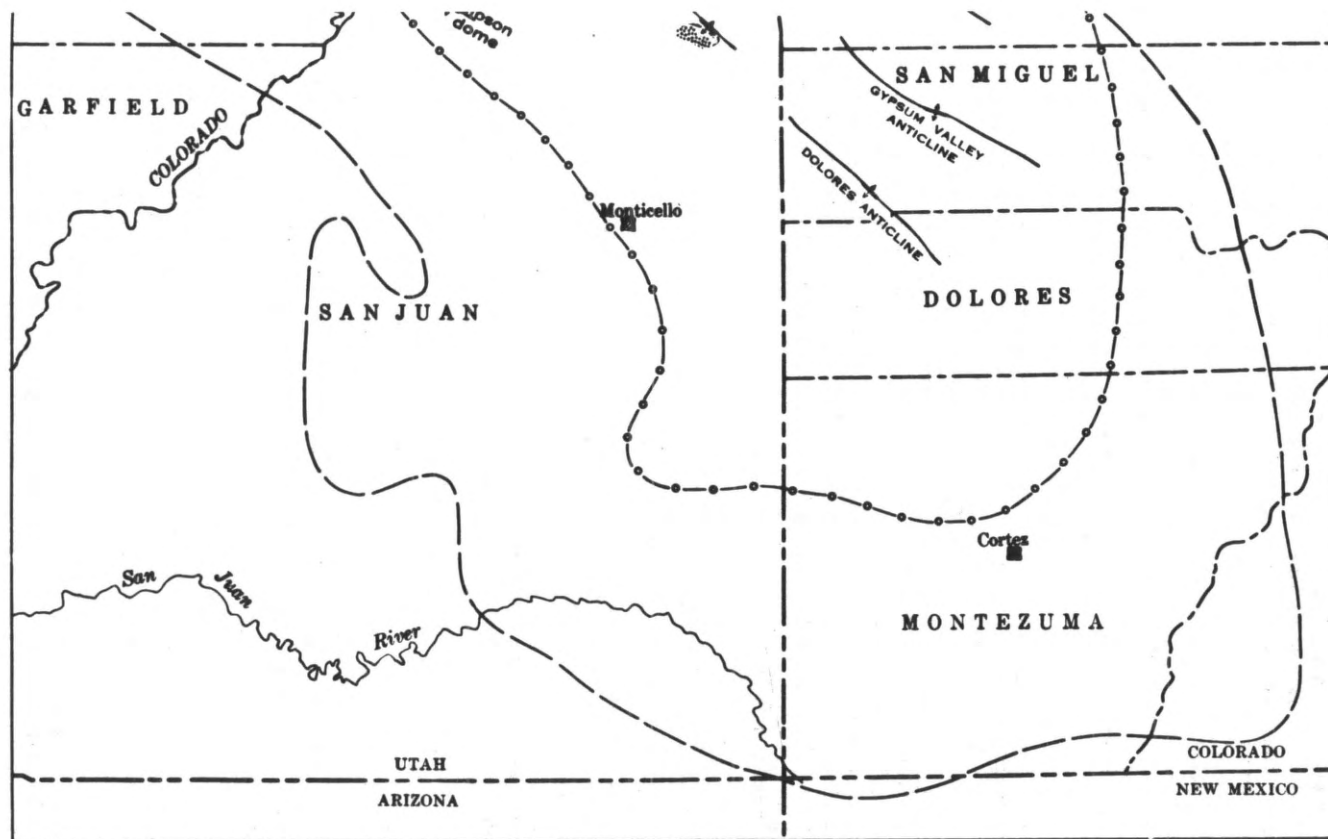
Like many mineral deposits of sedimentary type, the potash in the Paradox Basin was discovered by accident through petroleum exploration. Several of the early oil and gas wells drilled in the basin recorded the presence of potassium and magnesium in brines and cuttings from the Paradox member of the Hermosa formation. Since that time many discoveries have been made through interpretation of radioactivity logs which are run in nearly all oil and gas tests drilled in the basin.

The first discoveries of potassium and magnesium salts were made in 1924 at the northern end of the Paradox Basin by wells drilled for oil and gas in the Crescent Junction area on the northern terminus of the Salt Valley anticline (Figure 155). Shortly afterward additional indications of potash were reported from wells drilled on the Paradox Valley, Moab Valley, and Cane Creek anticlines and on Shafer dome (Figure 155). A later period of oil and gas exploration, starting in the 1940's, verified the presence of sylvite deposits in both the Cane Creek and Seven Mile anticlines. On the basis of favorable indications of potash found in the Delhi-Taylor Oil Corporation Utah well 2, located on the Seven Mile anticline in Grand County, Utah, the Delhi-Taylor Oil Corporation initiated a potash exploration program on the anticline which resulted in outlining the potash deposit. In 1956, the same company, acting on the interpretation of information from oil and gas tests drilled on the Cane Creek anticline, began a second exploration program which confirmed the occurrence of two rich sylvite deposits in this area. Both of these mineral properties were subsequently assigned to Texas Gulf Sulphur Company which has begun installation of plant facilities and sinking a shaft at Cane Creek. It is interesting to note that the Lisbon Valley anticline (Figure 155) potash deposits are the only deposits in the Paradox basin not discovered indirectly through exploration for petroleum. Although the Lisbon Valley anticline was drilled in 1929 by the Union Oil Company, whose well penetrated 3,390 feet of saline deposits, there was no information available indicating the presence of potash until Superior Oil Company began a series of potash test holes in 1958. The latter company's exploration program subsequently established the presence of potash deposits

1. Publication authorized by the Director, U.S. Geological Survey.
2. Geologist, U.S. Geological Survey, Salt Lake City, Utah.

Figure 155. Distribution of halite and potash in the Paradox Basin.





in this area. In 1949 considerable attention was drawn to this same locality by the discovery of oil and gas in the Mississippian rocks beneath the potash deposits on the southwest flank of the surface anticline (Figure 155). Development drilling in this oil and gas field has greatly augmented knowledge concerning the potash deposits in this area.

The most recent development in potash exploration is presently under way on the Salt Valley anticline (Figure 155) where three test holes have been drilled by the San Jacinto Oil and Gas Company. Continental Oil Company has also recently completed a combination oil and gas and potash test hole on this same structure.

Realizing that problems concerning simultaneous production of both oil and gas and potash from any one area could lead to serious conflict and loss, the Department of the Interior, by Secretarial Order, withdrew public lands encompassing 9,445 acres on the Cane Creek anticline from future oil and gas leasing on August 29, 1960 (Figure 156). The withdrawal was made to protect the valuable deposits of potash known to be present, and to allow mining operations to proceed without hazard from future oil and gas test holes which might be drilled in this area. Following the Cane Creek withdrawal, the Department also withdrew 4,918.21 acres of public lands on the Seven Mile anticline for the same reason on May 13, 1961 (Figure 157). Both withdrawals will terminate after a period of ten years from the date of withdrawal unless extended by appropriate order. After restoration the lands will again be subject to leasing for oil and gas exploration and development purposes.

GEOLOGY OF THE POTASH DEPOSITS

A detailed discussion of the Paradox basin potash deposits is beyond the scope of this paper; however, to enable the reader to better understand the problems of exploitation to be discussed in the next section, a brief outline of the geology is necessary.

The potash deposits of the Paradox Basin occur in the Paradox member of the Hermosa formation of Pennsylvanian (Des Moines) age. The Paradox member includes a "saline facies" consisting of a series of partial and complete evaporite cycles and intervening clastics consisting of dark organic-rich shales, mudstones, and siltstones. At the present time, 29 of these cycles have been recognized (Hite, 1960). Deposits of sylvite and carnallite of varying degrees of concentration are found in many of these cycles. At the present time, exploration is centered on two separate sylvite deposits which are found in the upper one-third of the "saline facies." The greatest concentration of potash deposits occurs in that part of the Paradox Basin commonly referred to as the Paradox fault and fold belt (Kelley, 1958). This area is characterized by a series of elongate northwest-trending salt anticlines. These salt anticlines, with their tremendously thick cores of salt and correspondingly higher concentrations of potash, are the only localities within the basin where the "saline facies" has been elevated to relatively shallow depths. Beneath the evaporite sequence lies a complex system of faults and folds which, although related, is disharmonious with the effect of salt tectonics seen at the surface. This masked structure forms favorable oil and gas traps in Mississippian and Devonian rocks. As a rule, the most favorable of these buried structures occurs on the southwest flank of the surface anticlines, although they may extend under part of the salt anticlines. Hydrocarbon accumulation within the "saline facies", which is

controlled largely by salt tectonism (Hite and Herman, 1962), is commonplace in most of the salt anticlines. Locally, these accumulations have shown some promise of commercial importance. It is this close association of oil and gas and potash deposits in the salt anticline region that creates the problems discussed in the ensuing section.

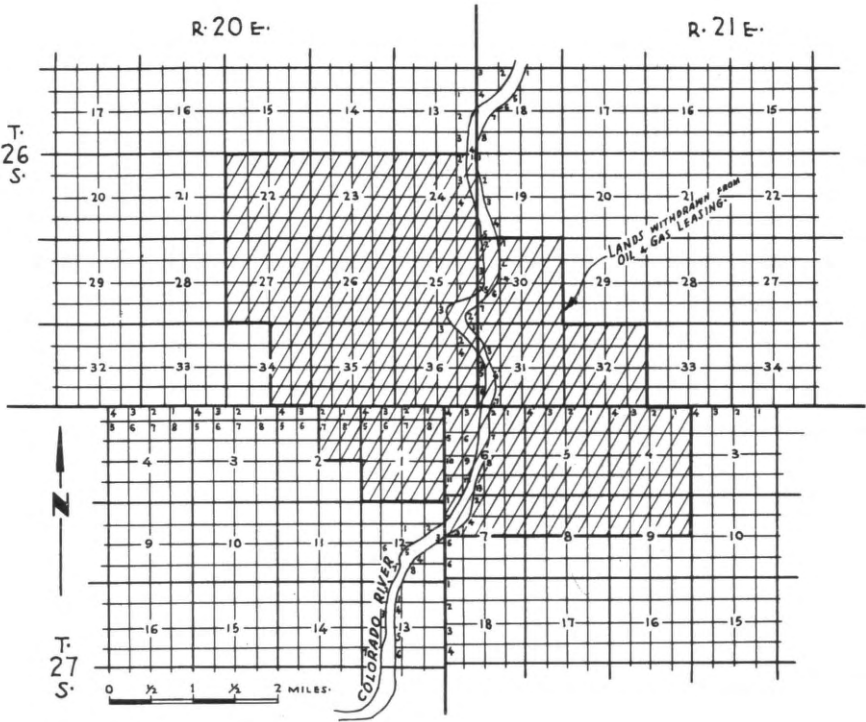


Figure 156. Cane Creek Anticline area showing lands withdrawn from oil and gas leasing.

SEVEN MILE

T. 24 S., R. 20 E., T. 25 S., Rs. 20-21 E., S.L.M., Utah

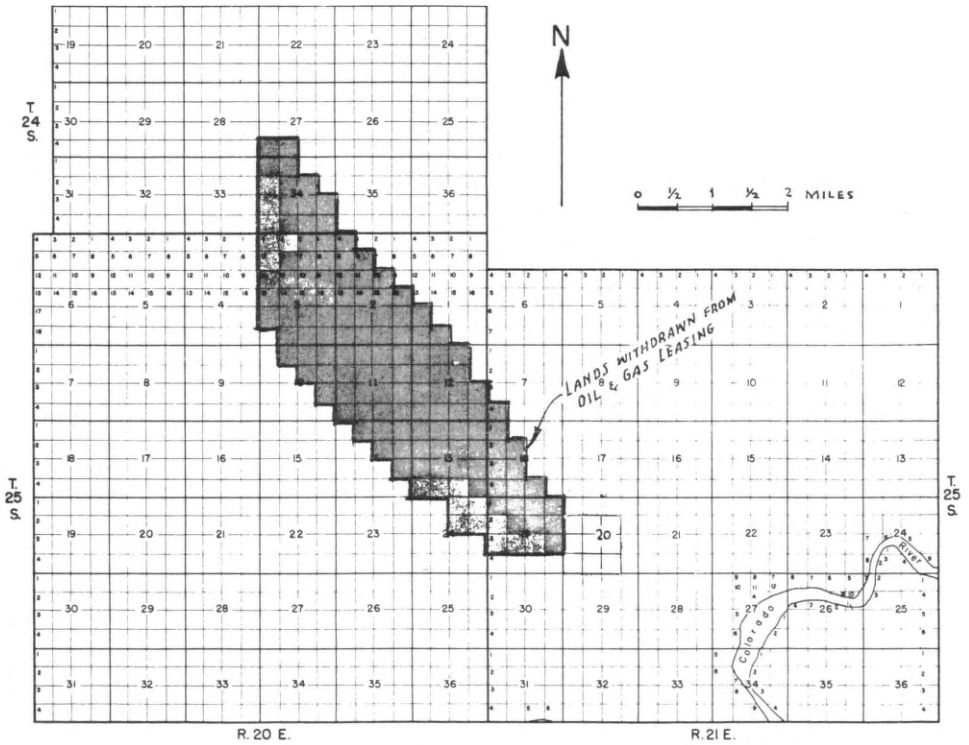


Figure 157. Seven Mile Anticline area showing lands withdrawn from oil and gas leasing.

PROBLEMS IN SIMULTANEOUS DEVELOPMENT OF DEPOSITS OF POTASH AND OIL AND GAS

The coincidental overlap of the Paradox Basin potash deposits and a structural environment favoring the entrapment of oil and gas in the underlying Mississippian and Devonian strata, which have already proven productive in more than one area, poses many problems concerning the simultaneous exploitation of both commodities. Any underground mining operation involving large scale extraction of material will bring on varying degrees of subsidence of the overlying rock. If producing oil and gas wells are located within a subsidence block, it can be expected that damage to some wells will result and that casings and tubing will be sheared off or collapsed in certain wells. In addition to the extensive damage of petroleum production facilities, mine workings in the area would then be endangered by possible entry of gas or fluids under high pressures. This problem of subsidence has been studied in detail in the potash mines of the Carlsbad district where the removal of pillars results in 95 to 98 per cent extraction of the ore bed. In the United States Potash Company mine at Carlsbad the potash deposit is about 1,000 feet below the surface. Studies in this mine (Miller and Pierson, 1958) have shown that the major amount of underground movement is estimated to be about 12 feet, while the major subsidence at the surface involves a much larger area than the actual underground mined area. Miller and Pierson calculated the "limiting angle" (measured from a line drawn vertically up from the edge of advance and a second line drawn upward from the edge of advance to the outermost point where subsidence was observed on the surface) to be between 30 and 51 degrees. The following factors which contribute to the degree of the "limiting angle" are quoted directly from Miller and Pierson (1958, p. 2):

"1. The overlying strata through which subsidence takes place, this angle being relatively small for strong rocks and relatively large for weaker members, the total limiting angle, of course, being the sum of the various limiting angles up through the different strata.

2. It has been observed that the limiting angle is greater in areas where final mining operations are bordered by first mining operations. Strictly speaking, this is not a true limiting angle because extraction outside the area effects an increase of the angle. However, from the practical point of view, it is quite necessary to take this influence under consideration. We have observed in some cases a limiting angle as large as 51 to 30 degrees. It may be when the ground completely stabilizes this angle will be somewhat greater."

Although the results of the Carlsbad studies can be applied as a tentative yard-stick to the Paradox Basin deposits, there are still many factors affecting the latter which leave the "limiting angle" in a stage of guesswork. For example, the Paradox Basin deposits are much deeper. The bottom of the Texas Gulf Sulphur mine shaft at Cane Creek will be approximately 2,800 feet below the surface while at Carlsbad the greatest shaft depth is about 1,800 feet. Because the rocks of the Cane Creek deposits dip as great as 15 degrees, unlike the Carlsbad deposits, the support pillars will be subjected to forces tending to cause them to override in the direction of dip. The "saline facies", being a sandwich of thick salt beds and thinner penesaline beds and clastics, may have more strength than is commonly realized and consequently act with less plasticity than a single unbroken thickness of halite. Another factor, the effect of which is hard to predict, is the tremendous thicknesses of salt below the potash deposits. For example, at Cane Creek a thickness of 4,530 feet of the "saline

facies" underlies the uppermost potash deposit. Also, it is difficult to estimate the effects that will be caused by the great differentials in overburden in the Paradox Basin deposits. Most of this area is canyon country where it is possible in less than one-half mile on the surface to achieve 1,500 feet of relief.

SUMMARY

Petroleum exploration in the salt anticline area of southeast Utah and southwest Colorado is expected to gain in impetus and scope. This area still has a very low density of drill holes testing pre-salt formations and there will probably be extensive exploration in the near future. Future drillings for oil and gas will indirectly supply valuable information concerning the potash deposits but will no doubt create new areas for conflict between oil and gas production and possible potash exploitation. As more is learned about the salt anticlines, it may be found that favorable hydrocarbon traps exist beneath the great masses of salt themselves. Until such time, the area of greatest conflict will be along the flanks of the salt anticlines, although production from the "saline facies" within the anticlines may also present a problem. Mine development by Texas Gulf Sulphur Company at the Cane Creek anticline will provide much needed information regarding subsidence at such depths and conditions. Then more precise estimates can be made of the size of pillars necessary for the protection of well casings present in the area affected by subsidence. This may or may not allow closer spacing of petroleum production facilities and underground mining operations.

CITED REFERENCES

- Hite, R. J., 1960, Stratigraphy of the saline facies of the Paradox Member of the Hermosa Formation of southeastern Utah and southwestern Colorado: Four Corners Geol. Soc. Guidebook, 3rd Ann. Field Conf., p. 86-89.
- Hite, R. J., and Herman, G., 1962, Salt Tectonics in the Paradox Basin (abs.): Am. Assoc. Petroleum Geologists, Program Booklet, 12th Ann. Meeting, Rocky Mountain Section, p. 12-13.
- Kelley, V. C., 1958, Tectonics of the region of the Paradox Basin: Intermountain Assoc. Petroleum Geologists Guidebook, 9th Ann. Field Conf., p. 31-38.
- Miller, E. H., and Pierson, F. L., 1958, Underground movement and subsidence over United States Potash Company Mine: Am. Inst. Mining Metall. Petroleum Engineers Trans., Preprint No. 5819P9.

INDEX

A

Abajo Mountains, 16, 155, 157, 160, 388, 397, 395
 Absolute Age, 158, 161, 165, 167
 Acidic Alkalic Rocks, 27
 Act of August 8, 1946, 512
 Act of August 13, 1954, 512
 Act of February 25, 1920, 512
 Act of July 17, 1914
 Aeolian Sandstone, 109, 119
 Akah Oil Field, 6
 Albertite, 215, 249, 251, 252, 257, 258, 259, 264,
 269, 271, 273
 Albite, 168
 Albrecht & Assoc. Morre-Elkhorn #1 Wildcat, 335
 Algal Limestone, 42
 Algal Tuff, 148
 Algonkian, 39
 Alien Valley Shale, 130
 Alluvial Deposits, 149, 150, 152
 Almond Formation, 125, 127
 Almy Formation, 25, 26, 27, 127
 "Alpine" Lake Beds, 150, 153
 Alta Intrusive Body, 155, 160, 167
 American Fork Canyon, 79, 330
 Amphibolite, 41, 168
 Amsden Formation, 96
 Amsden Sea, 95
 Anaerobic Bacteria, 277, 283
 Anderson Hudson #1 Well, 477
 Aneth Formation, 85, 411, 483, 485
 -complex, 413, 416
 Aneth Oil Field, 5, 6, 10, 405, 433, 443, 500, 501,
 502
 -area, 407, 409, 410, 411, 453
 Anderson, G. H., #2 Farmington, 297
 Anhydrite, 373
 Ankareh Formation, 110, 330
 Anorthite, 168
 Antelope Island, 40, 41
 Antimony, Utah, 327
 Antler Belt, 19, 89
 Antler Orogeny, 296
 Aquareous Plateau, 149
 Aquifers, 149
 Arapahoe Shale, 116, 118, 131, 291, 329, 333, 344
 Archean, 39
 Archeozoic Era, 389, 393, 394, 397, 398
 Arcturus Formation, 290
 Argo Oil Co., Hickman #1, Wildcat, 338
 Argulite, 255
 Argyle Canyon, 247
 Argyle Creek, 225, 255
 Arizona, 43, 102, 110, 111, 119, 306
 -northeastern, 405
 Aromatics, 258, 259, 261, 267, 271
 Ash Disposal, 210
 Ashley Creek, 497, 498, 499, 500, 501, 502, 504
 Ashley Valley, 225
 Ashley Valley Oil Field, 5, 6
 Aspeco Process, 209
 Aspen Formation (Shale), 24, 123, 125, 126, 127,
 128, 129, 177, 180
 Asphalt, 223, 253, 255, 278, 295, 298
 -origin of, 237
 Asphalt Canyon, 219
 Asphalt Ridge, 223, 225, 229, 241
 -sandstone member, 130, 225, 229
 Asphaltene, 257, 265, 268
 Asphaltic Sands, 225-229, 235, 237, 295, 297
 Asphaltic Resins, 268
 Asphaltites, 257
 Atchinson Formation, 162
 Atokan Time, 94, 95, 96, 98, 359
 Atomic Energy Commission, 210
 Awapa Plateau, 335

B

Bajada, 150
 Baldhills Member (Isom Formation), 163
 Bannock Highland, 94, 95
 Bannock Thrust, 25, 185
 Barrier Creek, 373
 Bar-X Anticline, 377
 Bar-X Gas Field, 7, 363, 369
 Base Metals, 45
 Basin and Range Faulting, 27-28
 Basin and Range Province, 13, 17, 18, 51, 109, 123,
 158, 168, 183, 287, 306, 309, 327, 383
 Bauer's Tuff, 163
 Baxter Shale, 125, 126
 Bear Lake, 113, 141, 185
 Bear River, 13, 18
 Bear River Formation, 127, 132, 190
 Bear River Range, 63, 90, 95, 141, 148, 149, 185
 Bear Valley, 323
 Beaver County, Utah, 160
 Beaver Dam Mountains, 81, 305, 309
 Beaver Lake Intrusives, 155, 160
 Beaver, Utah, 296, 338
 Beaver Valley, 293
 Bee Hive Dome, 309, 315
 Beckwith Formation, 190
 Beef Basin, 469
 Beirdneau Sandstone, 76, 85
 Belco # 2 State, 437, 441
 -#4 State, 437
 Belle Fourche Time, 135
 Belt System, 43
 Belknap Series, 168
 Ben H. Bullock, et al. #1 Unit, Redmond, 335
 Bend Gas Field, 7, 201
 Bentonite, 110, 111, 121
 Big Cottonwood Canyon, 40, 42
 Big Davis Mountains, 291
 Big Flat Oil Field, 6, 359, 365, 387, 399, 402, 447,
 462, 463
 -anticline, 455
 -area, 457
 Big Flattop Anticline, 373, 379
 Big Mountain Intrusive, 155, 157, 160
 Big Springs, Nevada, 67
 Bingham, Utah, 165
 Bingham Intrusive, 155, 160
 Bingham Quartzite, 45
 Bighorn, 425, 427
 Biotite, 168
 Bird Springs Formation, 100, 102, 305
 Bitumens, 261, 262
 -composition and origin of, 249-273
 -terminology and classification of, 254
 Bituminous Limestone, 225-247
 Bituminous Resources, 215, 220, 221, 223
 Bituminous Sandstone, (also see tar sands), 215, 220,
 223, 225-247, 249, 281
 -nature of, 235
 Black Dragon (gilsonite) vein, 217, 219, 257, 264
 Black Mesa Basin, 469
 Black Oil Zone, 453, 455, 457, 462, 467
 Black Rock, Utah, 295, 299
 Black Shales, 373
 Black Virgin Mine, 244
 Blackhawk Formation, 130, 132, 135, 334
 Blacksmith Fork Canyon, 148
 Blair Formation, 125, 126, 127
 Blanding Basin, 413, 420, 421, 427, 473
 Blanding, Utah, 424, 425
 Bloomington Dome, 309, 314, 317
 Blue Bell Gas Field, 7
 Blue John, 373
 Blue Mountain, 175, 229, 237
 Blue Point Limestone, 305
 Blue Springs Hills, 91, 95
 Bluebell Arch, 194

- Bluebell Dolomite, 66, 82
 - Bluegate Sandstone, 133, 334
 - Bluegate Shale, 130, 131
 - Bluepoint Limestone, 93
 - Bluff Bench Oil Field, 6
 - Bluff Oil Field, 6, 411, 500, 501, 502
 - Bluff Sandstone, 117, 121
 - Bluff, Utah, 117, 425
 - Bonanza Area, 255
 - Bonanza-Rainbow Area, 253
 - Bonanza Gilsonite Mine, 255, 267
 - Bonanza (gilsonite) Vein, 217, 218, 257, 261, 264, 265
 - Bonneville Formation, 152
 - Bonneville Salt Flats, 295
 - Bonneville Time, 147
 - pre Bonneville time, 161
 - Bonus (for lease), 5
 - Book Cliffs, 16, 17, 129, 132, 135-136, 141, 329, 341, 355, 357, 363, 369, 375, 377, 378
 - Boulder Mountain, 381
 - Boundary Butte Anticline, 405
 - area, 410
 - Boundary Butte Gas Field, 7
 - Boundary Butte Oil Field, 6, 499, 500, 501, 502
 - Box Elder County, 76, 77, 160, 296
 - Brachiopods, 53, 63
 - Brazier Limestone, 305
 - Brennan Bottom Oil Field, 6
 - Brian Head Formation, 281
 - Brigham City, 39, 185, 296, 298
 - Brigham City Quartzite, 43
 - Bright Angel Shale, 324, 382
 - Broken Hills Oil Field, 6
 - Brookline Oil Co. #1 Unit, Redmond, 335
 - Browns Park Formation, 143
 - Browns Park Ranch Area, 177
 - Brushy Basin Shale Member (Morrison), 117, 279, 334, 376, 377
 - Bryce Canyon, 141, 144, 383
 - Bryson Canyon, 377
 - Buckhorn conglomerate, 129, 130, 131, 133, 136, 355, 369, 371, 375, 377
 - Bull Valley District, 157, 159
 - Bull Valley Intrusive, 155, 157, 160, 303
 - Bullet Springs, 475
 - Bullion Canyon "Series", 161, 163, 168
 - Burbank Hills, 79, 81, 299
 - Bureau of Land Management, 511, 512, 513, 515
 - Bureau of Mines, 497, 498, 507
 - Burnt Canyon Limestone, 290
 - Burro Canyon Formation, 123, 125, 129, 133, 134, 369, 396, 431
 - Burrows Limestone, 290
 - Busby Quartzite, 290
 - Byrd Oil Gov't. Reese Canyon 1, 80
 - Bysmalith, 155, 157
- C**
- Cabeen Exploration No. 1 Big Flat-Govt., 457
 - Cabazon Sag, 96
 - Cache County, 76, 90, 91, 92, 183
 - Cache Valley, 95, 141, 147, 148, 149, 293, 300
 - Cache Valley Dairy Assoc. #1 Gossner, 298
 - Cache Valley Formation, 143
 - Cahone Mesa Oil Field, 6, 407
 - Cainville Anticline, 375, 377
 - Calcium, aluminio-carbonate molecules, 168
 - orthosilicate, 168
 - California, 5, 19
 - California Oil Co. No. 21-15 Arnold, 437
 - No. 1 Johns Valley, 383
 - test, 424
 - No. 1 St. George, 305
 - No. 1 Upper Valley, 383
 - Callville Limestone, 100, 305, 313, 314, 315, 337
 - Camay Standard, Levan #1, Levan, 335
 - Cambrian, 39, 43, 45-49, 66, 75, 83, 86, 131, 132, 150, 175, 290, 299, 305, 325, 358, 382, 388, 391, 402, 433, 451, 453
 - general, 45
 - paleotectonic history, 49
 - Cane Creek Anticline, 519, 521, 525, 526
 - area, 416
 - zone, 453, 457, 462, 463, 467
 - Cane Creek Marker, 379, 455, 462, 499, 500
 - Canyonlands National Park, 447-467
 - Canyonlands (subprovince), 16-17, 447-467
 - oil and gas occurrences in, 447-467
 - Canyon Junction Vein (bitumen), 257
 - Canyon Range, 49, 131, 143, 291, 292, 327
 - Capitol Reef National Monument, 116
 - Carbenes, 257
 - Carboids, 257, 268
 - Carbonates, 53, 76, 85, 86
 - Carbon County, 1, 4, 223, 225, 239, 353
 - Carbon Dioxide, 7
 - Carbon Gilsonite Vein, 219
 - Carbon Ridge Formation, 103
 - Carlsbad District, 525
 - Carlisle Time, 135
 - Carmel Formation, 116, 117, 118, 119, 120, 121, 157, 177, 305, 306, 311, 324, 325, 330, 334, 337, 382
 - Carson Peak Area, 186
 - Carter (Humble) Oil Co., 186
 - Aztec No. 2, 417
 - Glad Unit, 423
 - Larson State Well #1, 376
 - test, 424
 - Ruth Nelson #1, 229
 - Sphinx, #1, 424
 - Wheatley #1, Coon Springs, 335
 - Castlegate Formation, 369
 - Castlegate Sandstone Member (Price River Fm.), 135, 202, 334, 345
 - Castle Peak Gilsonite Vein, 219
 - Castle Valley, 334
 - Cataract Canyon, 97
 - Cedar Breaks, 141
 - Cedar City, Utah, 111, 141, 144, 150, 158, 159, 323, 326
 - area, 321
 - Cedar Hills, 23, 144, 331
 - Cedar Mesa Anticline, 469, 473, 475, 480
 - Cedar Mesa Member (Cutler formation), 100, 101, 361, 382, 473
 - Cedar Mountains, 158
 - Cedar Mountain Formation, 123, 125, 128, 129, 130, 131, 133, 134, 135, 201, 334, 355, 369, 371, 375, 377, 396
 - Cedar Pocket Canyon Fault, 315
 - Cement Plant, 118
 - Cenozoic, 141, 291-296, 300
 - oil and gas possibilities of, 291-296
 - Central Intrusive, 155
 - Chaetetes Colonial Coral, 423, 493
 - Chainman Shale, 93, 290
 - Chalk Creek Thrust, 191
 - Chapita Sandstone Member, 201
 - Chapita (gilsonite) Vein, 218
 - Chapita Wells Area, 225
 - Chapita Wells Bituminous Sandstones, 244
 - Chapita Wells Gas Field, 7, 201, 499
 - Chapita Wells Oil Field, 6, 202, 500, 501, 502
 - Charleston Thrust, 185, 327
 - Chazyan Age, 53
 - Chemical Sediments, 45, 123, 148
 - Cherry Creek Region (Montana), 41
 - Cheslerian Time, 89, 93
 - Chimney Rock Tongue, 126
 - Chimle Formation (group), 109, 110, 111, 112, 118, 177, 305, 324, 325, 330, 335, 337, 338, 361, 363,

- 368, 370, 375, 378, 382, 431, 450, 451
Chinle Wash Gas Field, 7, 483
-area, 410
Chlorite, 41, 42
Chokecherry Canyon, 197
Chromatography, 266-267
Church Rock Area, 417
Circle Cliffs, 17, 102, 110, 112, 338
-uplift, 19, 381
-upward, 383, 469
Cisco Anticline, 378
Cisco Dome Gas Field, 7, 376
Cisco Dome Oil Field, 6
Cisco Springs Gas Field, 7, 376
Cisco Townsite Gas Field, 7, 363, 375
Cities Service #1 Gov't. Well, 362
City Creek Canyon, 40
Claron Formation, 138, 157, 159, 162, 163, 303, 306, 307, 309, 311
Clay, 82
Clay Basin, 125, 126, 127, 177
Clay Basin Anticline, 177, 180, 186
Clay Basin Fault, 180
Clay Basin Gas Field, 7, 177-182, 183
Claystone, 110
Clayton Peak Intrusive, 155, 160, 167
Clear Creek Gas Field, 7, 10, 327, 341, 343, 344, 345, 349, 352, 369
Cloverly Formation, 125, 126
Coal, 4, 23, 24, 132, 134, 135, 136, 137, 264
-anthracite, 264
-bituminous, 264
Coal Creek Canyon, 144
Coalbank Pass, 393
Coalbed Canyon Gas Field, 7
Coalpits Wash, 309
Coalville Anticline, 187, 190, 191
Coalville, Utah, 127, 128, 141, 185, 190
Cocoonino Sandstone, 100, 101, 102, 305, 330, 334, 341, 345, 352, 361, 365, 369, 370, 371, 372, 373, 382, 398, 500
Coking Process, 236-237
Collinston Conglomerate, 141, 143
Coloradan Age, 24, 137, 138
Colorado, 47, 49, 51, 57, 89, 90, 93, 96, 98, 100, 104, 127, 128, 129, 130, 135, 136, 175, 181, 183, 207, 221, 223, 394, 413, 421
-central, 395
-southwestern, 405, 417
-western, 445
Colorado Plateaus (Province), 13-17, 18, 27, 51, 97, 103, 109, 110, 112, 113, 116, 117, 118, 125, 129, 133, 134, 141, 152, 158, 159, 166, 168, 291, 306, 334, 353, 355, 359, 373, 475
-craton, 358
-uplift of, 28, 49
Colorado River, 13, 16, 17, 97, 98, 102, 110, 112, 116, 117, 133, 134, 363, 376, 378, 381, 383, 445, 447, 455, 483
Colorado Time, 126, 303, 306
Colorado Trough, 96
Colton Formation, 144, 201, 330, 334
Colton, Utah, 144, 255
Columbia Plateaus Province, 13
Columbia River Basalt, 159
Comb Ridge, 416, 420, 425, 469, 473
Comb Wash, 101
Completion Procedures, 205, 206
Composition of Bitumens, 249-273
Compressor Plant, 181
Conchidium, 67-71
Condensate, 181, 205
Confusion Basin, 113, 287, 290
Confusion Range, 66, 67, 71, 72, 79, 81, 86, 287, 291, 299
-geologic section of, 290
Conodont, 53
Conradson Carbon, 499, 501
Conservation, 4
Coral, 53
Cordilleran Geosyncline, 19, 89, 102, 287, 325, 353, 355, 357, 373, 381, 394, 469
-region, 131, 280
Cosco Oil Co. #1 Shorty, Wildcat, 335
Cottonwood Anticline, 376
Cottonwood District, 90, 91
Cottonwood Gilsontite Vein, 219
Cottonwood Uplift, 329, 330
Country Gentlemen (bitumen) Vein, 257, 282
County Pit, 228, 235
County Pit Fault, 225, 228
Court House Syncline, 378
Cowboy (gilsontite) Vein, 217, 218, 221, 267
Cowboy-Bonanza (gilsontite) Vein System, 217
Crab Creek Formation, 330
Craton, 51, 53, 57
Crawford Mountains, 104, 185
Crazy Hollow Formation, 144
Crescent Junction Area, 519
Crescent Wash Syncline, 378
Cretaceous, 17, 20, 21, 123-138, 143, 144, 150, 199, 200, 224, 291, 296, 331, 363, 382, 383, 395, 396, 399, 431, 499, 500, 501, 502, 503, 507
-early, 127, 128, 133, 136, 167, 190, 313
-late, 127, 135, 138, 141, 183, 186, 190, 200, 201, 204, 303, 375
-lower, 115, 116, 125, 126, 129, 131, 133, 134, 306
-upper, 177, 180, 306, 309, 316
Cross-bedding, 42
Crossing of the Fathers, 116
Crystal Peak Intrusive, 155, 157, 160
Culbert Breccia, 162, 306
Cupola, 155, 157
Currant Creek, 130
Currant Creek Formation, 123, 128, 130, 245
Currant Peak, 128
Current Creek, 83
Curtis Formation, 116, 117, 118, 119, 120, 121, 128, 129, 136, 177, 239, 305, 324, 325, 330, 334, 337, 371, 382
Cutler Facies, 102
Cutler Formation, 98, 100, 101, 359, 361, 399, 400, 431, 451, 469, 471, 475
Cyathophyllum, 63
- D**
- D. Feldman #1 Diamond, 331
-#2, Sun, Diamond Fork, 331
Daggett County, 4, 177, 183, 186
Daily Production of Crude, 4
Dakota Formation (Sandstone), 123, 125, 126, 128, 129, 130, 131, 132, 133, 134, 135, 136, 177, 180, 181, 200, 201, 204, 224, 306, 324, 334, 341, 142, 344, 355, 359, 369, 375, 376, 377, 378, 382, 396, 431
Dakota (?) Formation, 115, 123, 306
Dakota Group, 123
Danish Wash Gas Field, 7, 376
Davis County, 152, 183
Decathon Dolomite, 67
De Chelly Member (Cutler Fm.), 100
Deep Creek, 149, 225
Deer Creek Range, 95, 157, 287
-geologic section, 290
Defiance Uplift, 113, 394, 397, 469, 480
Dehydration Plant, 181
Delhi Taylor No. 2 Utah-State, 453, 455
Deliverability, 205, 206
Department of Interior, 512, 513, 516
Depletion, 202
Deposition, 25
Deposits (see individual types, alluvial, lake, etc.)

- Depth of Wells, 205
 - Deseret Limestone, 90, 91, 330, 357, 398
 - Desert Basins, 150
 - Desert Creek Limestone, 493
 - Desert Creek Oil Field, 6, 411, 416, 500, 501, 502
 - Desert Creek Zone (of Paradox), 360, 417, 487, 489
 - of southeast San Juan Co., 405-411
 - Desert Mountain Stock, 155, 160
 - Desmoinesian Time, 93, 94, 96, 98, 99, 100, 357, 359, 395, 413
 - Detrital Deposits (alluvium), 149
 - Devils Slide, 118
 - Devonian, 19, 66, 75-88, 175, 290, 305, 358, 377, 382, 387, 394, 429, 433, 435, 440, 441, 443, 453, 455, 462, 507
 - Diamond Creek Sandstone, 102, 330
 - Diamond Oil #1 Fee, Diamond Fork, 331
 - #2 Fee, Diamond Fork, 331
 - #3 Fee, Diamond Fork, 331
 - #1 Unit, Diamond Fork, 331
 - Diamond Peak Formation, 93
 - Diamond Ridge, 377
 - Diatomite, 148
 - Dike, 155, 157
 - Dinosaur Canyon Sandstone Member (Moenave Fm.)
 - 111, 305
 - Dinwoody Shale, 113
 - Diorite Porphyry, 158
 - Dolomite, 43, 52, 53, 56, 57, 67, 71, 76, 77, 82, 85, 90, 91, 99, 102
 - Dome Limestone, 290
 - Douglas Creek Arch, 195
 - Douglas Creek Gas Field, 135, 175
 - Doughnut Formation, 91, 93
 - Dove Creek, Colorado, 499
 - Dragon-Asphalt Wash Asphaltic Sandstones, 244
 - Dragon, Utah, 223
 - Drilling Costs, 205, 206
 - Drum Mountain, 158
 - Drum Stock, 155, 160
 - Dry Hollow Latite, 161, 163
 - Dry Lake Section, 91, 92
 - Dry Mountain, 41, 79, 83
 - Dry Valley Quadrangle, 104
 - Duchesne Area, 211, 213
 - Duchesne County, 1, 4, 211, 219, 225, 500
 - Duchesne Fault Zone, 195
 - Duchesne Oil Field, 6, 251, 499, 500, 501, 502, 503, 504, 505
 - Duchesne River, 130, 194
 - Duchesne River Formation, 26, 143, 175, 194, 225, 229, 235, 237, 244
 - Duchesne, Utah, 195, 197, 255
 - Dudley Well No. 1, 427
 - Dugway Range, 79, 81
 - Dunes, 149
 - Durst Mountain, 79, 85
- E**
- E. L. K. Oil Company, 186
 - E. R. Bardwell #1 Venton Well, 312, 313
 - Eagle Springs Oil Field, 293
 - Earl N. Ramey Fee. R-1, Wildcat, 335
 - East Canyon, 27, 377
 - East Tintic Mountains, 79, 91, 92
 - Echo Canyon, 141
 - Echo Canyon Conglomerate, 24, 26, 123, 125, 127, 128, 130, 141, 150
 - Egan Range, 292
 - Egnar Unit Area, 423
 - Eight Mile Dacite, 162
 - Elbert Formation, 358, 382, 429, 433, 435, 453
 - El Capitan #1 James, 299
 - El Paso-Colorado Interstate, California, 203
 - Elbert Formation, 85, 483, 485
- Elemental Analyses (bitumen), 281
 - Elevation
 - Basin and Range Province, 17
 - Canyon Lands, 16
 - High Plateaus Subprovince, 16
 - Utah, 13
 - Wasatch Mountains, 18
 - Elliott 1-C, 437
 - El Paso Nat. Gas #1 Pack Saddle, 362, 390
 - #1 Salina Canyon, 335
 - Ely Limestone, 290
 - Emery County, 1, 4, 57, 98, 157, 160, 334, 353, 373, 497
 - Emery Sandstone, 130, 133, 135, 201, 334
 - Emery Uplift, 19, 357, 370, 395, 489
 - Enabling Act, 511
 - Enterprise, Utah, 138
 - Entrada Formation, 113, 116, 117, 118, 119, 120, 121, 138, 177, 180, 181, 206, 208, 305, 306, 324, 325, 330, 334, 337, 363, 369, 371, 375, 376, 377, 382, 500, 504
 - Eocene, 25, 26, 27, 128, 130, 141, 143, 144, 161, 165, 167, 168, 176, 183, 190, 200, 208, 244, 281, 292, 296, 382, 383
 - oil and gas possibilities of, 292
 - Eolus, 393
 - Epelrogenic Movement, 49
 - Equity Oil Government #1, 90
 - Bricson Formation, 125, 127
 - Escalante Desert, 158
 - Eugeosynclinal, 51
 - Eureka Area, 163
 - Eureka Quartzite, 56, 290
 - Evacuation Creek Member (Green River Fm), 209
 - Evanston Formation, 25, 26
 - Evaporite, 21, 102, 148
 - Exploration, 1
 - costs, 207
 - Extraction Techniques, 213
 - Extrusive Igneous Rocks, 27, 28, 158-167
- F**
- Fanglomerates, 148, 150, 151, 152
 - Farmington Gas Field, 295, 297, 300
 - Farmington, Utah, 295, 296
 - Farmington Wasatch, 26, 41
 - Farnham Dome Area, 357, 362, 369, 371-372, 373
 - Farnham Dome Gas Field, 7, 369, 371-372
 - Faults and Faulting, 27, 28
 - Fault Scarp, 150
 - Faunal Zones, 54-55, 57, Favosites, 63, 67, 72
 - Fayalite, 168
 - Federal Bureau of Mines Experiment Station, 497
 - Federal Code of Regulations, 512
 - Federal Oil #1 Bow knot, 462
 - Feldspar, 168
 - Fence Canyon, 377
 - Fernow Quartz-Latite, 163, 165
 - Ferron Anticline, 375
 - Ferron Gas Field, 7, 307, 343, 345, 349
 - Ferron Sandstone, 130, 131, 133, 135, 334, 341, 343, 344, 349, 352, 369
 - Field Price (gas), 205
 - Fillmore, Utah, 148, 159, 299
 - Fish Haven Dolomite, 51, 53, 59, 63, 66, 67, 290
 - Fish Lake Plateaus, 149, 331, 333, 335
 - Fish Springs Range, 158
 - Fisher Valley, 98
 - Fitchville Dolomite (formation), 85, 90
 - Fixed Carbon Content (bitumens), 257
 - Flagstaff Limestone (formation), 26, 27, 143, 144, 201, 330, 334, 337
 - Fiat Canyon Gas Field, 7, 327, 341, 343, 349, 352, 369

Flat Top Mountain Suite, 306
 Forsterite, 168
 Fort Duchesne (Gilsonite) System, 219
 Fort Union Formation, 186
 Fossils, Silurian, 67
 Four Corners Area, 93, 99, 117, 394, 402
 Fowkes Formation, 141, 143, 147, 293
 Fowkes Tuff (SW Wyo.), 27
 Fox Hills Formation, 127
 Frac Fluid, 205
 -oil-base frac, 205
 -water-base frac, 205
 Fractionation of Sulfur Isotopes, 276, 278
 Franson Tongue (Park City Formation), 104
 Fremont Sag, 96
 Fresco Intrusive, 155
 Frisco Area, 158, 167
 Front Range Highlands, 95
 Frontier Formation, 24, 123, 125, 127, 128, 129, 177,
 180, 187, 190, 191, 279
 Funk Valley Formation, 130
 Fuson (?) Shale, 177

G

Gallie Muley Creek #1, 80
 Gannett Formation (Wyoming), 190
 Gannett Group (SE Idaho), 23
 Garden City Formation, 51, 52-53, 58
 Gardison Limestone, 90
 Gardner Limestone, 330
 Farfield County, 4, 160, 321
 Garnet, 41
 Garrison, Utah, 66, 67, 299
 Gartra, 110
 Gas, 180, 224
 -natural gas, 180
 -reserves, 180, 181
 -storage, 187, 191
 -sweet gas, 180
 Gas Fields in Utah, general, 7
 Gas Hills District, Wyoming, 279, 280
 Gas and Oil possibilities (see oil and gas possibilities)
 Gastroliths, 134
 Gateway, Colorado, 388, 389
 Gathering Facilities, 1
 Geanticline, Cordilleran, 19, 20
 Geophysical Exploration, 5
 -surveys, 181
 Geosyncline, 53
 Geotronic Development #1 Jacketta, 297
 Gerster Formation, 104, 290
 Gibson Dome, 407, 455
 Gilsonite, 4, 261, 264, 265, 267, 268, 271, 273,
 195, 215-224, 249, 251, 253, 255, 257, 258, 259
 -map, 216
 -mining and markets, 221
 -uses, 215
 -vein systems, 217-219
 Gilson Range, 79
 Glacial, 149, 148,
 Glade Unit Well, 423
 Glauconite, 118, 121
 Glen Canyon Group, 116, 118, 119, 305, 363, 369,
 370, 375, 431, 451
 Gneiss, 39
 -hornblende, 41
 -injection, 41
 Gold, 111
 Gold Hill Intrusion, 160
 Gold Hill Mining District, 53, 66, 71, 77, 81, 82,
 91, 92, 104, 113, 158, 166, 167, 292, 293
 Gold Hill Stock, 155
 "Goodridge" Formation, 471, 481
 Goose Creek, 166, 167
 Goose Creek Area, 293
 Gordon Creek Gas Field (CO₂) 7, 341, 342, 343, 345,

349, 356
 Gordon Gray Co. #1 Emery, 335
 Goshute Lake, 193
 Gothic Mesa Oil Field, 6, 411
 Graben, 27
 Grafton, 309
 -fold, 315
 Grand Canyon, 100, 101, 103, 361, 383
 Grand Canyon System, 43, 393
 Grand County, 1, 4, 5, 6, 97, 98, 117, 160, 353,
 363, 389, 500
 Grand Valley, Colorado, 209, 375, 379
 Granite Mountain Intrusive (Iaccolith), 155, 157,
 160, 311
 Granite Range Stock, 155, 157, 158, 160
 Granitic, 41
 Grantsville, Utah, 298
 Granulite, 41
 Graptolites, 53, 60
 Grass Valley, 16, 335, 337
 Grass Valley Formation, 162
 Grassy Trail Unit (Moenkopi?), 368, 372
 Gravels, flood plain, 152
 -river terrace, 152
 Gravel Surfaces, 149
 Great Basin, 28, 56, 110, 113, 149, 150, 152, 159,
 168, 287, 290, 291, 316
 Great Basin Petroleum Chase #24-10 Wildcat, 335
 Great Blue Limestone, 91, 92, 330
 "Great" Fault, 190
 Great Salt Lake, 13, 45, 49, 148, 152, 185, 300
 Great Salt Lake Desert, 56, 158, 167
 Great Staircase, 16
 Greater Aneth Area, 463, 483
 Green Lakes, 150
 Green River, 18, 97, 102, 110, 113, 126, 198, 219,
 222, 445, 447
 Green River Time, 197, 161, 239
 Green River, Utah, 117, 135, 141, 209, 365, 378
 Green River Basin, 125, 183, 186, 213, 281
 Green River Desert, 101
 Green River Formation, 26, 143, 144, 161, 176, 201,
 208, 217, 221, 222, 224, 225, 237, 238, 239, 244,
 247, 249, 251-253, 255, 271, 281, 284, 292, 334,
 364, 369
 -basal member, 500
 -facies of, 195-197
 -index map of, 223
 -oil possibilities, 191-198
 -oil shale zones, 222
 -potential, 207-213
 -stratigraphy, 193, 198
 Green River Oil and Gas Field, 213
 Green River Tongue, 201
 Green River-Wasatch Transition Zone, 200, 204
 Greenhorn Limestone, 134
 Greenhorn Time, 135
 Greenschist, 41
 Grouse Creek Mountains stock, 155, 160
 Grouse Creek Range, 40, 42
 Grouse Creek Valley, 143
Gryphaea newberryi zone, 135
 Guadalupian Time, 103, 104
 Guilmette Limestone, 77, 80, 82, 290
 Gulf Oil Co., Aztec Lockhart Fed. 1, 80
 -Bishop Springs, 299
 -Coalbed Canyon, 80
 -Gronning No. 1, 293, 299
 -No. 1 West Desert Creek, 420, 421
 -No. 2 West Desert Creek, 420, 421
 Gulf of Mexico Embayment, 120
 Gunlock Fault, 309
 Gunnison Utah, 116, 144
 Gunnison Oil Co. #1, Gunnison Wildcat, 335
 Gunnison Plateau, 23, 24, 125, 131, 141, 143, 144,
 331
 Gusher, Utah, 219
 Gusher Oil Field, 6, 201, 499, 500, 501, 502, 503
 Gypsum, 98, 102, 109, 116, 121, 373

H

Halgaite Member (Cutler), 100, 101, 471, 477
 -High, 475
Halysites, 63, 67, 72
 Hansen Creek Formation, 63
 Happy Jack (copper) Deposit, 279
 Hardscrabble Hollow Intrusive, 155, 157, 160
 Harley Dome Gas Field, 7, 377
 Harmony Hills Tuff, 163
 Harrington Formation, 113
 Harrisburg Dome, 309, 314, 317
 Hartman Limestone, 485
 Hatch Oil Field, 6
 Hathaway Test, 425, 427
 Heaps Mountain, 157
 Heaps Mountain Intrusion, 157, 160
 "Heated Ball" Retorting Method, 209
 Henry Mountains, 16, 17, 117-132-133, 155, 157, 160, 381, 382, 383, 388, 397, 417
 Henrys Fork Group, 132
 Henrys Fork Thrust Fault, 183, 186
 Hermit Shale, 382
 Hermosa Formation, 93, 97, 98, 100, 338, 359, 382, 383, 400, 407, 411, 413, 429, 431, 432, 435, 451, 453, 471, 481, 500, 519, 521
 -group, 99, 371, 473, 475
 Hickey Oil Corp. #1 Cassidy, 298
 High Plateaus, 13, 16, 28, 105, 110, 117, 138, 149, 287, 291, 323, 327, 329, 493
 Hill, Et Al., State 1, 80
 Hilliard Shale, 125, 128
 Histogram, 269, 271
 Hite, Utah, 116
 Hogback, 144
 Hogup Mountains, 104, 291
 Hole-in-the-Rock, 116
 Hole-in-the-Wall Member (Iron Fm.), 163
 Homestake Formation, 119
 Honaker Trail Formation, 97, 98, 359, 360, 361, 365, 431, 447, 451, 455, 463, 471, 473, 477, 479, 489
 Hornblende, 41
 Horn Point Limestone, 473
 Horse Point, 377
 Horse Spring Formation, 292
 Horsts, 27
 Hoskinnini Member (Cutler Formation), 100, 101
 House Range, 45, 287
 -geologic section of, 290
 Humble Oil and Refining Co. Rosemary Lloyd #1, 251
 -Ruth Nelson #1, 251
 Humboldt Formation, 292, 293
 Humbug Formation, 91, 330, 359
 Hunt Government 1, 80
 Huntington Dome, 371
 Hurricane Cliffs, 136, 307, 323, 324
 Hurricane Fault, 16, 138, 303, 306, 307, 309, 315, 316, 321, 323, 337
 Hurricane Ledge, 307
 Hurricane Producing and Refining No. 3-A, 313
 Hurricane, Utah, 158
 Hydrocarbons, 268, 281, 283
 Hydrogenation, 210
 Hyrum Dolomite, 76

I

Ibapah Stock, 155, 157, 158, 160
 Ibex Basin, 51, 56-57
 Ibex Hills, 71
 Idaho, 41, 42, 45, 76, 95, 100, 102, 103, 104, 111, 113
 Idaho-Wyoming Thrust Belt, 183, 185-186
 Ignacio, 392, 393, 485, 486
 Igneous Rocks, 27, 28, 155-168
 Ignimbrites, 27, 159, 316

Ignimbrite Subprovince, 27

Iles Formation, 128, 130
 "In Situ" Retort Methods, 210, 211
 Indian Agency, 513
 Indian Canyon, 264, 282
 Indian Canyon - Lake Canyon, 225, 247
 Indianola Group, 23, 123, 130, 131, 291, 329, 329
 Ingramite, 215, 251, 252, 257, 258, 259, 261, 264, 269
Inoceramus, 128
 Intrusive Arch, 155, 157
 Intrusive Igneous Rocks, 24, 41, 155-158, 167
 -composition of, 160
 -distribution of, 155
 -structure relations, 155, 157, 158
 Iron, 4
 Iron County, 138, 155, 157, 160, 321
 Iron Mountain Intrusive (Iaccolith), 155, 157, 160, 311
 Iron Springs District, 119, 138, 157, 159, 163, 166, 168, 303, 309, 311, 317
 Iron Springs Formation, 23, 138, 157
 Iron Springs Gas Anticline, 309
 Iron Town Member (Page Ranch Formation), 163
 Iron Wash, 368
 Island Gas Field, 7, 201
 Ismay Limestone, 493
 Ismay Oil Field, 6, 501, 502
 Ismay Zone, 360, 405, 430, 432, 435
 -oil and gas possibilities of, 413-427
 Isom Formation, 161, 163
 Isopachs, 58, 59, 85, 435, 436
 Isotopes, 275
Ivanovia Species, 410, 420

J

J. Ray McDermott State No. 1, 324
 Jack Canyon Anticline, 195, 364
 Jack Valley Formation, 67, 71
 Jefferson Dolomite, 76, 77, 81, 85
 Jensen, Utah, 129
 Joana Limestone, 89, 90, 290
 Joes Valley Gas Field, 7, 327, 341, 343, 345, 349, 352
 -graben, 344, 345
 -rift, 344
 John Starr Flat, 225, 245
 Johnson Creek Unit, 425
 Jordan Narrows, 149, 293
 Jordan Valley, 300
 Juab County, 160, 291
 Junction Creek Formation, 121
 Jurassic, 17, 20, 21, 24, 112, 115-121, 128, 130, 131, 136, 138, 143, 144, 167, 177, 201, 237, 291, 296, 303, 305, 363, 382, 395, 396, 431, 451, 499, 500, 501, 502, 503, 507
 -early, 120
 -late, 120, 303
 -lower, 120
 -middle, 116, 117, 120
 -upper, 116, 117, 118, 375
 Jurassic-Cretaceous Boundary, 115-116

K

K. P. Owen #1 Sevier, 335
 Kaibab Limestone, 102, 103, 104, 290, 305, 307, 312, 315, 317, 324, 334, 337, 361, 365, 370, 382, 383
 Kaibab Plateau, 136
 Kaibab Sea, 100, 103
 Kaibab Uplift, (Upward), 381, 500
 Kaiparowits Formation, 90, 100, 101, 102, 123, 136, 137, 303, 306, 324, 382
 Kaiparowits Plateau, 133, 137, 381-384
 -Basin, 469, 473

Kaliophilite, 168
 Kanab, Utah, 111
 Kanarra Fold, 307, 309, 324
 Kanarraville, 307
 Kane County, 137, 321, 324, 381
 Kane Creek, 399
 Kane Point Tuff, 161, 163
 Kanosh Shale, 53
 Karmis-Gold Zone #1 Brown, 298
 Kayenta Formation, 109, 111, 112, 116, 118, 119, 305, 324, 334, 337, 431, 451
 Keewatin Age, 389
 Kelvin Formation, 23, 123, 127, 129, 190
 Kerr-McGee T. P. Utah 27, No. 1, 398
 Kinderhookian Time, 89
 Kings Oil No. 2 Ruby, 457
 Kings Canyon Dolomite, 67
 Kingwood No. 2, 427
 Kirkman Limestone, 102, 330
 Knight Formation, 25, 26, 27, 128, 141, 190
 Kolob Plateau, 150
 -oil and gas possibilities of, 321-328
 Kolob Terrace, 136
 Kyanite, 41, 42

L

Laccolith, 155, 157, 303
 Laccolithic groups, 27
 -mountains, 28
 Lake Bonneville, 148, 151, 152, 167, 196
 Lake Chalk, 148
 Lake Clays, 148
 Lake Deposits, 152
 Lake Fork-Yellowstone River Area, 225
 -bituminous Sandstones of, 245
 Lake Mountains, 165
 Lake Provo, 148
 Lake Uinta, 193, 194, 283
 Lakeside Mountains, 53, 77, 79, 95
 Laketown Canyon, 96
 Laketown Dolomite, 63, 66, 71, 290
 Laketown, Utah, 185
 Lakota (?) Sandstone, 177, 280
 "Lamb Point" Tongue (of Navajo Fm.), 111
 Lance Formation, 127
 Lance (?) Formation, 125
 Landslide Debris, 148, 150
 Land Slides, 149, 150
 Laramide Anticline, 306
 Laramide Kanarra Fold, 307, 331
 Laramide Orogeny, 176, 185, 190, 296, 303, 306, 333, 334, 393, 394, 396, 398, 399
 Laramide Thrust, 331
 Laramide Zone, 329
 La Sal Mountains, 16, 149, 155, 157, 160, 167, 388, 397
 Last Chance Anticline, 375
 Last Chance Gas Field, 327
 Latite Volcanic Series, 165
 La Verkin Creek, 307
 Leach Canyon Tuff, 161, 163, 309
 Lead-Alpha Age Determinations, 161, 164, 167
 Leadville Limestone, 89, 90, 98, 359, 453, 455, 457, 463, 483, 485
 Leatham Formation, 90, 91
 Lee's Ferry, 116
 Leonardian Time, 100, 101, 102, 104, 359
 Leonora #1 Saboda Well, 298
 Leucocrate Base Group, 168
 Lewis Shale, 125, 126, 127, 128
 Lime-Ridge Anticline, 480
 Linwood Anticline, 186
 Linwood, Utah, 126, 127, 177
 Liquid Asphalt #1 Eller Well, 298
 Liquid Hydrocarbons, 181

Lisbon Anticline, 377, 399, 417, 425
 Lisbon Dome, 483
 Lisbon Oil Field, 6, 10, 358, 359, 365, 379, 387, 400, 407, 463
 -geology of, 429-446
 Lisbon Salt Anticline, 429, 519
 Lisbon Valley, 112, 402
 "Limiting Angle", 525
 Little Bonanza (gilsonite) Vein, 218
 Little Chapita (gilsonite) Vein, 218
 Little Cottonwood Canyon, 40
 Little Cottonwood District, 79
 Little Cottonwood Intrusive Body, 155, 157, 168, 160, 167
 Little Flattop Anticline, 373
 Little Grand Fault, 378
 "Little Loop" Oil Sand, 479
 Little Mountain, 40, 42
 Little Willow Series, 41
 "Liverite", 255
 Lockhart, 399, 455
 Lodgepole Limestone, 90
 Logan Canyon, 63
 Logan Peak, 141
 Logan Quadrangle, 51, 76, 91
 Logan, Utah, 79, 90, 143, 295, 296, 298
 Lone Mountain Formation, 63
 Long Ridge, 79, 144, 292, 331
 Long Trail Shale, 91, 330
 Longwall Sandstone, 190
 Lower Red Member (Moenkopi), 112
 Lower Volcanic Group, 293, 299
 Lucin, 104
 Lynch Formation (Dolomite), 453, 485

Mc

McCook Ridge, 221
 McCracken Sandstone, 458, 429, 433, 435, 439, 441, 443, 485
 McElmo Creek Oil Field, 6, 407

M

Macentire Red Beds (Woodside Fm), 104
 Madison Age, 457
 Madison Group, 90
 Madison Limestone, 89, 90, 177, 305, 359, 453, 463, 485
 Mahogany Ledge, 209, 253, 271
 Main Salt Basin, 425
 Malthenes, 257
 Mancos Group, 130, 133
 Mancos Sea, 126, 137, 396
 Mancos Shale, 23, 123, 125, 126, 128, 129, 130, 131, 132, 133, 134, 135, 136, 177, 180, 186, 201, 244, 306, 334, 355, 363, 375, 377, 378
 -"B" zone, 135
 Manila, Utah, 125, 126, 127
 Manitou Formation, 57
 Manning Canyon Shale, 89, 92, 93, 96, 333, 341, 359, 365
 Mantua, 63, 79
 Mantua Uplift, 77, 85
 Mantua Valley, 76
 Map of Utah, physiographic, 14
 Marble, 39, 41
 Marjum Limestone, 290
 Markagunt Fault, 16
 Markagunt Plateau, 13
 -oil and gas possibilities of, 321-328
 Market, 203
 Marketing Facilities, 1
 Maristone, 96
 Maroon Formation, 96
 Martin Limestone, 81, 382

- Marysville, Utah, 144, 158, 159, 280, 281, 337, 160
 Mass Spectrometry, 276, 284
 Masuk Sandstone, 133
 Masuk Shale, 130, 334
 Meade Park Phosphatic Shale Member (Phosphoria Fm)
 103, 104
 Medicine Bow Range (S Wyo.), 41
Meerkoceras, 112, 113
 "Mendenhall" Sandstone, 479
 Meramecian Time, 89, 90, 93
 Mercur Intrusive (body), 155, 160
 Mesaverde Group, 123, 125, 126, 128, 129, 130, 132,
 133, 135, 136, 177, 180, 324, 355, 369, 431, 500
 Mesaverde Sandstone Formation, 134, 143, 177, 186,
 200, 201, 202, 204, 205, 224, 225, 229, 235, 237,
 245, 334, 378, 396
 Mesocordilleran Geanticline, 176
 Mesozoic Era, 144, 175, 176, 186, 237
 - oil and gas possibilities of systems, 291
 - strata, 307
 Metamorphic Complex (Precambrian), 39, 41-42
 Metamorphosed, 41
 Metaquartzite, 41, 42
 Mexican Hat, 97, 101, 313, 469
 Mexican Hat Oil Field, 469-482
 Middle Mountain, 126
 Middle Red Member (Moenkopi), 112
 Middle Rocky Mountain Province, 13, 17-18
 Midwest Hughes, 1, 80
 - Elk Ridge, No. 1, 391
 - No. 1 F. Shafer, 455
 Migmatite, 41
 Milford Valley, 295
 Millard County, 56, 68-69, 155, 160, 293
 Millard Limestone, 290
 Miller Mine, 264
 Mineral Fork Tillite, 42
 Mineral Leasing Act, 511, 512
 Mineral Mountain, 291
 Mineral Mountain Intrusive, 155, 160
 Mineral Range Intrusive, 155, 157
 Minersville Tuff, 163
 Mining, 210, 235, 241
 Mink Creek Conglomerate, 143
 Minnie Maude Creek, 247
 Miocene, 27, 161, 167, 183, 190, 292, 293, 295
 - oil and gas possibilities of, 293, 295
 Miogeosyncline, 19, 25, 51, 56, 183
 Mississippian, 19, 83, 85, 86, 98, 105, 176, 287,
 290, 296, 305, 313, 325, 359, 373, 377, 382, 383,
 387, 394, 396, 397, 398, 399, 400, 403, 413, 429,
 432, 435, 437, 438, 439, 441, 443, 445, 447, 451,
 456, 457, 462, 507
 - correlation chart, 92
 - system, 507
 Missourian Time, 97, 99, 177, 357, 359, 395
 Moab Anticline, 379, 445
 Moab Tongue (Entrada Fm), 117, 118, 121
 Moab Utah, 98, 134, 361, 373, 445, 447, 455
 - area, 401
 - valley, 519
 Modco Inc. No. 2 Gov't, 457
 Moenave Formation, 109, 111, 305, 324
 Moenkopi Formation, 110, 112, 177, 305, 307, 312,
 315, 325, 334, 337, 361, 362, 368, 369, 370, 372,
 375, 382, 383, 389, 431, 433, 441, 451, 500
 - middle red shale member, 312, 313
 Moffit Pass, 125
 Molas Formation, 359, 382, 394, 432, 433, 453, 463,
 477, 497, 498
 Molas Sea, 94
 Montan Wax, 253
 Montana, 90, 104
 Montana Age, 24, 130, 132, 137, 190, 303, 306
 Monte Cristo Limestone, 305
 Montezuma County, Colorado, 424, 425, 427
 Monument Upwarp, 373, 391, 392, 396, 397, 399,
 469, 471, 473
 Monument Valley, 100, 101
 Monument Valley Uplift, 17, 97, 98, 99, 420
 Monzonite Hill Intrusive, 155
 Moonshine Wash, 365
 Moraines, 148, 149
 Morehouse Quartzite, 66
 Morgan County, 183, 185
 Morgan Valley, 27, 141, 143, 185
 Morgan-Weber Facies, 95-96
 Morgan Formation, 95, 96, 177
 Moroni, 31
 Moroni Formation, 144
 Morrison Formation, 115, 117, 119, 121, 126, 128,
 129, 132, 133, 134, 135, 177, 181, 201, 278,
 329, 330, 334, 355, 363, 365, 369, 375, 376,
 377, 396, 500
 Morrison Time, 176, 395, 431
 Morrowan Time, 94, 95, 96, 100, 359
 Moss Back Member (Chinle), 110, 112, 363, 431
 Mt. Belknap Series, 161, 163
 Mounds Structures, 372, 373
 Mount Carmel, 116
 Mount Nebo, 24, 83
 Mount Nebo Oil Co. #1 Juab, 335
 Mount Timpanogos, 18
 Mountain Fuel Supply, 177, 180, 187, 190, 191, 205
 - Accord Lakes #1, Accord Lakes Unit, 335
 - Last Chance 1-A, 80
 - Government Well No. 1, 190, 191
 - Government Well No. 2, 191
 - Government Well No. 3, 191
 - Government Well No. 4, 191
 - Morrison Flat No. 1, 425
 - Wells Draw Unit No. 1, 197, 201
 Mountain View Crest, 393
 Mowitza Shale, 81
 Mowry Shale, 125
 Muav Limestone, 382
 Muddy Mountains, 93
 Muddy Peak Limestone, 81, 305, 306
 Mudrock Deposits, 148, 151
 Mudrock Flows, 150
 Muddy Hills, Nevada, 23
Murchisonia, 67
 Mud Cracks, 42
 Mud-rock Flows, 42
 Mudstone, 101, 104
 Murphy, R. D., Well #1, 180
 - Little Valley, 462
 - Well #2, 180
 - Well #6, 181
 Muscovite, 41
 Mutual Formation, 42, 43
 Myton, Utah, 219

N

- Nabors No. 2 Rowley Well, 425
 - No. 1, 427
 Naheolite, 253
 Nak, J. A., #1 Fee, 297
 Naphthenes, 258, 261, 267, 268
 Natural Gas Lines, 10
 Navajo Formation (Sandstone), 109, 111, 116, 117,
 119, 157, 237, 391, 305, 315, 324, 330, 333,
 334, 337, 369, 371, 382, 431, 451, 469
 Navajo Lake, 323
 Navajo Mountain, 16, 17, 155
 Nebo Thrust, 327
 Needle Creek, 393
 Needle Range Formation, 161, 163
 Neffs Canyon, 151
 Nephi, 13, 16, 24, 158, 327, 330, 331
 Nepheline, 168
 Nequicia Arch, 365, 371, 373-374, 388, 391, 394,
 394, 396, 397, 398, 486
 Nevada, 19, 23, 49, 51, 64, 89, 93, 100, 102, 103,

Nevadan Orogeny, 23
 Newcastle, Utah, 138
 Newfoundland Mountains, 77, 79
 Newfoundland Mountains Stock 155, 160
 New Harmony, Utah, 138, 307
 New Mexico, 5, 89, 119, 413
 -northwestern, 405, 417, 424
 Niagara, 63, 71
 Nigrite, 257
 Niobrara, 24, 130, 137
 North Creek, 312, 313
 North Horn Formation, 123, 128, 130, 132, 135, 143, 201, 334
 North Lily Stock, 167
 North Tabiona Area, 225
 -bituminous sandstones of, 245
 Northeast Nevada Uplift, 287
 Northeastern Utah Basin, 76, 77, 85
 Northern Utah Shelf, 85-86
 Northwest Salt Anticline Region, 377
 Northwestern Utah Basin, 77, 81, 85
 Northwestern Utah Highland, 185
 Norwood Tuff, 27, 141, 147, 293
 Notch Peak, 160
 Notch Peak Intrusive, 155
 Notch Peak Limestone, 290
 Nuclide, 275
Nube ardente Eruptions, 159
 Nugget Formation, 109, 116, 118, 177, 186, 240, 329, 330
 Number of Gas Wells 1961, 7
 Number of Oil Wells, 1961, 1, 6

O

Ochre Mountain Limestone, 91
 Ogden, 85
 Ogden Canyon, 79, 85
 Ogden Thrust, 25
 Ohio Oil Co., 186, 190
 -Government #1, 191
 -Navajo 1, 80
 Oil, 224, 277
 -characteristics of 497-510
 -high pour-point oils, 224
 -low pour-point oils, 224
 Oil and Gas Leasing in Utah, 511-518
 Oil and/or gas possibilities (see table of contents)
 Oil and Gas Value, 1, 4
 Oil Fields, 2, 6,
 Oil Shale, 207-213, 217, 218, 221, 223, 224, 249, 251-252, 253, 269
 -distribution, 223
 -environment, 208
 Oil Springs Gas Field, 7
 Oily Medium, 268
 Olefins, 261
 Oligocene, 27, 141, 143, 165, 167, 175, 176, 225, 292, 293, 296, 382, 383
 -oil and gas possibilities of, 293
 Oolite, 91, 103
 Oolitic Limestone, 148
 Ophir Formation, 49, 485
 Oquirrh Basin, 19, 89, 91, 93, 96, 100, 105, 287, 357, 359, 373
 Oquirrh Formation, 93, 95, 100, 102, 150, 330, 337, 360
 -facies, 95
 Oquirrh Mountains, 79, 83, 85, 91, 92, 149, 165
 Ordovician, 19, 51-60, 63, 131, 175, 290, 305, 358, 394, 433
 -index map, 52
 -of eastern Utah craton, 57
 -regional relations, 51
 Orem, Utah, 343
 Organ Rock Member (Cutler Formation), 100, 101, 102
 Organic Structures of Asphalts, 261

Orogeny, 19, 21, 23, 26, 127
 Orr Formation, 290
 Orthoclase, 168
 Osagean Time, 89
 Ostracods, 53
 Otter Creek, 16
 Ouray and Bitter Creek Gas Field, 7
 Ouray Formation (limestone), 85, 88, 358, 393, 429, 435, 437, 441, 443, 453, 485
 Ouray (gilsonite vein) System, 219
 Ouray, Utah, 255
 Outwash, 149
 Overton Fonglomerate, 23
 Oyster Ridge Sandstone, 190
 Ozocerite, 215, 224, 249, 255, 257, 258, 259, 261, 264, 266, 267, 268, 271, 273, 282
 -at Soldier Summit, 251
 -origin of, 251

P

Pachyteuthis densis, 118
 Pacific Natural Gas Exploration Co., 186
 Pacific Seaways, 120
 Pacific Western Oil Corp. Gordon Creek #1, 341
 -Teasdale #1, 80
 -Thompson #1 Well, 378
 Packard Quartz-Latite, 163, 165
 Pack Creek, 134
 Page Ranch Formation, 161, 162, 163
 Painted Desert, 305
 Pakoon Limestone, 305, 313, 315, 382, 383
 Paleocene, 25, 123, 128, 130, 135, 138, 143, 144, 176, 183, 193, 291-292, 382
 Paleogeography, 45, 46
 Paleotectonic History, 49
 Paleozoic, 120, 141, 144, 175, 177, 185, 237, 287, 290, 297, 298, 299, 377, 383, 387, 392, 393, 396, 398
 -marine sediments of, 17
 -middle, 77
 -oil and gas possibilities of 287, 290
 -provinces of, 19, 20
 -upper, 21
 Pan American No. 1 U.S.A. Cullen, 398
 -No. 1 Fehr, 405
 -No. 1 Murphy Range, 453, 463
 Panguitch, 323, 325, 326
 Panguitch Lake, 326
 Parachute Creek Member (Green River fm.), 209, 210, 281
 Paradise Fault Zone, 337
 Paradox Basin, 5, 10, 19, 85, 90, 93, 96-99, 100, 101, 102, 105, 353, 355, 357-358, 359, 360, 361, 365, 371, 373, 375, 378, 381, 391, 392, 393, 394, 395, 396, 397, 400, 402, 403, 405, 413, 417, 424, 427, 429, 433, 447, 469, 489, 491, 493, 499, 500, 503, 505, 507, 519
 -basement rocks of, 387-403
 -potash and oil and gas possibilities 519-526
 -oil and gas, 519-526
 Paradox Formation, 96, 375, 358, 359, 360, 365, 373, 375, 378, 387, 401, 407, 429, 430, 432, 435, 437, 441, 495, 451, 463, 471, 473, 500, 519
 Paradox Salt, 377, 378, 424, 432, 435, 436, 441, 445, 447, 454, 455, 456, 457, 462, 463, 467
 Paradox Salt Embayment, 361
 Paradox Salt Valley, 519
 Paradox Sea, 357
 Paraffins, 258, 259, 261, 267, 271
 Parlette Bench, 245
 Parlette System (gilsonite), 219, 222
 Park City District, 103, 157, 158, 165, 166, 327
 Park City Formation, 96, 102, 103-104, 112, 177, 224, 330
 Park City Intrusive (body), 155, 160

- Park City-Phosphoria Sea, 100
 Park City Volcanic Field, 27
 Park Valley, 293
 Parowan, 321, 323
 Parry Oil Co. Fed #1, Teasdale, 338
 Parunuweap (?) Formation, 162
 Paunsaugunt Fault, 16, 393
 Paunsaugunt Plateaus, 381
 Pavant Plateau, 141, 143, 144
 Pavant Range, 13, 16, 132, 291, 299, 331
 Pavant Thrust, 327
 Payson Canyon, 79
 Peat, 148, 295, 300
 Pegmatite Dikes, 41
 Penesalpine Rocks, 98
 Pennsylvanian, 19, 24, 89, 93-100, 103, 105, 150, 176, 177, 186, 224, 238, 287, 290, 296, 298, 299, 305, 359, 382, 394, 395, 396, 398, 401, 403, 405, 413, 424, 429, 431, 432, 435, 437, 445, 447, 451, 498, 499, 500, 501, 502, 503, 507
 -correlation chart, 99, 373
 -late, 100
 -paleogeographic maps, 94, 97
 -post, 387, 392
 -pre, 392, 394
 Pentamerus, 63, 66
 Peor Springs (bituminous sandstones), 225, 244
 Permeability, 210
 Permian, 19, 24, 95, 96, 97, 100-105, 109, 112, 176, 177, 224, 287, 290, 305, 307, 315, 359, 382, 384, 395, 398, 399, 401, 431, 451, 499, 500, 501, 502, 503, 507
 -correlation chart, 105
 -lower, 89
 Permian (variation), 276, 282
 Permo-Pennsylvanian, 201
 Permo-Triassic Strata, 307
 Peters Point Gas Field, 7, 364
 Peters Point Jack Canyon Field, 201
 Petrified Forest, 305
 Petroleum Possibilities, 86, 275-284
 Phillips Petroleum No. 2 Escalante Anticline, 383
 Phosphate, 103, 104
 Phosphatic Shale, 19
 Phosphoria Formation, 103, 177, 201, 500
 Physiographic Map, 14, 15
 Physiography, 13
 Piceance (Creek), Basin, 175, 193, 207, 213, 253, 281, 369
 Piedmont, 150
 Pilot Mountains, 158, 293
 Pilot Range Intrusion, 160
 Pilot Shale, 77, 81, 290
 Pilot Stock, 155
 Pilot Range Intrusion, 160
 Pine Valley Area, 159, 166
 Pine Valley Igneous Mass, 155, 157
 Pine Valley Laccolith, 307, 309-311
 Pine Valley Latite, 162
 Pine Valley Monzonite Porphyry, 311
 Pine Valley Mountains, 138, 157, 159, 160, 303, 305, 306, 307, 309
 -generalized volcanic rock sequence, 162
 Pink Cliffs, 144
 Pinkerton Trail Formation, 98, 359, 372, 451, 453, 471
 Pinto Peak, intrusive, 311
 -dome, 311
 Pinto Sandstone, 138
 Pintura Dome, 307, 315
 Pinyon Peak Limestone, 81, 82, 83, 85, 90, 91
 Pioche Shale, 290, 305
 Pipelines, 13, 15, 100, 181, 199
 -Mountain Fuel Supply El Paso Nat. Gas, 199
 -Pacific Northwest-El Paso Nat. Gas, 199
 -Rangeley-Salt Lake, 199
 Piute County, 160, 327, 337
 Piute Valley, 335
 Plateau Province, 4, 28, 167, 168, 329
 Playa Bed, 148
 Playa Lake Facies, 120
 Pleasant Valley Rift, 344
 Pleistocene, 17, 18, 27, 28, 147, 151, 168, 176, 205
 Pliocene, 28, 143, 147, 161, 167, 168, 176, 293, 295, 306, 383
 -late, 161
 -oil and gas possibilities of, 293, 295
 Plug Dome, 157
 Plympton Formation, 290
 Pogonip, 53, 56, 58, 290
 Potash, 319-326
 Powtwin Vein (bitumen), 257
 Precambrian, 39-44, 45, 49, 591, 150, 177, 180, 185, 297, 303, 305, 375, 382, 387, 388, 389, 390, 391, 392, 393, 394, 396, 398, 401, 402, 403
 -general, 39
 -location of, 40
 Precious Metals, 45
 Pressure Decline, 202
 Preuss Sandstone Formation, 117, 118
 Price, Crude Oil, 10
 Price River Conglomerate, 24
 Price River Formation, 24, 25, 128, 130, 132, 135, 137, 143, 176, 334
 Price, Utah, 135, 136, 141
 Pride-of-the-West Segment (Rainbow Gilsonite Vein), 219
 Pride-of-Utah gilsonite vein, 219
 Producers Oil Co. #1 Ephraim, 335
 Producing Gas Wells, 180, 181
 Producing Zones, 201
 Production, gas, 7, 180, 181-182, 220
 Production Refert Plant, 209
 Productive Zones, 201
 Products Lines, 10
 Promontory Point, 40, 42
 Promontory Range, 43, 77, 79, 91, 92, 95
 Prospect Mountain Quartzites, 45, 290, 299, 305
 Proterozoic Era, 393
 Provo, 91, 92
 Provo Canyon, 95
 Provo Lake Beds, 152
 Provo River, 13, 18
 Provo Rock Canyon, 79
 Pubco #1 Federal 2-21-F, 335
 Punch Bowl Dome, 309, 315
 Pure Oil Co. #1-A, 437, 439, 441, 443
 #2A, 437, 439, 441
 #1B, 437
 #2B, 437
 -#1 Big Flat, 457
 -#2 Big Flat, 457
 -#3 Big Flat, 462
 -#4 Big Flat, 462
 -#5 Big Flat, 379, 462
 -#1 Big Indian, U.S. A., 437, 441, 443
 -#1C, 437
 -#2C, 437
 -#3C, 437
 -#2D, 437
 -#1H, 437
 -#1 Desert Lake, 390, 398
 -#2 NW Lisbon-C, 462
 -#1 USA Mineral Point, 462
 Pyrobitumens, 252, 255, 258, 259, 261
 Pyroclastics, 159

Q

- QLM Values, 168
 Quartz, 41, 168
 Quartz Latite, 27
 Quartz Monzonite Porphyry, 158

Quaternary, 125, 147-153, 295-296, 297, 298, 299, 300, 307, 363, 383
 -oil and gas possibilities of, 295-296
 Queantowasp Sandstone, 305
 Quichapa Group, 162, 307

R

Rabbit Valley, 335
 Radioactive, 107
 Raft River, 166
 Raft River Mountains, 40, 42, 49, 95, 158, 167
 Raft River Mountain Stock, 155, 160
 Raft River Uplift, 287, 296
 Railroad Valley, Nevada, 292, 293
 Rainbow Natural Bridge, 116
 Rainbow Unit, 201
 Rainbow (gilsonite) Vein System, 217, 219, 222, 264
 Rainfall in Utah
 -average, 13
 -Canyonlands Subprovince, 16
 -highest, 13
 -lowest, 13
 Randolph Quadrangle, 51, 76, 79
 Randolph, Utah, 185
 Rangely Oil Field, 175
 Raplee Anticline, 473, 481
 Rat Hole Canyon, 267
 Rutherford Oil Field, 6, 407, 500, 501, 502
 Raven Gilsonite Vein, 219
 Raven Park Fold, 175
 Raven Ridge, 223, 225, 253
 -asphaltic sandstone, 247
 Recapture Creek Oil Field, 6, 500, 501, 502
 Recapture Member (Morrison Fm), 117
 Recent, 147, 306
 Recent Flows, 159
 Recharge Areas, 149
 Recovery Programs, 10
 Red Beds, 96, 98, 100, 102, 103, 109, 110
 Red Creek, 129, 130, 264
 Red Creek Canyon, 43
 Red Creek Quartzite, 177, 180
 Red Creek Series, 41
 Red Creek Syncline, 180
 Redwall Limestone, 89, 305, 313, 315, 382, 485
 Red Warrior Limestone, 81
 Red Wash Oil Field, 6, 10, 196, 197, 198, 213, 224
 Red Wash-Walker Hollow Oil Field, 200, 201
 Redwash Formation, 112
 Red Wash-Roosevelt Trend, 195
 Refineries, 1
 Refractive Index (bitumens), 258, 259
 Refrigeration Plant, 181
 Rencher Formation, 162, 163
 Reserves, asphalt, 225, 229, 237, 239
 -bituminous sandstone, 223, 225
 -gas, 180, 181, 204
 -oil shale, 211, 221
 Reservoir Beds, 56, 168
 Reservoir, Gas, 181, 213
 Retorting, 210
 Rex Chert Member (Phosphoria Fm), 104
 Reynolds Mining Corp. Hat #1, 80
 -#1 Gibon Dome, 457
 -#1 Sinbad Unit, 80, 390
 Rheem Manufacturing Company, 186
 Rhine Petroleum Industries #1, Elgham City, 298
 Rich County, 76, 95, 104, 183, 185
 Richfield Oil Co. #1 Hatch Mesa, 463
 -#1 Onion Creek, 358
 Richfield, Utah, 116, 141, 327, 331
 Richmond Stage, 60
 Rico-Facies-Cutler Formation, 99, 361, 471, 475, 361, 477, 479
 Rico Formation, 93, 97, 98, 100, 395, 401, 431, 432, 451, 481

Rico Mountains, Colorado, 98
 Rifle, Colorado, 209, 210
 Rim Rock Sandstone, 130, 225, 229, 236
 Ripple Marks, 42
 Roan Cliffs, 135, 355, 357, 363, 364
 Roberts Mountain Formation, 63, 67, 71
 Roberts Mountains, Nevada, 67
 Rock Canyon, 91
 Rock House Gas Field, 7, 201
 Rock Springs Formation, 125, 126, 127
 Rock Springs, Wyoming, 177
 Rockport, Utah, 127, 128, 129
 Rocky Intrusive, 155
 Rocky Mountain Geosyncline, 120, 287, 396
 Rocky Mountain Chain, 183
 Rocky Mountain Region, 176, 395, 429, 455, 499, 503
 Rocky Mountain Sea, 93
 Rocky Range Intrusion, 160
 Rogers Springs Limestone, 88, 90, 305, 315
 Roosevelt Oil Field, 6, 197, 201, 224, 251, 499, 500, 501, 502, 503
 Roosevelt, Utah, 195
 Round Valley Limestone, 93, 96
 Royalties, 5
 Rozel Hills, 166, 167
 Rozel Point Oil Field, 4, 297-298, 300
 Rozel Point, 143, 158, 293, 295, 300
 Rozel Point Asphalt, 284
 Rustler, 455

S

Sagers Wash Syncline, 378
 Saint George, 110, 309, 313, 315
 Salina Canyon, 131, 143, 144, 333, 341
 Salina, Utah, 144
 Salt, 116, 373
 Salt Anticline, 377, 379, 429, 430, 434, 448
 Salt Creek, 330
 Salt Creek Formation, 151
 Salt Lake City, 79, 85, 90, 91, 149, 177, 185, 295, 296
 Salt Lake City Refinery Center, 10
 Salt Lake County, 151, 160, 183
 Salt Lake Formation, 141, 143, 147, 167
 Salt Lake Group, 141, 143, 147, 153, 167, 293, 295, 297, 298, 299, 300
 Salt Lake Valley, 300
 Salt Valley Anticline, 362, 378, 445, 449, 521
 -graben, 378
 Salt Wash Mississippian Structure, 399
 Salt Wash Member (Morrison Formation), 117, 278, 279, 334, 402
 Salt Wash Oil Field, 6, 359, 365, 378-379, 401, 463
 San Arroyo Gas Field, 7, 369, 377
 San Francisco District, Utah, 80, 113
 San Francisco Mountain Range, 81, 160
 San Juan County, 1, 4, 6, 85, 97, 98, 99, 117, 160, 353, 407, 408, 411, 420, 429, 500
 -oil and gas objectives in, 483
 San Juan Mountains, 387, 393, 394, 469
 San Juan River, 97, 101, 469, 471, 480, 481
 San Pete County, 335
 San Pitch-Sevier Area, 331-335
 Sanpete Oil Co. #1 Redmond, 335
 -#2 Redmond Anticline, 335
 San Pitch Valley, 327, 329, 333, 334
 San Rafael Field, 57
 San Rafael Group, 116, 118, 119, 363
 San Rafael Highlands, 193, 197
 San Rafael Swell, 17, 57, 91, 97, 101, 102, 110, 111, 112, 116, 117, 118, 119, 131, 155, 334, 345, 353, 357, 358, 359, 360, 361, 362, 363, 365, 368, 369, 370-371, 373, 375, 388, 390, 394, 395, 396, 397, 398, 402, 491
 San Pete County, 4
 Sanpete Formation, 130, 131

San Pete Valley, 23, 24, 119, 144
 Santaquin, Utah, 39
 Sappington Sandstone, 90
Scaphites hippocrepis, 135
 Scipio, 79
 Scofield, 341
 Seiber Nose Oil Field, 6, 363, 376-377, 499, 500, 501, 502
 Seven Mile Anticline, 379, 519, 521
 Sevier Arch, 291, 292, 296
 Sevier County, 160, 291, 327
 Sevier Desert, 300
 Sevier Fault, 16, 321, 324, 337, 383
 Sevier Lake, 13
 Sevier Plateau, 333, 335
 Sevier Plateau Intrusive, 155
 Sevier River, 13
 Sevier River Formation, 161, 323, 337
 Sevier Valley, 16, 24, 116, 119, 144, 323, 327, 329, 333, 334
 -graben, 337
 Sevy Dolomite, 66, 67, 77, 81, 82, 83, 290
 Shafer Dome, 455, 519
 Shafer Limestone, 471
 Shamrock Oil Unit #4, 201
 Shebit (Shivwits) Anticline, 317
 -fault, 309, 315
 Shebit Indian Reservation, 315
 Sheep Pass Formation, 292
 Sheeprock Mountains, 40, 42, 43, 79, 82, 167
 -intrusion, 160
 Sheep Rock Series, 42
 Sheeprock Stock, 155
 Shelf, 19, 57, 85, 176, 183
 Shell Oil Co. Baker Creek #1, 299
 -bluff #1, 80, 392
 -desert Creek #1, 80
 -eagle Spring #1, 292
 -eagle Springs #2, 292
 -#1 North Springs Unit, 343, 365
 -#1 Salduro, 295, 299
 -sunset Canyon, 299
 -west Portal Unit, 331
 Shinarump Formation (conglomerate), 110, 111, 112, 177, 305, 307, 312, 324, 325, 334, 337, 363, 382, 431, 451
 Shivwits (Shebit) Fault, 309, 315
 Shnabkaib Member (Moenkopi Fm.), 112, 305
 Shore gravels, 148
 Shorelines, 152
 Shumway Oil, Gov't #1-23, Thousand Lakes, 338
 Shurtz Canyon, 326
 Shurtz Sandstone (Navajo Fm.), 111
 Sierra Madre (S. Wyo.), 41
 Sierra-Nevada Revolution, 121
 Sill, 156
 Silurian, 53, 175, 290, 299, 358, 394, 433
 -distribution by outcrops, 66
 -regional distribution, 63-67
 -stratigraphic column, 68-69
 -stratigraphy of, 67, 71-72
 -terms, 64
 Silver, 111
 Silver City Rock, 55, 160, 161, 167
 Silver Island Range Stock, 155, 160
 "Silver Reef" Bed, 111, 305
 Simonson Dolomite, 66, 77, 81, 82, 83, 290
 Simpson Mountains Intrusion, 160
 "Sinbad Limestone" (member of Moenkopi Fm.), 112, 341, 343, 345, 352, 362, 368
 Sinclair Fehr-Federal #1, 80
 Sixmile Canyon Formation, 130, 143
 Skelly Oil Nokai, 1-A, 80
 -#2 Bryner, 343, 352
 -#1 Emery Fed. Wildcat, 335
 Snake Range, 49, 72
 Soldier Summit, 13, 16, 209, 249, 257, 264, 267, 327, 431
 Soldier Summit Mine, 251
 Sorrel Butte, 368
 South Flank Fault, 175
 South Flat Formation, 125, 130, 131, 132
 South Last Chance Field, 57
 Southeastern Utah Shelf, 83-84
 Southern Natural Gas, #1 USA, 463
 Southern Pacific Railroad #1 Lemay, 297
 Southman Canyon Gas Field, 7, 201, 202
 South Myton Bench Area, 225
 -bituminous Sandstones, 245-247
 South Wash, 309
 Southwestern Utah Basin, 81
 South Whiterocks Tertiary Bituminous Sandstones, 245
 Spanish Fork Oil Co. #1 Unit, 331
 Split Mountain, 229, 237
 Spring Creek Anticline, 186
 Spring Hollow Fault, 190
 Springdale Sandstone Member (of Moenave fm), 111, 305
 Springeran Time, 94, 95
 Spring-Terrace Deposits, 148
 Stanaker Formation, 110, 111
 Standard Oil of Calif. #1 Burbank, 299
 -#1 Levan, 291, 299
 -#1 Moonshine Wash, 335
 -#1 Sigurd, 291, 335
 Stansbury Anticline, 19
 Stansbury Formation, 83
 Stansbury Island, 79
 Stansbury Mountains, 53, 76, 77, 79, 83, 91, 95, 149, 291
 Stansbury Uplift, 85, 86
 Starpoint Sandstone, 130, 135, 334, 345
 Starr Flat Field, 196
 Starr Intrusive, 155, 160
 Starvation Creek, 338
 Starvation Peak, 157
 Starvation Point, 160
 Stateline Gas Field, 7
 Staurolite, 41
 Stock, igneous, 155, 157
 -intrusives, 27
 Stockton-Fairfield Area, 165, 166
 Stoddard Mountain, 155, 157, 160, 311
 -laccolith, 309, 311
 Stone Cabin Gas Field, 7
 Straight Canyon Syncline, 344
 Straight Cliff, 136, 137
 Straight Cliff Sandstone, 136, 137, 306, 324, 382
 Stratigraphic Column, Silurian, 68-69
 Strawberry Quadrangle, 129
 Strawberry Reservoir, 128, 130
 Strawberry River, 194
 Strawberry Valley Anticline, 185
 -area, 331
Strophomenid brachiopods, 67, 71, 72
 Structural Evolution, 19
 Stump Sandstone, 118
 Sublett Range, 104
 Success Ratio of Wells, 1
 Sultan Limestone, 81
 Summerville Formation, 116, 117, 118, 119, 120, 121, 334
 Summit County, 4, 85, 125, 183, 186, 190
 Sun Oil Co. #1 Diamond Fork, 331
 -#2 Diamond Fork, 331
 -Ouay Well, 209
 Sunnyside, Utah, 197, 223, 244, 364, 497
 -bituminous sandstones, 239, 241
 -deposits, 225
 Sunrise Peak Stock, 155, 160
 Supai Formation, 100, 103, 305
 Superior Salt Wash Test, 424
 -#43-20 Bowknot, 462

Supervised United, 5
 Supervising Agency, 4, 5
 Swan Peak Formation, 51, 53, 56, 290
 Swasey Limestone, 290
 Sweetwater Creek Area, 201, 373
 Sweet Tuff, 163
 Syndicate Oil & Ming. #1 Fee, 331

T

Tabor (gilsonite) Vein, 218
 Tabby Canyon, 255, 264
 Tabbyite, 215, 255, 264, 269
 Talus, 148, 150
 Tapeats Sandstone, 324, 382, 392, 393, 483, 485, 386
 Tar Sands, 215, 223
 Tar Seeps, 225, 236
 Taylor Thrust, 25
 Tectonic Structures, 306
 Temple Mountains, 397
 Temple Springs, 391
 Tennessee Gas Transmission No. 1 Irons, 31
 -#1-A, Poison Springs, 383
 Tenny Canyon Tongue (Kayenta), 111
 Tensleep Formation, 96
 Tertiary, 16, 17, 18, 125, 128, 141-144, 150, 158, 161, 175, 176, 199, 215, 221, 224, 238, 244, 251, 296, 297, 298, 299, 300, 306, 363, 393, 395, 396, 409, 500, 501, 502, 503
 -early, 137, 161, 180, 185, 190, 200, 204, 222, 283, 386
 -folding, 307
 -lower, 201
 -middle, 20, 161
 Texaco Nequoa No. 6, 335
 -Thousand Lake #1, 338
 -Temple Springs No. 1, 391
 -Temple Springs No. 2, 391
 -#1-B, 427
 Texas, 5
 Texas Gulf Prod. No. 1-A Federal, 462
 -Unit 1, 80, 207
 Textota Oil Co. Fed. "L" Well #1, 191
 Thayne Formation (limestone), 20, 110, 112, 239, 290, 291, 330
 Thermopolis Formation, 125
 Thistle, Utah, 13, 118, 141, 144
 Thisle Well, 331
 Thomas Mountains, 158, 166
 Thompson Anticline, 378
 Thompson, Utah, 135
 Thousand Lake Mountain, 335, 337, 338
 Three Forks Shale Formation, 76, 85
 Three Mile Canyon, 223
 Three Peaks Intrusive, 155, 157, 160, 161, 167, 311
 Thrust Faults, Thrusts, and Thrusting, 23, 25, 26
 Tidewater Big Flat 74-11, 80, 455
 Tillite, 42
 Timiskaming Age, 389
 Timpowep Member (Moenkopi), 112, 305, 312, 313, 315, 324, 325, 383
 Tintic Mining District, 45, 49, 53, 66, 79, 82, 83, 85, 90, 91, 157, 158, 161, 163, 165, 166, 168, 390, 391, 392
 Tintic Mountains, 291, 293
 Tintic Quartzite, 45, 49, 305
 Todilto Formation, 119
 Tohonadia Oil Field, 6
 Tooele Arch, 19, 51, 53
 Tooele County, 77, 81, 160, 296
 Tooele Valley, 300
 Topache Mountains, 291
 Torowep Formation, 102, 104, 305, 337, 361, 382
 Torowep Kaibab Sea, 103

Total Oil Content Map, 211, 212
 Toquerville, 307, 309
 Trans-Basin Arch, 394, 396
 Transcend Time, 49
 Transcontinental Arch, 19, 75, 76, 77, 85, 86, 394
 -Uplift, 83, 85, 86
 Transition Zone, 306
 -belt, 373
 -oil and gas possibilities of, 327-389
 Traverse Mountains, 158, 165
 Traverse Volcanics, 293
 Triassic, 20, 103, 109-115, 116, 120, 177, 185, 186, 290, 291, 305, 307, 361, 363, 382, 389, 395, 396, 431, 441, 451, 489, 500, 501, 502, 503
 -early, 113
 -late, 111
 -lower, 112, 113
 -middle, 110, 112
 -nomenclature of, 114
 -upper, 110, 111, 112
 Triassic-Jurassic Boundary, 112, 115
 Tribal Council, 513
 Tribal Lands, 5
 Trilobite, 52, 53, 57
 Troilite Ratio, 276
 Tropic Formation, 136-137, 306, 311, 324, 382
 Trough, 19, 20, 21, 23, 45
 Tununk Sandstone, 133
 Tununk Shale, 130, 131, 133, 334
 Turner Bluff Oil Field, 6
 Tushar Intrusive, 155
 Tushar Fault, 331
 Tushar Mountains, 13, 16, 160, 334, 337
 Tuscher Formation, 135, 201
 Twelve Mile Canyon Member (Arapien Fm.), 116
 Twin Creek Limestone, 116, 118, 121
 Twist Gulch Formation, 116, 117, 118

U

U.S. Biological Survey #2 Water Well, 298
 U.S. Bureau of Reclamation, 511
 Uinta Arch, 96
 Uinta Basin, 5, 10, 17, 75, 86, 95, 141, 143, 175-176, 183, 193-198, 199-206, 207, 208, 211, 215, 221, 225, 244, 245, 247, 249-273, 281, 291, 327, 329, 341, 353, 363, 369, 365, 497, 499, 500, 503, 507
 -stratigraphy, 175-176
 -structure, 175, 194
 Uinta Basin Pipeline, 203, 205, 213
 Uinta Fault, 180, 183
 Uinta Fold, 330
 Uinta Formation, 130, 143, 144, 194, 200, 201, 213, 217, 244, 249, 255, 271
 -Formation (?), 26, 38
 Uinta Mountains, 13, 16, 17, 24, 25, 26, 39, 40, 42, 43, 45, 49, 79, 85, 89, 90, 91, 92, 93, 95, 96, 103, 104, 109, 111, 112, 113, 116, 117, 118, 119, 121, 125, 127, 128, 141, 143, 148, 149, 175, 177, 180, 193, 194, 195, 196, 208, 237, 281, 387
 Uinta Uplift, 329
 Uintah and Bitter Creek Gas Field, 7
 Uintah County, 1, 41, 5, 6, 211, 215-224, 225, 498, 500
 Uintah Gas Field, 201
 Unaweep Canyon, 388, 389
 Uncompahgre Basement Fault, 378
 Uncompahgre Fault, 358
 Uncompahgre Uplift, 19, 85, 100, 195, 287, 353, 355, 361, 394, 395, 401, 417, 429, 453, 480, 489
 -highlands, 95, 193, 197, 355, 357, 358, 359, 360, 361, 365, 375, 377, 378, 379
 -plateau, 175, 361, 387, 388, 389, 390, 393, 394, 397, 401

Uncompahgre System, 43
 Uncompahgran Mountains Range, 429
 Union Oil Company, 209
 -Cottonwood Springs Well, 409
 Unit Agreements, 8, 9
 U.S. Dept. of Interior, 5
 Upheaval Dome, 453
 Uranium, 4, 110, 111, 117, 275-284
 Uravan, Colorado, 401
 U.S. Geological Survey, 401, 439
 Utah, central, 5, 24, 26, 109, 123, 125, 129, 130, 143, 144, 287, 383, 421
 Utah Drilling and Development Co. Buskirk #1, Diamond Fork, 331
 Utah, east-central, 90
 -oil and gas possibilities of, 353-380
 Utah, eastern, 1, 5, 37, 109, 118, 123, 296, 445
 -northcentral, 23, 47, 141, 292
 -northeastern, 51, 76-77, 102, 113, 205, 224, 499
 -northern, 19, 26, 45, 41-53, 75, 89, 96, 109, 141, 147, 149, 183-191, 293, 295, 298, 300, 325
 -northwestern, 4, 39, 42, 77, 80, 89, 95, 104, 105, 141, 287, 295, 296
 -south central, 26, 102, 103, 149, 382, 383, 384
 -southeastern, 10, 75, 95, 98, 105, 112, 133-134, 149, 316, 387, 391, 405, 413, 449, 499
 -southern, 26, 109, 135-137, 143, 287
 -southwestern, 4, 27, 39, 51, 90, 93, 100, 105, 109, 111, 116, 117, 118, 119, 123, 138, 291, 305, 306, 311, 396, 499, 500, 507
 -west central, 45, 93, 100, 102
 -western, 1, 26, 45, 56-57, 64, 66, 71, 75, 86, 123, 149, 167, 193, 287, 291, 293, 296, 300
 Utah County, 152, 160
 Utah-Idaho Basin, 287
 Utah Lake, 148, 152
 Utah Valley, 300
 Utah Natural Gas Co. 205
 Utah Oil and Gas Conservation Commission, 5
 Utah Oil Refining Co. #1 Fitzhugh, 371
 Utah Southern Oil Co. Cedar Mesa No. 1, 392
 -Noble #1, 80
 -Wells, 298
 Utah Wax, 255
 Ute Mountains, 397
 Ute Royalty Corp. #1 Government Well, 377
 Ute Trail Gas Field, 201
 Ute Trail Unit Oil Field, 6
 -area, 211, 213
 Ute Tribal, #1, 267
 -Tribal #2, 267
 Ute land Butte Gas Field, 201
 Ute land Butte Member, 201

V

Valley Field, 150
 Valley Mountains, 331
 Vanadium, 111
 Vermilion Creek, 126, 135
 Vermilion Cliffs, 111
 Vernal, Utah, 129, 130, 223, 225, 497
 Veyo Utah, 138, 161
 Veyo Fault, 309
 Victoria Quartzite (formation), 82, 83
 Virgilian Time, 97, 357, 359, 361
 Virgin Anticline, 309, 314
 Virgin Limestone Member (Moenkopi), 112, 305, 313, 337
 Virgin Mountains, 80
 Virgin River, 307, 312
 Virgin Oil Field, 4, 6, 291, 311-313, 315, 316, 317, 324, 499, 500, 501, 502, 503

Virgin - Kanarra Anticline, 303
 Vishnu Schist, 305
 Volcanic Activity, 27, 355
 Volcanic Rocks, 163, 168

W

Wagonhound (gilsonite) Vein, 218
 Wahwah Springs Tuff, 162
 Wahweap Creek, 137
 Wahweap Sandstone, 136, 137, 306, 324, 382
 Walter Nelson Finlayson #1, S Diamond Fork, 331
 Wanship Formation, 24, 123, 125, 127, 128, 190
 Warm Springs Mountain, 83
 Wasatch Age, 239, 244
 Wasatch Basin, 281
 "Wasatch" Coal, 190
 Wasatch County, 4, 160
 Wasatch Fault, 18
 Wasatch Front, 196
 Wasatch Formation, 137, 138, 143, 144, 180, 185, 193, 200, 201, 204, 205, 208, 218, 224, 225, 241, 244, 249, 251, 271, 306, 323, 325, 334, 364, 382
 Wasatch Group, 369
 Wasatch Line, 19, 75, 81, 86, 327
 Wasatch Mountains, 13, 18, 24, 26, 28, 39, 42, 45, 49, 63, 83, 90, 91, 95, 102, 103, 104, 109, 112, 113, 116, 117, 118, 121, 127, 141, 144, 147, 148, 149, 183, 185, 287, 291, 293, 295, 300, 327, 329, 330-331, 355, 357
 -geosyncline, 176
 -monocline, 331
 Wasatch Oil and Gas Field, 213
 Wasatch Plateau, 23, 24, 27, 130-132, 135, 141, 143, 144, 149, 291, 325, 331, 333, 334, 337, 353, 355, 363, 364, 369, 375
 Wasatch Sands, 197
 Wasatch Zone, 28
 Washington County, 4, 5, 111, 138, 155, 157, 160, 324, 500
 -geology of, 303-317
 -oil and gas possibilities of, 303-317
 -stratigraphy of, 304
 Washington Dome, 309
 Water Canyon Formation, 76, 77, 81
 Water Encroachment, 202
 Waterpocket Monocline, 338
 Watson, Utah, 221
 Wax, 251, 255, 257
 Wayan Formation, 23
 Wayne Formation, 23
 Wayne County, 4, 327, 353, 381
 Weaver-Corralito (gilsonite) Vein, 217, 218
 Weber Canyon, 40, 41
 Weber County, 183
 Weber Sandstone, 93, 95, 96, 150, 170, 181, 186, 201, 224, 238-239, 497, 498, 500
 Weber Quartzite, 103
 Weber River, 13, 18, 95
 Weeks Formation, 290
 Wells, Artesian, 152
 Wells Formation, 95, 102, 103, 104
 Wellsville Mountains, 90, 95, 141
 Wendover, Utah, 56, 77, 79
 Wendover Arch, 296
 West Canyon Limestone, 94
 West Mountain, 83
 West Tintic Mountains, 293
 West Tintic Stock, 155, 160
 Westwater Anticline, 377
 Westwater Field, 369
 West Water Canyon Member (Morrison), 117
 Western Natural Redd #1, 80
 -Byrd Frost Navajo No. 1, 405

Western Petroleum Syndicate #1 Nebeker, 296-297
 Westwater gas field, 7, 10
 Wheeler formation, 290
 Whirlpool Canyon, 96
 White Butte Dome, 309, 315
 White Canyon, 101, 110
 White Mesa oil field, 6, 407
 White Rim Member (Cutler fm.), 100, 102, 361, 383, 451
 White River, 194, 217, 218, 221, 224
 White River gas field, 7
 Whiterocks Canyon, 225, 237-239, 240, 241
 Whiterocks River, 75, 241
 White Sage formation, 292
 Whitlock, L. E., #1 Morton Salt, 297
 Widdop Peak area, 186
 Wildcats, 6, 198, 199
 Wild Horse Bench, 219
 Willard Thrust, 25
 Williams Fork formation, 128, 130
 Willow Creek (gilsonite) system, 219, 222
 Wilson-Walker Drilling #1 Cassity, 299
 Windblown deposits, 116
 Wind River formation, 279
 Wingate formation (sandstone), 109, 111, 112, 113, 116, 118, 119, 305, 330, 333, 337, 382, 401, 431, 451, 469, 473

Winsor formation, 136, 305, 306, 324, 387, 392
 Wolfcampian, 95, 99, 100, 101, 102, 355, 357, 359, 361
 Wood River formation, 95
 Wood Shale, 111
 Woodman formation, 91
 Woodside Anticline, 371
 Woodside formation (shale) 109, 112, 113, 330
 Wurtzilite, 215, 249, 255, 257, 258, 259, 261, 264, 267, 268-269, 271, 273, 282
 Wygaret Terrace, 321
 Wyoming, 41, 51, 57, 95, 100, 104, 113, 119, 125, 127, 129, 183, 193, 207, 221, 223, 279
 Wyoming Shelf, 93, 95, 96, 100
 Wyoming, University of, 497

Y

Yellow Cat Dome, 378

Z

Zion National Park, 112, 116, 305, 312, 324
 Zuni Uplift, 19, 387, 394, 395, 397



UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

**LIST OF
PUBLICATIONS
AND MAPS**

JANUARY, 1963

Publications may be purchased from the Utah Geological and Mineralogical Survey, Room 103, Civil Engineering Building, University of Utah, Salt Lake City 12, Utah. Out-of-print material may be consulted in public or college libraries.

Payment by check, cash, or money order (stamps will not be accepted) should accompany all requests.

The Survey assumes that orders have been filled unless notification of non-receipt is given within one month.

NEW PUBLICATIONS
of the
UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

IN PRESS

Special Studies 3 -- A RECONNAISSANCE SURVEY OF THE
COAL RESOURCES OF SOUTHWESTERN UTAH , by Dr.
Richard A. Robison, 40 p., 2 figs., 1 table.

Expected Publication: Feb., 1963 Price.....\$1.00

A concise summary of all available data, together with the
information gained from reconnaissance field trips and
additional sampling.

Bulletin 49 -- KANAB, GATEWAY TO SOUTHERN UTAH, by
Dr. Herbert E. Gregory, 24 p., 10 figs.

Expected Publication: Feb., 1963 Price.....\$.75

Written by Doctor Gregory for the layman, this volume,
published posthumously, describes the cultural geology
and physiography of the Kanab region.

PUBLICATIONS OF THE UTAH GEOLOGICAL SURVEY

Bulletins

- 24 - Tungsten Reserves Discovered in the Cottonwood-American Fork Mining District, Utah, by Arthur L. Crawford and Alfred M. Buranek, 1944, 56 p., 6 figs. (formerly RS-55) _____ \$.50
- 25 - Tungsten Deposits of the Mineral Range, Beaver Co., Utah, by Arthur L. Crawford and Alfred M. Buranek, 1945, 48 p., 5 figs. (formerly RS-56) _____ \$.50
- 35 - Halloysite of Agalmatolite Type, Bull Valley District, Washington County, Utah, by Arthur L. Crawford and Alfred M. Buranek, 1948, 12 p. _____ \$.10
- 36 - Directory of Utah Mineral Resources and Consumers Guide, by Alfred M. Buranek and C. E. Needham, 1949, 95 p., 1 pl. _____ \$1.00
- 37 - The Geology of Eastern Iron County, Utah, by Herbert E. Gregory, 1950, 153 p., 53 plates and photographs, 1 map _____ \$1.50
- 38 - Stratigraphy of the Burbank Hills, Western Millard County, Utah, by Richard W. Rush, 1951, 24 p., 6 figs. _____ \$1.00
- 39 - Lower Ordovician Detailed Stratigraphic Sections for Western Utah, by Lehi F. Hintze, 1951, 99 p., 4 maps, 7 illustrations _____ \$1.50
- 40 - Bibliography of Utah Geology to December 31, 1950, by Walter R. Buss, 1951, 219 p. _____ \$4.00
- 41 - Geology of Lake Mountain, Utah, by Kenneth C. Bullock, 1951, 46 p., 7 pls., 3 tables _____ \$1.00
- 42 - Geology of Dinosaur National Monument and Vicinity, Utah-Colorado, by G. E. and B. R. Untermann, 1954, 225 p., 3 pls., 10 figs., 51 photographs _____ \$2.50
- 43 - Eastern Sevier Valley, Sevier and San Pete Counties, Utah--With Reference to Formations of Jurassic Age, by Clyde T. Hardy, 1952, 95 p., 9 pls., 4 figs., 1 table _____ \$1.00
- 44 - Geology and Ore Deposits of the Silver Reef (Harrisburg) Mining District, Washington County, Utah, by Paul Dean Proctor, 1953, 169 p., 11 pls., 13 figs., 8 tables _____ \$2.00

- 45 - Geology of the Selma Hills, Utah County, Utah, by J. Keith Rigby, 1952, 107 p., 6 pls., 21 figs., 3 tables _____ \$1.50
- 46 - Uranium-Vanadium Deposits of the Thompsons Area Grand County, Utah -- With Emphasis on the Origin of Carnotite Ores, by W. L. Stokes, 1952, 51 p., 2 pls., 12 figs., 1 table _____ \$1.50
- 47 - Microfossils of the Upper Cretaceous of Northeastern Utah and Southwestern Wyoming, by Daniel Jones, David Gauger, Reed H. Peterson, and Robert R. Lankford, 1953, 158 p., 16 pls., 8 figs., 4 tables _____ \$2.00
- 48 - Lower Ordovician Trilobites from Western Utah and Eastern Nevada, by Lehi F. Hintze, 1952, 249 p., 28 pls. _____ \$4.00
- 50 - Drilling Records for Oil and Gas in Utah, by George H. Hansen and H. C. Scoville, 1955, 110 p., 30 illustrations, 1 table. _____ \$5.00
- 51 - The Rocks and Scenery of Camp Steiner, Summit and Wasatch Counties, Utah, by Daniel Jones, 1955, 30 p., 13 pls. _____ \$.25
- 52 - Geologic Atlas of Utah, Emery County, by Wm. L. Stokes and Robert E. Cohenour, 1956, 92 p., 38 colored geologic map plates _____ \$5.00
- 53 - Silurian Rocks of Western Millard County, by Richard W. Rush, 1956, 66 p., 12 figs. _____ \$1.50
- 54 - Oil and Gas Possibilities of Utah, Re-evaluated, compiled and edited by Arthur L. Crawford, 1963, 540 p., 158 figs., 25 tables _____ \$6.50
- 54a- Surface, Structure, and Stratigraphy of Utah, Parts I and II of Bulletin 54, compiled and edited by Arthur L. Crawford, 1963, 170 p., 50 figs., 12 tables _____ \$4.00
- 55 - Clays of Utah County, Utah, by Edmond P. Hyatt, 1956, 83 p. 22 figs., 4 tables _____ \$2.00
- 56 - Geology of the Southern Lakeside Mountains, Utah, by John C. Young, 1955, 108 p., 3 pls., 2 figs. _____ \$1.50

- 57 - Middle Ordovician Detailed Stratigraphic Sections for Western Utah and Eastern Nevada, by Gregory W. Webb, 1956, 77 p., 12 figs. _____ \$1.50
- 58 - Geology of the Pine Valley Mountains, Utah, by Earl F. Cook, 1957, 111 p., 52 figs. _____ \$2.00
- 59 - Phosphate in Utah, by Thomas Cheney, 1957, 54 p., 3 pls., 12 figs., 3 tables _____ \$1.50
- 60 - The Rocks and Scenery of Camp Hunt, Rich County, Utah, by Clyde T. Hardy, 1957, 26 p. _____ \$.25
- 61 - The Oquirrh Formation, Stratigraphy of the Lower Portion in the Type Area and near Logan, Utah, by Paul W. Nygreen, 1958, 67 p., 4 pls., 5 figs., 3 tables _____ \$2.00
- 62 - Notch Peak Intrusive, Millard County, Utah, by Harry M. Gehman, Jr., 1958, 50 p., 4 pls., 12 figs., 3 tables _____ \$1.50
- 63 - Geology of the Sheeprock Mountains, Tooele County, Utah, by Robert E. Cohenour, 1959, 200 p., 15 pls., 6 figs., 3 tables. _____ \$5.00
- 64 - Geologic Atlas of Utah, Cache County, by J. Stewart Williams, 1958, 98 p., 13 pls., 2 figs., 13 colored geologic map plates _____ \$5.00
- 65 - Geology of the Stansbury Range, by John S. Teichert, 1959, 75 p., 2 pls., 12 figs. _____ \$1.50
- 66 - Geologic Atlas of Utah, Daggett County, by Howard R. Ritzma, 1959, 111 p., 4 pls., 10 figs., 8 colored geologic map plates _____ \$5.00
- 67 - The Rocks and Scenery of Camp Maple Dell, Utah County, Utah, by J. Keith Rigby, 1959, 55 p., 5 pls., 16 figs. _____ \$.25
- 68 - Beaver Lake Mountains, Beaver County, Utah, by Patrick J. Barosh, 1960, 88 p., 5 pls., 17 figs. _____ \$2.00
- 70 - Geologic Atlas of Utah, Washington County, by Earl F. Cook, 1960, 119 p., 16 pls., 8 figs, 19 photographs, 8 colored geologic map plates _____ \$5.00
- 71 - The Mineral Resources of Uintah County, Utah, by Robert G. Pruitt, 1961, 101 p., 11 pls., 19 figs. _____ \$2.00

WATER RESOURCE BULLETINS

- 1 - Water Production from Oil Wells of the Uinta Basin, Uintah and Duchesne Counties, Utah, by Harry D. Goode and Richard D. Feltis, 1962, 32 p., 3 pls., 4 figs., 2 tables _____ \$1.00

SPECIAL STUDIES

- 1 - Glauber's Salt Bed, West of Promontory Point, Great Salt Lake, by Armand J. Eardley, 1962, 16 p., 3 figs. — \$.50
- 2 - Gypsum Dunes and Evaporite History of the Great Salt Lake Desert, by Armand J. Eardley, 1962, 32 p., 6 figs., 2 plates _____ \$.75
-

DISCOUNTS ON SURVEY PUBLICATIONS

ORDERS OF THE SAME PUBLICATIONS

1-4	No discount
5-9	10% discount
10 or more	25% discount
\$39.99, thereafter	30% discount

MIXED ORDERS OF VARIOUS SURVEY PUBLICATIONS

\$10-\$19.99	10% discount
\$20 to \$39.99	20% discount
\$40 and over	30% discount

MAPS --

MAPS OF THE UTAH GEOLOGICAL SURVEY:

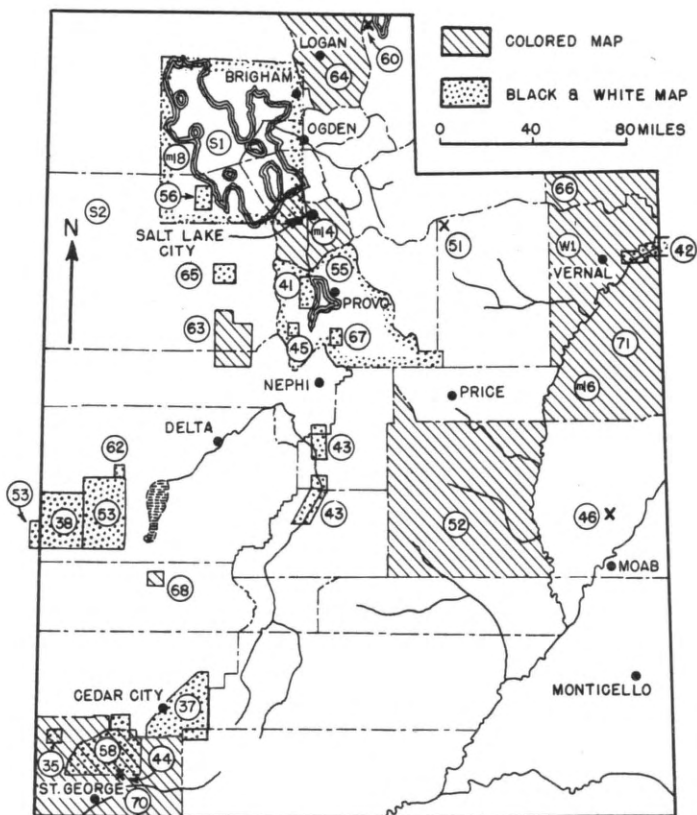
- 1 - Reconnaissance Geologic Map of Eastern Iron Co., Utah, by Herbert E. Gregory (formerly RS-37; plate II from Bull. 37) _____ \$.50
- 3 - Colored Relief Map of Utah (formerly RS-22) _____ \$.50
- 4 - A Correlation Chart of Formations in Utah (formerly RS-25) _____ \$.50
- 5 - Geology of the Egnar-Gypsum Valley area, San Miguel and Montrose Counties, Colorado (formerly RS-27) _____ \$.50
- 6 - Geology of the West-Central part of the Gunnison Plateau, Utah, by Clyde T. Hardy and Howard D. Zeller (formerly RS-33a) _____ \$.25
- 7 - Index to Unpublished Geologic Thesis Mapping in Utah (formerly RS-58) _____ \$.25
- 8 - Colored Geologic Map of Utah, from Guidebook to Annual Brigham Young University geology field trip (see reprint 57, formerly RS-57a) _____ \$.15
- 9 - Physiographic Map of Utah (formerly RS-78) _____ \$.15
- 12 - Colored Geologic Map of Cache County, Utah, by J. Stewart Williams (formerly RS-64) _____ \$ 1.00
- 13 - Colored Geologic Map of Daggett County, Utah, by Howard R. Ritzma (formerly RS-76) _____ \$ 1.00
- 14 - Colored Geologic Map of Washington County, by Earl F. Cook (formerly RS-84) _____ \$ 1.00
- 15 - Colored Geologic Map of Salt Lake County (formerly RS-85) _____ \$ 1.00
- 16 - Colored Geologic Map of Uintah County, Utah, in two halves (formerly RS-90) _____ \$ 1.50
- 17 - Mineral Resources Map of Uintah County, by Robert G. Pruitt _____ \$.35
- 18 - Earthquake Fault Map of a Portion of Salt Lake County, Utah _____ Free

MAPS AVAILABLE THROUGH THE SURVEY

- The Great Salt Lake, Utah, by Armand J. Eardley (formerly RS-88) _____ \$.50
- Wildcat Map of Utah (42" x 50"), by Utah Oil Report--kept up to date _____ \$10.00
- Geologic Map of Utah, Northeast Quarter \$3.50 (by mail \$4.00)
Northwest Quarter
(available Winter '62-'63)

Various plates from Utah Geological Society and Intermountain Association of Petroleum Geologists Guidebooks.

INDEX MAP TO PUBLICATIONS OF THE UTAH GEOLOGICAL AND MINERALOGICAL SURVEY



Reprints

- 6 - The Precambrian Rocks of Utah, by Eliot Blackwelder, 1949, 6 p., 1 fig. (reprinted from the Oil and Gas Possibilities of Utah) _____ \$.25
- 7 - The Cambrian Stratigraphy of Utah, by Hyrum M. Schneider, 1949, 7 p., 3 figs. (reprinted from the Oil and Gas Possibilities of Utah) _____ \$.35
- 16 - Grand-San Juan Area, 1949, 26 p., 8 figs. (reprinted from the Oil and Gas Possibilities of Utah) _____ \$.75
- 17 - Uinta Basin Area, 1949, 22 p., 3 charts, 3 figs., (reprinted from the Oil and Gas Possibilities of Utah) _____ \$.75
- 18 - Gilsonite and Related Hydrocarbons of the Uinta Basin, by Arthur L. Crawford, 1949, 17 p., 1 fig., 4 tables (reprinted from the Oil and Gas Possibilities of Utah) _____ \$.75
- 19 - The Clay Basin Gas Field, by M. M. Fidler, 1949, 7 p., 3 figs. (reprinted from the Oil and Gas Possibilities of Utah) _____ \$.35
- 20 - Utah Plateaus Area, 1949, 22 p., 8 figs., (reprinted from the Oil and Gas Possibilities of Utah) _____ \$.75
- 21 - Basin and Range Area, by Arthur E. Granger, Carroll Wegemann, and C. Max Bauer, 1949, 134 p., 9 figs. (reprinted from the Oil and Gas Possibilities of Utah) _____ \$1.00
- 33 - Geology of the West-Central Part of the Gunnison Plateau, Utah, by Clyde T. Hardy and Howard D. Zeller, 1953, 20 p., 2 pls., 2 figs., 1 geologic map (reprinted from Geol. Soc. America Bull., v. 64, p. 1261-1278) _____ \$.75
- 39 - Tertiary Well Logs in the Salt Lake Desert, by Joseph F. Schreiber, 1954, 14 p., 1 fig. (reprinted from records made available by the Southern Pacific Railroad) _____ \$.50
- 43 - The Uinta Mountains and Vicinity, a Field Guide to the Geology, by G. E. and B. R. Untermann, 1954, 10 p. (reprinted from Paper No. 1 of the Utah Field House of Natural History) _____ \$.25
- 50 - The Riddle of Mountain Building, by Armand J. Eardley, 1955, 31 p., 21 figs. (reprinted from Bulletin No. 1 of the University of Utah, v. 46, no. 11) _____ \$.25

- 52 - A Legal Guide for the Uranium Prospector, with an Analysis of the Impact of the "Uranium Boom" on Mining Law, by J. Thomas Greene, 1954, 31 p. (reprinted from Utah Law Review, v. 4, no. 2) _____ \$1.00
- 59 - Hydrology of Lake Bonneville and Sediments and Soils of its Basin, by A. J. Eardley, Vasyl Gvosdetsky, and R. E. Marsell, 1957, 60 p., 4 pls., 24 figs., 16 tables (reprinted from Geol. Soc. America Bulletin 68, p. 1141-1202) _____ \$.50
- 60 - A Catalogue of Utah Minerals and Localities, by Maynard Bixby, 1959, 34 p. (reprinted from a pamphlet published by R. H. Office and Company and Maynard Bixby) _____ \$.50
- 65 - Crater Hill Lava Flow, Zion National Park, Utah, by Richard L. Threet, 1958, 6 p., 3 figs. (reprinted from Geol. Soc. America Bull., v. 69, pp. 1065-1070) _____ \$.25
- 66 - Paleozoic Stratigraphy and Oil Possibilities of the Kaiparowits Region in Utah, by Edgar B. Heylman, 1958, 30 p., 6 figs. (reprinted from Am. Assoc. Petroleum Geologists Bull. 42, no. 8) _____ \$.50
- 68 - Middle Ordovician Stratigraphy in Eastern Nevada and Western Utah, by Gregory W. Webb, 1958, 42 p., 13 figs. (reprinted from Am. Assoc. Petroleum Geologists Bull. 42, no. 10) _____ \$.75
- 71 - Sulphur Isotope Abundance in Hydrocarbons and Source Rocks of the Uinta Basin, Utah, by A. G. Harrison and H. G. Thode, 1958, 7 p., 3 figs. (reprinted from Am. Assoc. Petroleum Geologists Bull. 70, p. 207-218) _____ \$.75
- 75 - Upper Devonian Unconformity in Central Utah, by J. Keith Rigby, 1959, 12 p., 5 figs. (reprinted from Geol. Soc. America Bull. 70, p. 207-218) _____ \$.25
- 89 - Analysis of Pleistocene Core from Great Salt Lake, Utah, by A. J. Eardley and Vasyl Gvosdetsky, 1960, 21 p., 1 pl., 2 figs., 4 tables (reprinted from Geol. Soc. America Bull., v. 71, p. 1323-1344) _____ \$.50

GUIDEBOOKS OF THE UTAH GEOLOGICAL SOCIETY

3 -	Geology of the Utah-Colorado Salt Dome Region, with emphasis on Gypsum Valley, Colorado, 1948 _____	\$2.50
4 -	The Transition between the Colorado Plateaus and the Great Basin in Central Utah, 1949 _____	\$3.00
6 -	Geology of the Canyon, House, and Confusion Ranges, Millard County, Utah, 1951 _____	\$4.00
8 -	Geology of the Central Wasatch Mountains, Utah, 1952 _____	\$3.50
9 -	Uranium Deposits and General Geology of Southeastern Utah, 1954 _____	\$3.00
10 -	Tertiary and Quaternary Geology of the Eastern Bonneville Basin, 1955 _____	\$4.00
11 -	Geology of Parts of Northwestern Utah, 1956 _____	\$4.00
12 -	Geology of the East Tintic Mountains and Ore Deposits of the Tintic Mining Districts, 1957 _____	\$4.00
13 -	Geology of the Stansbury Mountains, Tooele County, Utah, 1958 _____	\$4.00
14 -	Geology of the Southern Oquirrh Mountains and Five Mile Pass--Northern Boulder Mountains Area, Tooele and Utah Counties, Utah, 1959 _____	\$4.00
15 -	Geology of the Silver Island and Adjacent Areas in the Great Salt Lake Desert Northeast of Wendover, Utah, 1950 _____	\$4.00
16 -	Geology of the Bingham Mining District and Northern Oquirrh Mountains, 1961 _____	\$6.00

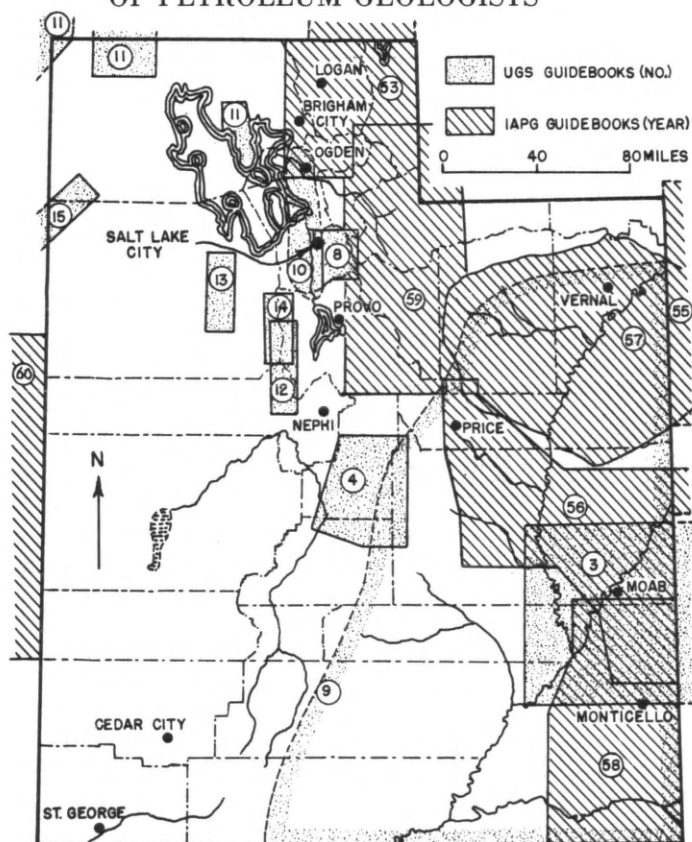
UTAH GEOLOGICAL SOCIETY DISCOUNTS

Orders of

5-9 Guidebooks _____ 20% discount
 10 or more _____ 25% discount

25% discount on all Guidebooks to students.

INDEX MAP SHOWING AREAS TREATED BY THE GUIDEBOOKS OF THE UTAH GEOLOGICAL SOCIETY AND BY THE INTERMOUNTAIN ASSOC. OF PETROLEUM GEOLOGISTS



GUIDEBOOKS OF THE
INTERMOUNTAIN ASSOC. PETROLEUM GEOLOGISTS

1951 - Geology of the Canyon, House, and Confusion Ranges, Millard County, Utah _____	\$ 4.00
1952 - Cedar City, Utah to Las Vegas, Nevada _____	\$ 4.00
1953 - Geology of Northern Utah and Southeastern Idaho _____	\$ 7.50
1954 - Geology of the High Plateaus, Central and South Central Utah _____	\$ 7.50
1955 - Geology of Northwest Colorado _____	\$ 7.50
1956 - Geology and Economic Deposits of East-Central Utah _____	\$ 7.50
1957 - Guidebook to the Geology of the Uinta Basin _____	\$ 7.50
1958 - Guidebook to the Geology of the Paradox Basin _____	\$11.00
1959 - Guidebook to the Geology of the Wasatch and Uinta Mountains Transition Area _____	\$12.00
1960 - Guidebook to the Geology of East Central Nevada _____	\$12.00
1961 - Oil and Gas Fields of Utah--Symposium _____	\$10.00

MISCELLANEOUS PLATES FROM GUIDEBOOKS

UTAH GEOLOGICAL SOCIETY GUIDEBOOK PLATES

- | | | |
|------|---|--------|
| 8 - | Plate I. Geologic Map of Central Wasatch Mountains East of Salt Lake Valley, Utah, with roadlogs from Guidebook No. 8 | \$.50 |
| 12 - | Plate I. Generalized Geologic Map and Section of the East Tintic Mountains, Utah | \$.50 |
| | Plate III. Index Map of Mines and Mining Districts of the East Tintic Mountains, Utah | \$.50 |
| | Plate XVII. Mines and Prospects of the Tintic Mining District | \$.50 |
| 13 - | Geologic Cross Sections of the Stansbury Mountains | \$.30 |
| 16 - | Plate I. Generalized Geology of the Northern and Central Oquirrh Mountains, Salt Lake and Tooele Counties, Utah | \$.50 |
| | Plate II. Surface Geology Map of the Bingham District | \$.50 |
| | Plate III. Section A-A'; B-B'. To accompany surface geologic map of Bingham District | \$.50 |
| | Plate IV. Section C-C'; D-D'. To accompany surface geologic map of Bingham District | \$.50 |
| | Plate V. Stratigraphic Correlation Chart. Bingham Mining District and Adjacent Areas | \$.50 |
| | Plate VII. Map showing location of Field Trip Road Log, Bingham Mining District and Central Oquirrh Mountains, Utah. | \$.50 |

INTERMOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS

- | | | |
|--------|---|--------|
| 1953 - | Geologic Map of Northern Wasatch Mountains, Utah and Idaho, by Clyde T. Hardy and J. Stewart Williams, (formerly RS-40) | \$.75 |
| | Idaho, Wyoming Thrust Belt (formerly RS-41) | \$.75 |
| 1954 - | Geologic Map of Portions of the High Plateaus and Adjacent Canyon Lands, Central and South Central Utah. | \$4.00 |

MISCELLANEOUS

The Great Basin, with Emphasis on Glacial and Postglacial Times	_____ \$2.00
Low-Temperature Carbonization of Utah Coals	_____ \$5.00
Glossary of Selected Geologic Terms, with special reference to their use in engineering, by W. L. Stokes	_____ \$2.75
Uranium, Where It Is and How To Find It, by Paul D. Proctor	_____ \$2.50
Uranium, the World's Expanding Frontier, by A. J. Eardley	_____ \$2.00
The Special Uranium No., Economic Geology, v. 50, no. 2	_____ \$1.00

CONSIGNMENT (Survey Discounts Not Applicable)

Utah Geological Society (see following pages)	
Intermountain Assoc. Petroleum Geologists (see following pages)	
Gazetteer of Utah Localities and Altitudes	_____ \$1.50
Outline of the Geologic History and Stratigraphy of Utah, by Wm. L. Stokes and E. B. Heylmun	_____ \$.75
Geologic Map of Utah -- Northeast Quarter	
Northwest Quarter (Winter '62-'63)	_____ \$3.50
by mail -	\$ 4.00

The following publications are out of print. Copies of these may be obtained from local or university libraries.

Bulletins 1-34 were published by the Utah Publicity and Industrial Development and are no longer available, with the exception of Bulletins 24 and 25.

Guidebooks 1, 2, 5, and 7

Maps 2, 10, and 11

Bulletins 49 and 69 are still pending.

FREE CIRCULARS AND REPRINTS OF THE SURVEY

CIRCULARS:

- 24 - Utah Iron Deposits Other Than Those of Iron and Washington Counties, Utah, by Arthur L. Crawford and Alfred M. Buranek
- 25 - The Occurrence of Celestite on the San Rafael Swell, Emery County, Utah, by Arthur L. Crawford and Alfred M. Buranek.
- 28 - The Molybdenum Deposits of White Pine Canyon, near Alta, Salt Lake County, Utah, by Alfred M. Buranek.
- 38 - Diatomaceous Earth near Bryce Canyon National Park, Utah, by Arthur L. Crawford
- 39 - The Library of Samples for Geologic Research, Mines Building, University of Utah -- Facilities and Potentialities, by Arthur L. Crawford
- 41 - Oil Shale on Chris's Creek, Juab County, Utah--The Mystery of the Legendary First Retort, by Arthur L. Crawford.
- 42 - List of Publications

REPRINTS

- 28 - Geologic Index Map of Utah
- 30 - Utah Raw Materials of Interest to the Chemical Engineer (reprinted from Chemical and Engineering News, v. 27, p. 3017, 1949).

The Mineral Industry of Utah, 1955 through 1960.

*Have you used the Utah Geological Survey's
Library of Samples for Geologic Research?*



Housed in the basement of the School of Mines, at the
University of Utah

*Information is as near as the telephone —
DA 8-9011, Ext. 2384*