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

MINERAL AND WATER RESOURCES OF UTAH

BULLETIN 73, 1964 • PRICE $1.00 • REPRINTED JUNE 1969

Compiled by the
U. S. GEOLOGICAL SURVEY, in cooperation with

THE UTAH GEOLOGICAL AND MINERALOGICAL SURVEY, and

THE UTAH WATER AND POWER BOARD, for the

U. S. SENATE COMMITTEE ON INTERIOR AND INSULAR AFFAIRS

The Utah Geological Survey expresses its appreciation to the Honorable Frank E. Moss, U.S. Senator from Utah, not only for his permission to issue as Bulletin 73 of the Utah Geological and Mineralogical Survey, this report of the Interior and Insular Affairs Committee of the U.S. Senate, but for having it reprinted.

91st Congress, 1st Session | SENATE | Document No. 91–12

MINERAL AND WATER RESOURCES OF UTAH

REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

IN COOPERATION WITH

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

AND THE

UTAH WATER AND POWER BOARD

PREPARED AT THE REQUEST OF

SENATOR FRANK E. MOSS
OF UTAH

OF THE

COMMITTEE ON INTERIOR AND INSULAR AFFAIRS
UNITED STATES SENATE

March 10 (Legislative day, March 7), 1969.—Ordered to be printed with illustrations

U.S. GOVERNMENT PRINTING OFFICE

26-803 O

WASHINGTON : 1969

SENATE RESOLUTION 98

Submitted by Mr. Moss of Utah

IN THE SENATE OF THE UNITED STATES,
Agreed to March 10, (legislative day, March 7), 1969.

Resolved, That the report entitled "Mineral and Water Resources of Utah" be printed as a Senate document and that there be printed two thousand six hundred additional copies of such document for the use of the Committee on Interior and Insular Affairs.

FRANCIS R. VALEO,
Secretary.

MEMORANDUM FROM THE CHAIRMAN

To Members of the Senate Committee on Interior and Insular Affairs:

I am transmitting for your information a report entitled "Mineral and Water Resources of Utah," prepared by the U.S. Geological Survey at the request of our colleague, Senator Frank E. Moss.

This detailed survey will be particularly helpful to government and business leaders in Utah. It will also be valuable to the Congress and members of this committee as we consider legislation regarding mineral and water development.

HENRY M. JACKSON, *Chairman.*

FOREWORD

This report was prepared at my request by the U.S. Geological Survey in cooperation with the Utah Geological and Mineralogical Survey and the Utah Water and Power Board.

Its purpose is to make all significant data on Utah's important mineral and water resources available to interested citizens, to professional personnel in mining and water development, and to government, civic, and industrial leaders. I think that purpose has been well met.

I wish to thank all of those both in Utah and Washington who have contributed to the making of this report.

FRANK E. MOSS.

MINERAL AND WATER RESOURCES OF UTAH

REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

IN COOPERATION WITH

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

AND THE

UTAH WATER AND POWER BOARD

PREPARED AT THE REQUEST OF

SENATOR FRANK E. MOSS

OF UTAH

LETTER OF TRANSMITTAL

U.S. DEPARTMENT OF THE INTERIOR,
GEOLOGICAL SURVEY,
Washington, D.C., December 30, 1963.

Hon. FRANK E. MOSS,
U.S. Senate, Washington, D.C.

DEAR SENATOR MOSS: In response to your letter of April 18, 1963, I am pleased to transmit herewith a summary report on the mineral and water resources of Utah which has been prepared by the Geological Survey in cooperation with the Utah Geological and Mineralogical Survey and the Utah Water and Power Board.

The report describes the mineral commodities known to occur in Utah, and it presents information on their manner of occurrence, distribution, and relative importance to the mineral industry of the State. Surface and ground water resources are described in considerable detail, as is water power. The narrative discussion on most commodities is supplemented by small scale maps and other illustrations.

It is hoped that data in the report will be adequate to supply the information you desire.

Sincerely yours,

THOMAS B. NOLAN, *Director.*

CONTENTS

ILLUSTRATIONS

TABLES

INTRODUCTION

(By L. S. Hilpert, Salt Lake City, Utah)

This report summarizes the mineral and water resources of Utah by describing their manner of occurrence, distribution, relative importance to the State and Nation, and the outlook for their development and use. To provide a background to the resource evaluations, production figures for the various mineral commodities are given, if available and pertinent, and their uses in industry are described, together with the economic factors that affect their exploration and development. All mineral commodities are discussed that are known to occur in Utah and that might have economic significance within the foreseeable future, whether or not they have been mined. In an introductory section, the geology of the State is outlined briefly and the distribution and relations of the mineral resources to the regional geology are summarized.

This report was compiled by members of the staff of the U.S. Geological Survey and was financed in part by the Utah Geological and Mineralogical Survey and the Utah Water and Power Board. The report is based on the published literature regarding the mineral and water resources of Utah, supplemented by unpublished material in the files of the U.S. Geological Survey and the personal observations and experience of the 37 individuals who have contributed to the various sections. Although treatment of the various resources is brief, the report is planned to provide a convenient reference for anyone seeking additional information. Specific references are cited in the text, and comprehensive bibliographies are listed at the back of each principal section.

Much of the basic hydrologic data used was collected as part of cooperative programs with State, Federal, and local agencies that have been continuous since 1909. The report "The Role of Ground Water in the National Water Situation," by C. L. McGuinness, was used extensively in the preparation of the section on water resources. Credit is extended to H. D. Goode for his contribution to the section on ground water and to W. V. Iorns for material on the sediment discharge and chemical quality of streams in the Upper Colorado River Basin.

The geologic map (fig. 5) is based in part on "The Geologic Map of Utah," compiled and edited by W. Lee Stokes and others (1961, 1963, and in press), and the southeast part of figure 5 is based in part on the map by Andrews and Hunt (1948). Special thanks are extended to Drs. A. J. Eardley and W. Lee Stokes, University of Utah, and to the Utah State Land Board, for making available in advance of publication the plates of the southwest quadrant. The summary papers in "Surface, Structure, and Stratigraphy of Utah," edited by A. L. Crawford (1963), were most helpful in the preparation of the section on stratigraphy. Thanks also are extended to Dr. Osmond

Harline and his associates in the Bureau of Economics and Business Research, University of Utah, for their assistance in collecting and developing statistics on Utah's mineral industry.

Mineral production data given in the text, unless otherwise cited, are from the U.S. Geological Survey's Mineral Resources of the United States (1880–1921), the U.S. Bureau of Mines' Minerals Yearbook (1922–61), and supplemented by data from the U.S. Bureau of Mines, Denver and Washington, D.C. Thanks are extended to W. H. Kerns, Denver, for granting access to the Bureau's microfilm records. Appropriate credits are listed on individual figures and tables.

THE MINERAL INDUSTRY IN UTAH

(By R. A. Weeks, Washington, D.C., and L. S. Hilpert, Salt Lake City, Utah)

The year 1963 has been celebrated as the centennial of mining in Utah; so it is timely and appropriate to summarize Utah's mineral industry as a preface to the discussion of the mineral resources.

In the past century the mines, quarries, and petroleum and brine wells of Utah have furnished more than $8 billion worth of mineral products, making Utah's mineral industry a vital factor in each phase of the State's history and economic growth. Not only has the value of the mineral output exceeded other raw materials, but the development of the mineral wealth has established other major industries that were required to transport, refine, and market the mineral products. Significant as the past production has been, the resources described in the subsequent sections of this report are equal to or surpass those that have been extracted.

Unlike most western states, Utah's earliest mining was not for gold, but for the more utilitarian resources such as salt, coal, sulfur, and lead that were needed by the isolated pioneer settlements. It was not until 1863, 16 years after the arrival of the Mormon settlers, that the first ores containing gold were found in Bingham Canyon. Although the history of mining in Utah predates this discovery, the real rise of the mining industry stemmed from the 1863 discovery. By the 1870's the wave of prospecting following the discovery had located most of the State's metal mining districts, including Tintic, Park City, Ophir, San Francisco, Cottonwood, and Mercur. Most of these districts, however, proved richer in silver and lead, and in combined copper and zinc, than gold. This combination of metals in the ores required special treatment for their recovery, which proved to be advantageous to the State in several ways. It required the establishment of smelters, by the early 1870's, to recover the values in the ores. The smelters, in turn, stimulated the establishment of the railroads which were needed to transport the ores and carry the supplies for the burgeoning industry. Other important mineral developments followed in later years, including the mining of coal, iron, uranium, and petroleum. Coal and iron were among the earliest commodities sought and found by the Mormon pioneers, but both were produced only in modest amounts until rail transportation, mechanization, and ultimately the establishment of a steel plant at Provo during World War II stimulated the output. Since then, both commodities have assumed major importance. The demand for uranium, following World War II, brought another metal into prominence; and a more recent development has been the emergence of petroleum as a major commodity within the last 10 years.

As shown on figure 1,[1] the mineral output of Utah has grown pro-

[1] The values on fig. 1 are "constant dollars," based on the 1957–59 dollar. In other words, actual values have been adjusted to reflect the changing value of the dollar in terms of its purchasing power. For the most part, therefore, the curves mark the significant changes in volume of material produced.

26-803 O 69—2

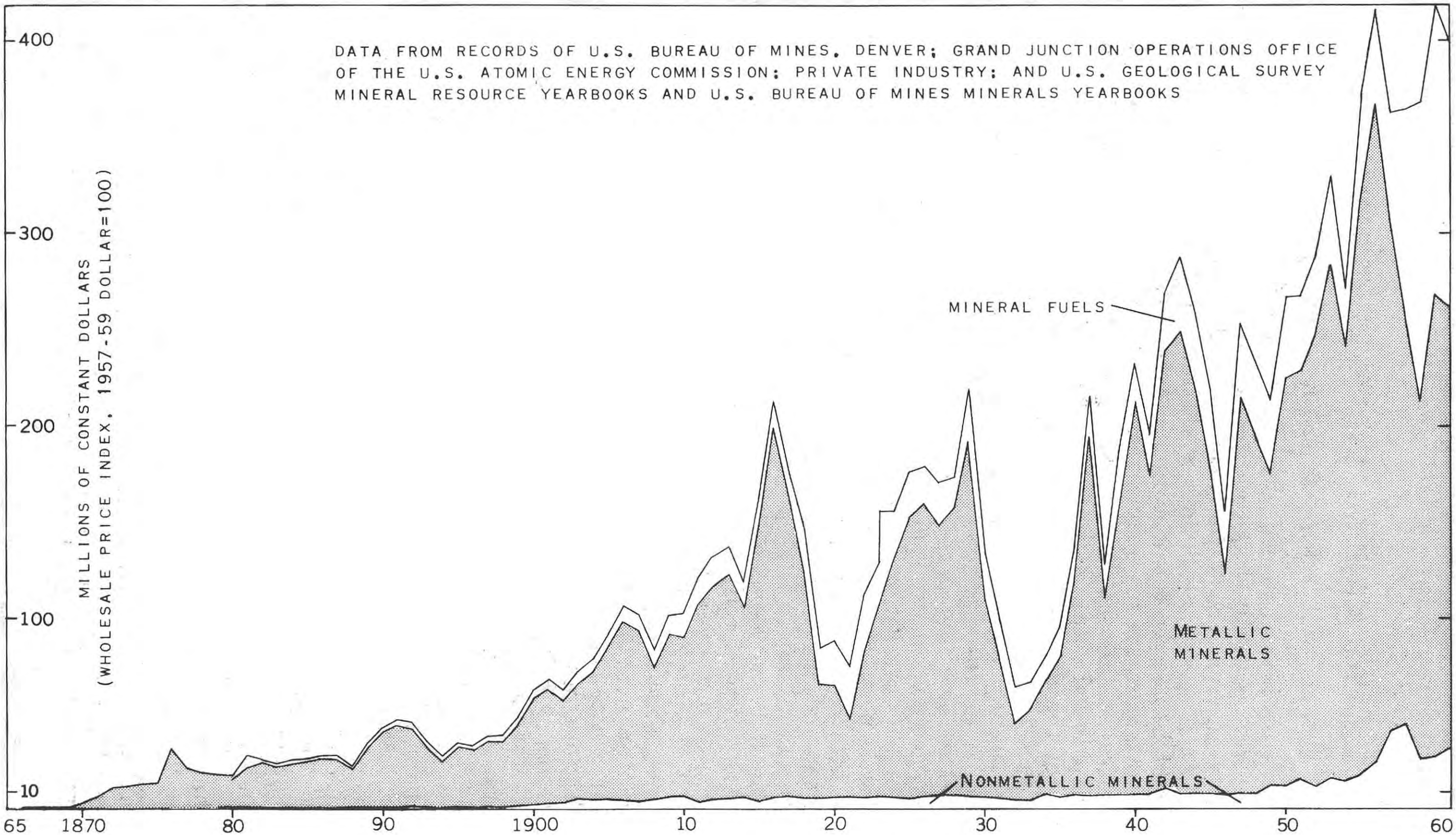


FIGURE 1.—Mineral production in Utah, 1865 through 1961.

gressively during the first 100 years and each segment of the mineral industry has responded favorably to each period of increased demand, indicating a strong resource base. Major economic and historic events are marked by sharp changes in output of minerals, notably the peak output during wartime and the low output immediately after each World War and during the depression of the early 1930's.

The metallic minerals have played the most notable part in the industry, followed by the mineral fuels, and the nonmetallic minerals. The metals gold, silver, copper, lead, and zinc have been the bulwark of the industry through the past 100 years, having supplied two-thirds of the total value of the mineral output. Before about 1900, however, gold, silver, and lead were by far the most important. Zinc was not recovered until 1904, and copper did not become important until the advent of open-pit mining at Bingham Canyon. The production of these metals is shown on figure 2.

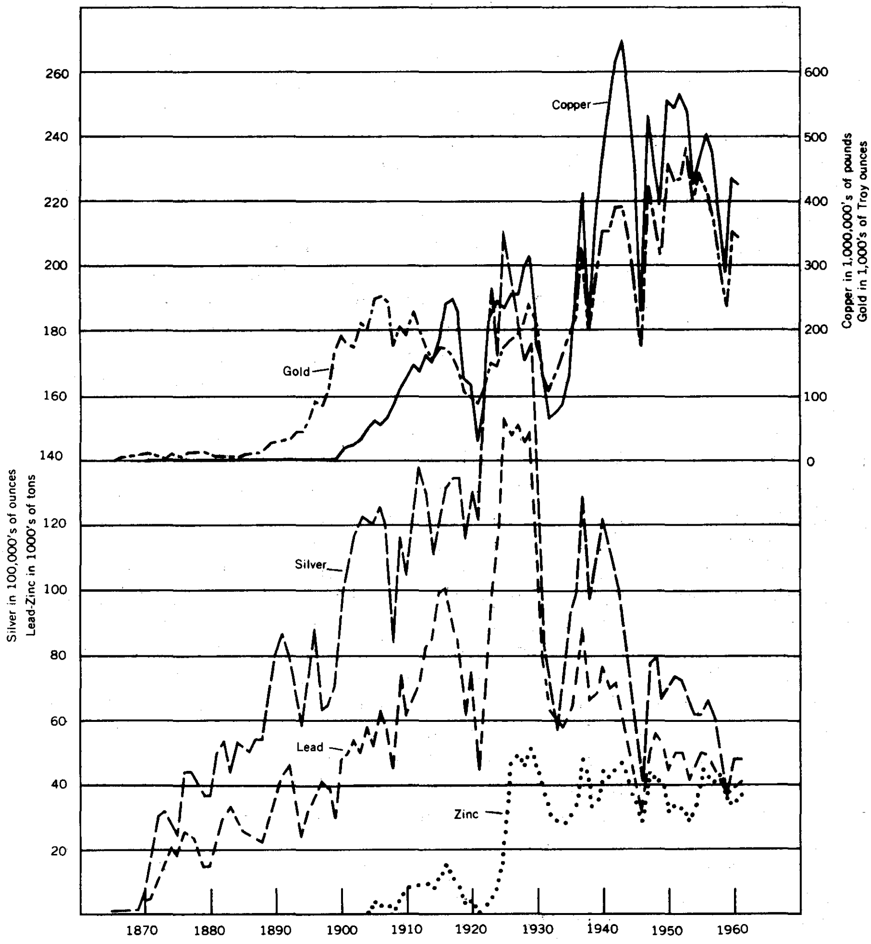


FIGURE 2.—Production of copper, gold, lead, silver, and zinc in Utah, 1865 through 1961. (Data from 1865 to 1917 from Butler and others (1920); and from 1918 to 1961 from U.S. Bureau of Mines).

In more recent years, the production of three other metals has come to the forefront. Iron started an upswing in the 1920's and attained a peak output of more than $30 million in 1957; uranium climbed from less than a million dollars in annual output before 1951 to a peak of more than $38 million in 1958; and molybdenum output, which essentially started with recovery from porphyry copper ore in the mid-thirties, now has attained a total value near that of uranium. In all, the metallic minerals have yielded, through 1961, more than three-fourths of Utah's mineral wealth (fig. 3).

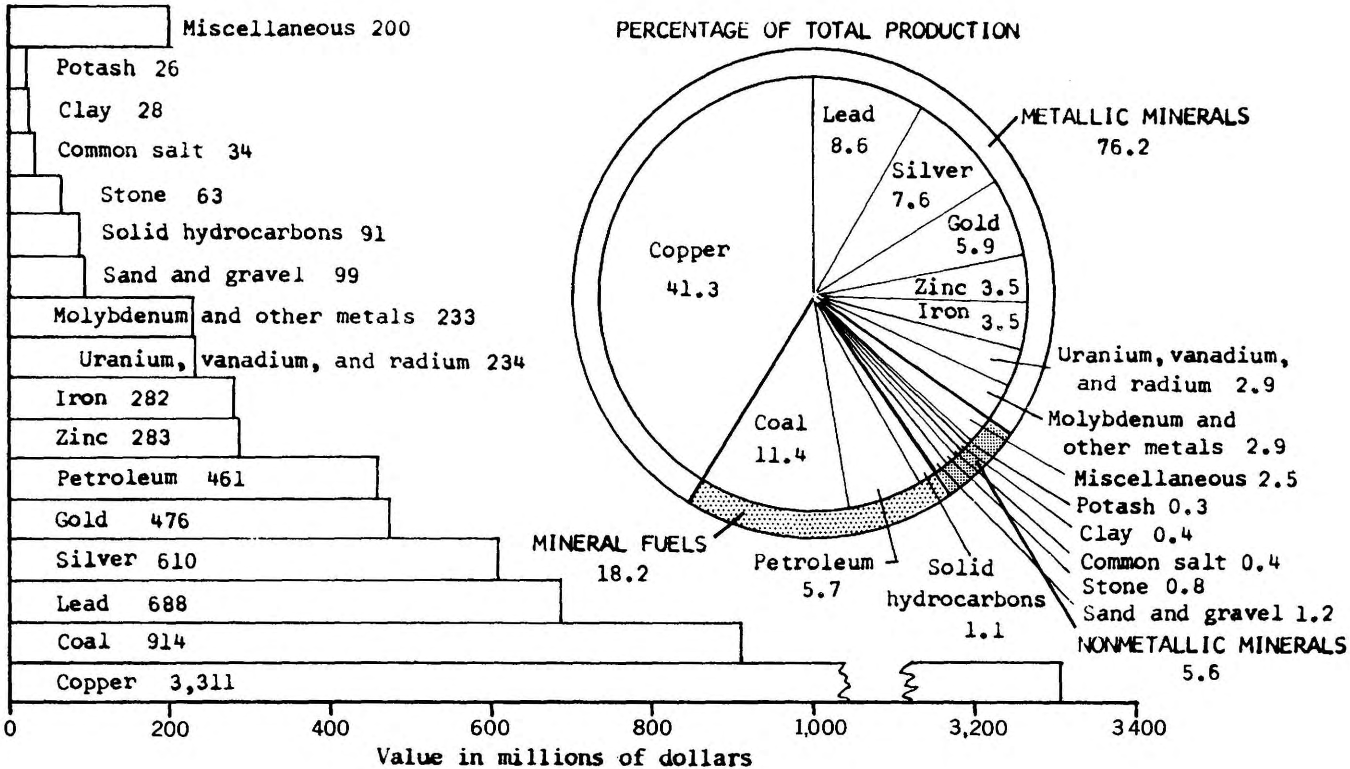
Of the mineral fuels, coal has been the most important commodity until recent years. It has now been supplanted by petroleum. Prior to 1956, petroleum output amounted to only a few million dollars a year, but by 1959 it had attained a peak of about $117 million. The mineral fuels in 1961, largely through the increased output of petroleum, constituted about one-third of Utah's mineral output for the year (fig. 1) and in total amounted to about 18 percent of Utah's total 1865–1961 mineral output (fig. 3).

The nonmetallic minerals have contributed at a rather uniform and modest pace throughout the years. An upswing started in mid-1955, however, that denotes an awakening interest by industry in these commodities. Through 1961, the value of the nonmetallics had contributed about 6 percent of the total mineral output.

Utah's diversity of available mineral products in useful quantities is probably equaled by few other comparable-sized areas in the world. About 35 commodities or groups of commodities have been mined or may soon be exploited and, of these, 10 (copper, coal, lead, silver, gold, petroleum, zinc, iron, uranium, and molybdenum) each have total yields that exceed $200 million in value and 6 commodities (sand and gravel, solid hydrocarbons, stone, common salt, clay, and potash) each have total yields that range between $25 million and $100 million in value (fig. 3).

The importance of Utah's mineral industry can be portrayed in many ways. In 1961, Utah ranked 14th in the Nation in the value of minerals produced; provided 2.24 percent of the value of the minerals produced in the Nation; and provided 11.9 percent of the value of the Nation's metals produced. Nationally, the State ranks as follows in the production of each of the following commodities: second in copper, gold, molybdenum, and asphalt; third in lead, silver, and potash; and fourth in iron and uranium. It also is the Nation's only producer of gilsonite, and provides the only major amount of catalytic-grade halloysite. The State's mineral industry is unique in other respects. It has the support of one of the world's most productive mining districts, with a record $4.5 billion total yield. In this district is the world's largest copper mining operation, centered around the Bingham Canyon mine, which has produced about 15 billion pounds of copper—a world's record—and furnishes each year about 20 percent of the Nation's newly mined copper.

The important part played by the mineral industry in Utah's economy is borne out by comparing it with other segments of the economy. Data used in these comparisons, which follow, were provided by the Bureau of Economics and Business Research, University of Utah (written communication, 1963). In 1961, for example, the value of the mineral products produced in the State amounted to more



(Data from U.S. Geol. Survey Mineral Resources of the United States 1880–1921; U.S. Bur. Mines Mineral Resources of the United States 1922–1930; U.S. Bur. Mines Minerals Yearbook 1931–1961; U.S. Atomic Energy Comm.; Utah Oil and Gas Comm.; private companies; and U.S. Geol. Survey unpublished data.)

FIGURE 3.—Values of the principal mineral commodities mined in Utah, 1865 through 1961.

than $400 million, of which the metallic minerals alone amounted to more than $229 million. In marked contrast, the value of the other raw materials produced—namely, the farm and forest products sold—amounted to $154 million and $157,000, respectively. As another example, in 1958, $412 million was added to the State's economy by manufacturing. In this same year the mineral output amounted to about $366 million, or 89 percent of the value added to the economy by manufacturing. This comparison is most striking because a large percentage of the value added by manufacturing was directly concerned with mineral products processing. The indirect contribution of mineral products to manufacturing is not easily measured, but some examples can be given for 1958. The value added by manufacturing of stone, clay, and glass products was $33 million; the value added in primary metals manufacturing was $141 million; and the value added in manufacturing of coal and petroleum products was about $23 million. These values alone amount to 45 percent of the total value of all manufacturing.

In 1962, the industry directly employed 13,113 people, or 4.6 percent of the nonagricultural work force. An additional 10,367, or 3.6 percent, were employed in the manufacturing of mineral products. Employees in the mineral industry have been either the highest paid or the second highest paid group in the State for almost 30 years, and have been the highest paid group since 1946. This fact, however, has its somber side. Rising costs have forced the companies to consolidate their properties, make technological improvements, and improve their general efficiency to remain solvent. This has resulted in fewer operating companies, in more mechanization and automation, and the attendant reduction in the work force. This trend toward lower employment in each operation has been only partly offset by the increasing mineral output.

Figures on the total capital investment in mining and directly affiliated manufacturing in the State is another item of great importance, although such figures are not available. A measure of the capital investment is reflected in the mining property tax paid to the State. In 1962, this amounted to $14.5 million, compared to the total State property tax of $96.5 million for the same year.[2]

It has been estimated that each dollar's worth of new raw material that becomes available contributes as much as $8 worth of business activity in manufacturing, trade, service, communication, and transportation (based on the ratio of total value of raw materials to the remainder of the gross national product). If this ratio is applicable to minerals, the mineral industry in Utah may well generate as much as $3 billion worth of business activity in the State and Nation each year.

The abundant and varied mineral resources in Utah are the key to the establishment and expansion of new industry. A trend of expansion appears favorable in this respect. At Cane Creek the potash industry is currently developing large previously untapped potash deposits. Recent interest in development of the saline resources in the brines of western Utah may further increase both potash and salt production, as well as add two more commodities, magnesium

---

[2] From "Utah Property Tax, 1962," Utah Foundation Research Report 203, March 1963.

and lithium, to the growing number of Utah's mineral products. At Spor Mountain the recently discovered large beryllium deposits are being explored and, when developed, can provide a dependable long-term supply of beryllium for the Nation in quantities never before available. Other large but mostly unexploited resources such as oil shale, lightweight aggregate, and silica deposits remain a challenge for future development and utilization. These and other commodities can become important items in Utah's mineral economy.

The following sections on the geology and occurrence of the resources point out that each mineral commodity has unique qualities and habits. Understanding of the geologic features as well as the economic and technological factors are needed to evaluate the potential of each of these mineral commodities. In this report the term "resources" applies to materials in the ground that are known to be minable now, plus materials that are likely to become minable at some time in the future. Reserves, on the other hand, are materials that may or may not be completely explored but which may be quantitatively estimated and are considered to be economically exploitable at the time of the estimate. Ore is mineral material that may be mined at a profit, and the term "ore" reserves is applied to mineral deposits currently being mined, or to deposits known to be of such size and grade that they may be profitably mined.

Mineral resources are fixed in quantity and quality and are not renewable. Reserves, on the other hand, fluctuate in amount. They are a continually changing quantity, the estimates of which are dependent on economic conditions, technologic changes, and available information. A low reserve figure for a commodity today, for example, doesn't necessarily mean the resource is near exhaustion. It may mean that a depressed market has lowered the value of the commodity to the point where the material no longer can be considered as a reserve. The progressive annual drop in reserves of uranium is a good example of how economic conditions can affect the reserve picture. In 1956, Utah had a reserve of 7.5 million tons; in January 1963, the reserve had been reduced to 3 million tons—a reduction brought about by depletion through mining, and curtailment of exploration and development caused by a saturated uranium market.

In summary, Utah has a mineral industry that constitutes a vitally important part of the State's economy. It is founded on an unusually broad and varied resource base, and promises to continue to expand in the future.

GEOLOGY

INTRODUCTION

(By L. S. Hilpert, Salt Lake City, Utah)

Mineral resources are geologic materials that result from various geologic processes and events that have been taking place throughout geologic history. It follows, therefore, that an understanding of the geology provides a background that is necessary for a better understanding of the resources. The following sections on topography, stratigraphy, and structure are intended to provide the reader with such a background, brief though it must be, and the section on economic geology summarizes the geologic occurrences of the various mineral commodities within the State's geologic framework.

TOPOGRAPHY

(By E. W. Tooker and J. H. Stewart, Menlo Park, Calif.)

Utah includes parts of three physical provinces, the Basin and Range, Colorado Plateaus, and Rocky Mountains (fig. 4) (Fenneman, 1931). These provinces, which converge on the junction of the Wasatch and Uinta Mountains, differ in their surface expression, in the areal distribution, composition, and structure of the sedimentary rocks, and in their history. The Basin and Range (or Great Basin) in the western part of the State, is characterized by isolated narrow mountain ranges separated by desert basins, and marked by interior drainage. The shorelines of Pleistocene Lake Bonneville, of which Great Salt Lake is a remnant, are marked by terraces on the flanks of the mountain ranges (fig. 4) (Gilbert, 1890). The strata are simple to complexly folded and cut by faults; thrust faults locally have modified the original stratigraphic relations. Igneous rocks, principally monzonitic and in the form of stocks, dikes, sills, and irregular masses, locally intrude the sedimentary rocks.

The Colorado Plateaus province, in the eastern part of the State, is characterized by plateaus incised by canyons that are tributary to the Colorado River. The Uinta Basin constitutes the northern part. The strata in the province are modified by simple faults and flexures and intruded locally by monzonitic and dioritic laccolithic igneous bodies. These bodies constitute the cores of the La Sal, Abajo, and Henry Mountains.

The Rocky Mountains province, in the northeastern corner of the State, consists of the east-trending Uinta Mountains and the north-trending Wasatch Range. Both are characterized by broadly folded layers, cut by faults, and dissected by drainage that is tributary to the Great Basin and the Colorado River. Intrusive rocks are present in the vicinity of the intersection of the two ranges.

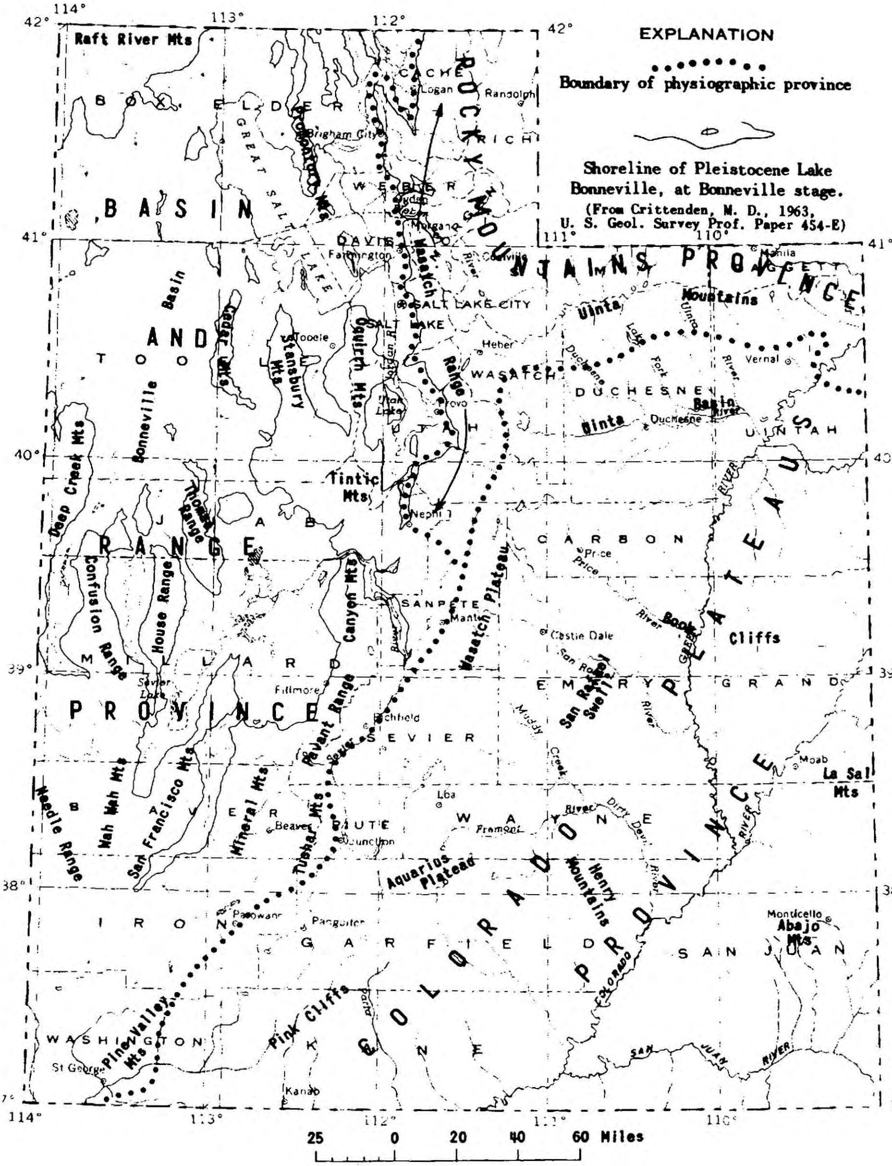


FIGURE 4.—Physiographic provinces and principal features of Utah, showing also the outline of Pleistocene Lake Bonneville.

The western front of the Wasatch Range is a prominent topographic feature that separates the Basin and Range province to the west from the Rocky Mountains and Colorado Plateaus. This front is the present expression of a part of a major geologic feature, the Wasatch line or hinge line, that has bounded different geologic provinces for a very long time.

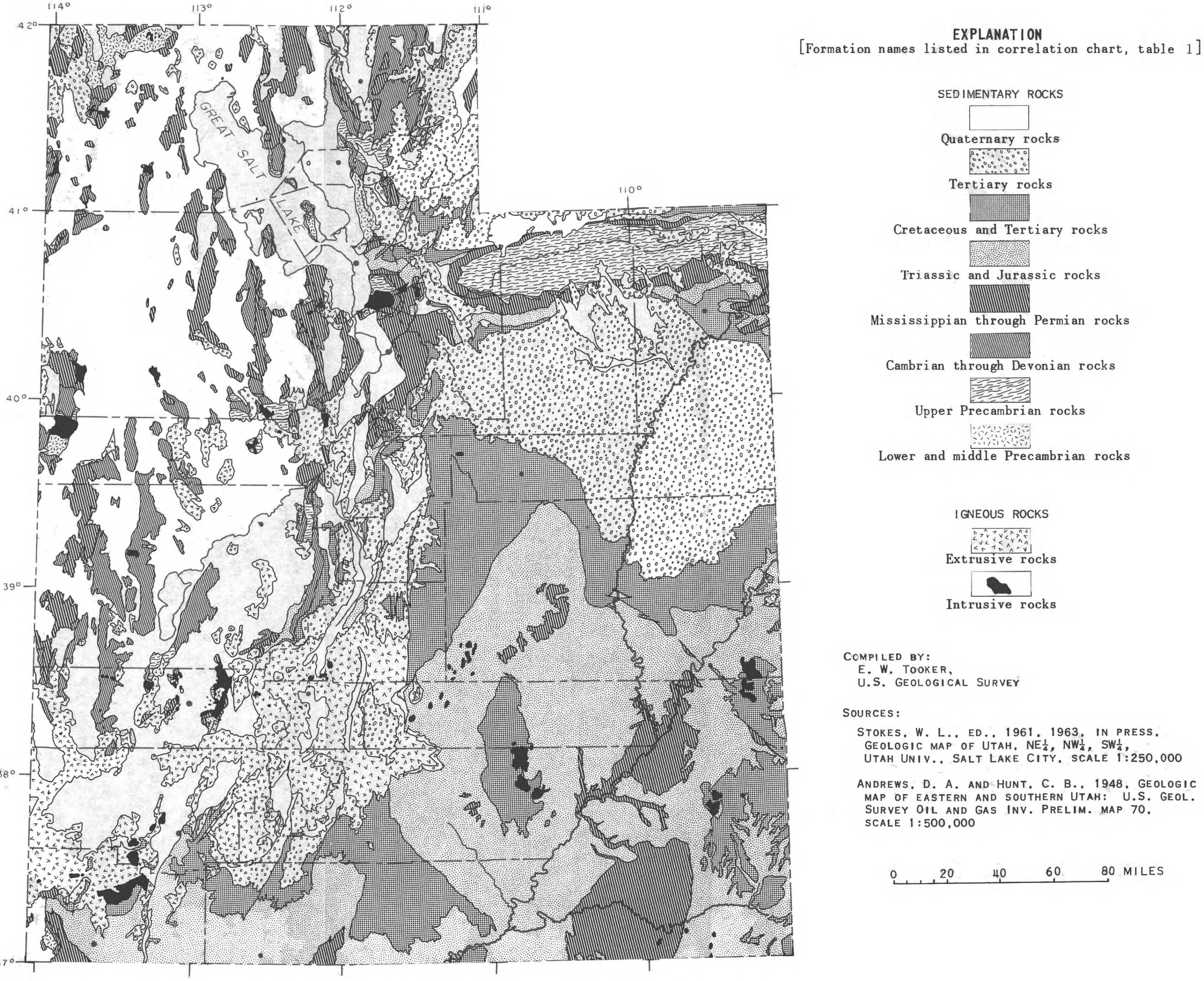


FIGURE 5.—Geologic map of Utah.

26-803 O - 69 (Face p. 19)

STRATIGRAPHY

(By E. W. Tooker and J. H. Stewart, Menlo Park, Calif.)

SEDIMENTARY ROCKS

Sedimentary rocks, as the name implies, are lithified sediments, mixtures of detrital materials, such as pebbles, sand, and mud; and chemical components, such as calcite, gypsum, and salt that accumulate either in bodies of water, or subaerially on the land. Near-shore gravels, sand, and mud form deltas or layers of conglomerate, sandstone, and shale. Farther from shore, carbonate deposits, such as banks of limy mud, reefs of organic remains, or accumulations of shells and corals, form layers of argillaceous or bioclastic limestone. On the continents, coarse to fine clastics form alluvial fans, braided stream channel fills, and sheetwash nonmarine conglomerate, sandstone, and mudstone. In barred basins or playa lakes and delta swamps, at or near the junction of land and sea, evaporite and coal deposits may form.

Layered rocks provide a record of changes through geologic time, such as changes in topography, source of sediment, and environments of deposition, and often provide clues to subsequent structural and chemical alteration. The character and distribution of many mineral and water resources of Utah may be directly related to specific types of sedimentary rocks. Salt, coal, oil, uranium, clays, sand and gravel, and pure soft water are but a few of the State's resources that owe their origin and location at least in part to the vagaries of sedimentary rocks and rock structures. Intervals of geologic time during which sediments accumulated in geosynclinal basins or on continental margins are separated by mountain building intervals—orogenies—often accompanied by intrusion and extrusion of igneous rocks.

Beginning with the oldest, the sedimentary and associated igneous rocks, and the events that affected them, are described briefly in the following pages. The exposures of the principal rock units are shown on the geologic map (fig. 5) and the principal formational units in the different parts of the State are shown on the stratigraphic correlation chart (table 1).[1]

Precambrian Era

Precambrian rocks, which are exposed in scattered mountain ranges and canyons throughout the State, are subdivided here into structurally deformed and metamorphosed lower and middle Precambrian rocks, and less-deformed, virtually unmetamorphosed upper Precambrian rocks.

Lower and middle Precambrian rocks.—Strongly folded and metamorphosed crystalline limestone, schist, gneiss, and associated granitoid and pegmatite bodies are as much as 3,000 feet thick locally. The main exposures of these rocks are in northern Utah in the Raft River Mountains, Grouse Creek Mountains, and Vipont Mountains; in the west-central Wasatch Mountains north of Salt Lake City; in the southern part of the Deep Creek Mountains; in the southwestern corner of the State near St. George; and along the Colorado River and in the Uinta Mountains in eastern Utah. The lead-alpha age of zir-

[1] The stratigraphic nomenclature and age designations used in this chart do not necessarily follow the usage of the U.S. Geological Survey, but follow the usage of authors who have described stratigraphy in the several parts of the States.

Table 1.— *Generalized stratigraphic*

By E. W. Tooker

[Horizontal terms refer to formally named rock stratigraphic units of formation rank. Vertical terms in boxes refer to for

Geologic Divisions			Basin and Range province: Northwest	Basin and Range province: Northeast	Basin and Range province: Southern	Colorado Plateaus: Central Utah	Colorado Plateaus: Uinta basin
CENOZOIC	Quaternary	Recent	*Alluvium* *Dune sand* *Oolites*	*Alluvium* *Dune sand* *Oolites*	*Alluvium*	*Alluvium*	*Alluvium* *Dune sand*
		Pleistocene	*Lake deposits*	*Lake deposits*	*Volcanic rocks* *Landslide breccia*	*Volcanic rocks* *Landslide debris*	*Moraine* *Terrace gravel*
						— Axtel-Sevier River —	
	Tertiary	Pliocene			*Volcanic rocks*	*Basalt*	
			— Salt Lake —	— Salt Lake —			
		Miocene		*Rhyolite* (Thomas Range)		Joe Lott Mount Belknap	Browns Park
						— Bullion Canyon —	
		Oligocene		*Welded tuff*	Page Ranch Rencher Quichapa Isom Needles Range	Gray Gulch	Bishop
							— Duchesne River —
		Eocene		*Volcanic rocks*	Wasatch-Claron	Crazy Hollow Green River Colton	Uinta Bridger Green River Colton-Wasatch
						— Flagstaff —	
		Paleocene					
						— North Horn —	— Currant Creek —
MESOZOIC	Cretaceous			Indianola	Iron Springs Dakota	Price River [Indianola]	Mesaverde Mancos Frontier Mowry Dakota Cedar Mountain
	Jurassic				Winsor Curtis Entrada Carmel-Homestake	Arapien-Carmel	Morrison Curtis Entrada Twin Creek
					[Glen Canyon] — Navajo — Kayenta Moenave Wingate	— Navajo —	— Navajo —
	Triassic		Thaynes		Chinle Moenkopi	Chinle Moenkopi	Chinle Ankareh Moenkopi
PALEOZOIC	Permian		Gerster Plympton Kaibab Arcturus	Park City-Phosphoria Diamond Creek	Kaibab Toroweap Coconino Hermit Pakoon	Kaibab Coconino	Park City-Phosphoria
				— Oquirrh —	— Talisman —		
	Pennsylvanian		Ely		Callville		Weber Morgan Round Valley
				— Manning Canyon —			
	Mississippian		Chainman Joana	Great Blue Humbug Deseret Gardison Fitchville	Redwall		*Shale* Humbug Deseret Madison
			— Pilot —	— Pinyon Peak —			— Pinyon Peak —
	Devonian		Guilmette Simonson Sevy	Stansbury-Victoria	Muddy Peak Guilmette		
	Silurian		Laketown	Bluebell			
	Ordovician		Fish Haven [Pogonip] Eureka-Swan Peak Garden City	Fish Haven Opohonga	*Limestone*	*Limestone*	
	Cambrian		Notch Peak Corset Spring Johns Wash Orr-Weeks Marjum Wheeler Swasey Howell-Chisholm Tatow Busby Pioche	Ajax Opex Cole Canyon Bluebird Herkimer Dagmar Teutonic Ophir Tintic	Chisholm Lyndon Pioche	Ophir Tintic	Lodore
			— Prospect Mountain —		— Prospect Mountain —		
Upper Precambrian				Mutual Big Cottonwood	*Quartzite*	Mutual Big Cottonwood	[Uinta Mountain]
			— *Quartzite and schist* —				
Lower and middle Precambrian			Dove Creek Harrison	Farmington Canyon	*Gneiss and schist*		*Metaquartzite and schist*

correlation chart for Utah
and J. H. Stewart

mally named rock-stratigraphic units of group rank. Italicized terms refer to informally named rock-stratigraphic units.]

Geologic Divisions	Province: Southeast	Province: Southwest	Rocky Mountains province: Northern Wasatch	Rocky Mountains province: Central and southern Wasatch	Rocky Mountains province: Eastern Uinta
CENOZOIC — Quaternary — Recent	*Alluvium* *Dune sand*	*Alluvium* *Dune sand*	*Alluvium*	*Alluvium*	*Alluvium*
CENOZOIC — Quaternary — Pleistocene	*Moraine* *Terrace gravel*	*Terrace gravel* Sevier River	*Moraine* *Lake deposits*	*Moraine* *Lake deposits*	*Moraine*
CENOZOIC — Tertiary — Pliocene		Parunuweap	Salt Lake		
CENOZOIC — Tertiary — Miocene		Brian Head			Browns Park
CENOZOIC — Tertiary — Oligocene					Bishop
CENOZOIC — Tertiary — Eocene		Wasatch-Claron	Fowkes Wasatch Knight	Norwood Knight	Duchesne River Uinta Bridger Green River Wasatch
CENOZOIC — Tertiary — Paleocene			Almy		Currant Creek
MESOZOIC — Cretaceous	Mesaverde Mancos Dakota Burro Canyon	Kaiparowits Wahweap Straight Cliffs Tropic Dakota	Henefer Frontier Aspen Kelvin Bear River	Echo Canyon Wanship Frontier Aspen Kelvin	Mesaverde Mancos-Hilliard Frontier Mowry Dakota Cedar Mountain
MESOZOIC — Jurassic	Morrison San Rafael: Summerville, Curtis, Entrada, Carmel	Winsor San Rafael: Summerville, Entrada, Carmel	Gannett Beckwith Stump Preuss Twin Creek Nugget	Preuss Twin Creek-Arapien Nugget-Navajo	Morrison Curtis Entrada Carmel Navajo
MESOZOIC — Triassic	Glen Canyon: Navajo, Kayenta, Wingate Chinle Moenkopi	Glen Canyon: Navajo, Kayenta Chinle Moenkopi	Ankareh Thaynes Woodside-Dinwoody	Ankareh Thaynes Woodside	Chinle Moenkopi
PALEOZOIC — Permian	Cutler *Carbonate rocks*	Kaibab Coconino Rico	Park City-Phosphoria	Park City-Phosphoria (basin) (shelf) Diamond Creek Kirkman	Park City-Phosphoria
PALEOZOIC — Pennsylvanian	Hermosa Molas	Callville	Wells-Oquirrh	Oquirrh Weber Morgan Round Valley	Weber Morgan
PALEOZOIC — Mississippian	Leadville	Redwall	Brazer Lodgepole	Manning Canyon Great Blue Doughnut Humbug Gardison Fitchville	Manning Canyon Madison
PALEOZOIC — Devonian	Ouray Elbert Aneth		Three Forks Jefferson Water Canyon		
PALEOZOIC — Silurian			Laketown		
PALEOZOIC — Ordovician			Fish Haven Swan Peak Garden City		
PALEOZOIC — Cambrian	*Dolomite* *Shale* Ignacio	*Carbonate rock*	St. Charles Nounan Bloomington Blacksmith Ute Langston Brigham	Maxfield Ophir Tintic	Lodore
Upper Precambrian			Mutual Mineral Fork Big Cottonwood	Mutual Mineral Fork Big Cottonwood	Uinta Mountain
Lower and middle Precambrian	*Gneiss, schist, and pegmatite*		Farmington Canyon	Little Willow Farmington Canyon	Red Creek

cons from granite gneiss in Ogden Canyon is about 1,600 million years (Odekirk, 1962). In contrast, folded and recrystallized rocks along the Green River in northeast Utah are 2,300 million years (Hansen, 1963).

Upper Precambrian rocks.—Little-metamorphosed sequences of quartzite, sandstone, argillite, dolomite, conglomerate, and glacial tillite, which may aggregate more than 20,000 feet in thickness locally, rest unconformably on a smooth erosion surface (Crittenden, in press). These sediments were deposited in a large geosyncline—a slowly subsiding depression that covered most of the Great Basin and extended as an arm eastward along the present site of the Uinta Mountains. The range of ages of these rocks is somewhere between 1,500 and 600 million years. Subsequent tilting, elevation, and erosion to a relatively smooth surface occurred in the area peripheral to the Great Basin prior to the deposition of quartzites of Cambrian age, while deposition in the central part continued uninterrupted into the Paleozoic (Christiansen, 1963, p. 49).

Paleozoic Era

Rocks of the Paleozoic Era (from 600 to 181 million years ago, Kulp, 1961, p. 1111) are divided on the geologic map (fig. 5) into the Cambrian through Devonian and Mississippian through Permian rock sequences. They were deposited generally in the northeast-trending Cordilleran geosyncline that extended northerly across western Utah, and was bounded on the east by a stable platform or shelf. At times, however, the seas extended eastward across the shelf area.

Cambrian through Devonian rocks.—Most deposition, which consisted largely of sand and carbonate rock, occurred west of the Wasatch line, or hinge line, and was thickest in the western part of the Great Basin; sedimentary rocks of this age exist in the subsurface but are not exposed at the surface in the plateau area. In Cambrian time (100 million years duration), the geosyncline subsided in the west, and as the shore moved eastward across Utah, sands and muds were succeeded in deeper water by thick sequences of limestone, shale, and dolomite. About 12,000 feet of these sedimentary rocks were deposited in western Utah compared with 1,300 to 2,000 feet in central and eastern Utah. During the Ordovician and Silurian Periods (95 million years duration), about 5,800 feet of limestones, shales, quartzites, and dolomites were deposited in western Utah, but only 1,600 feet in the East Tintic Mountains area, and none in and east of the Wasatch area. In Devonian time (60 million years duration), uplift of the Uinta area and a western area, now roughly outlined by the Stansbury Mountains, provided coarse conglomerate and sand to near-shore deposits, whereas farther from shore, shale, dolomite, and limestone were deposited. Devonian rocks are 5,400 feet thick in western Utah and thin eastward to less than 100 feet in the Wasatch area, and about 600 feet in the plateau area.

Mississippian through Permian rocks.—In Early Mississippian time the pattern of sedimentation was little changed from earlier patterns in the Paleozoic; cherty carbonate units 100 to 1,000 feet thick were deposited over the State. In middle Mississippian time, thick limestones were laid down in western and central Utah, but in Late Mississippian time the pattern changed owing to uplift in northeastern Nevada. Coarse sands were deposited in northwestern Utah that grade southeastward into shales containing thin sandy and pebbly beds. These deposits range from 600 to 6,000 feet thick across the Great Basin and average 1,000 feet thick east of the hinge line, where marine and shore deposits interfinger.

The Oquirrh and Paradox basins in central and eastern Utah were centers of abundant yet contrasting sedimentation during Pennsylvanian time (30 million years duration); moderately thick deposits occur also in the western part of the State. Up to 3,000 feet of thin-bedded limestone and shale of Early Pennsylvanian age occur in the Oquirrh basin, and up to 200 feet of clay and fine clastics are in the Paradox basin, but sediments of this age are few or absent in the northeastern part of the State. Middle Pennsylvanian rocks, up to 8,000 feet thick in the Oquirrh basin, primarly are marine sandstone, limestone, and shale. These rocks thin to the east and grade upward into marine sands and interbedded limestone. On the plateau, restricted marine sediments in excess of 4,000 feet accumulated in the Paradox basin and consist of interfingering silts, sand, gypsum, and saline evaporites, dolomite, and dolomitic limestone. Upper Pennsylvanian deposits in the Oquirrh basin are primarily sandstone and quartzite with interbedded limestone and dolomite up to 11,000 feet thick; no comparable sediments were preserved in the Rocky Mountains area. Red-gray cherty marine limestone and siltstone are transitional with nonmarine coarse clastic deposits in the Paradox basin, especially eastward toward the Uncompahgre highland which was emerging in western Colorado during the Pennsylvanian. Deposition of moderate amounts of limestone and other rocks, may have been continuous throughout most of Pennsylvanian time in western Utah.

During Early and Middle Permian time deposition continued in previously established areas of sedimentation: marine calcareous, locally crossbedded sandstone, cherty limestone, and dolomite up to 12,000 feet thick occur in the center of the Oquirrh basin; shore and near-shore eolian sandstone and oolitic limestone form deposits locally as much as 2,500 feet thick along the hinge line; marine sandstone, dolomite, and limestone, terrestrial red beds, and local restricted marine evaporite sequences are as much as 6,500 feet thick in the western part of the State; and arkosic red beds and eolian sandstone deposits are as much as 5,000 feet thick in the Paradox basin area. Late Permian deposits are primarily marine limestone, dolomite, shale, and phosphorite in the Oquirrh basin, in the Wasatch-Uinta shelf area, and in western Utah, but are absent in the uplifted Paradox basin area adjacent to the Uncompahgre highland.

The Oquirrh basin and shelf facies of Mississippian, Pennsylvanian, and Permian ages are juxtaposed by later thrust faulting along the east margin of the Great Basin (Baker, 1947; Tooker and Roberts, 1962).

Mesozoic Era

The gradual demise of the Cordilleran geosyncline during the Mesozoic Era resulted in a change, during the Triassic and Jurassic (95 million years duration) and Cretaceous (72 million years duration) Periods, from predominantly marine to nonmarine sedimentation.

Triassic and Jurassic rocks.—During Early Triassic time, marine waters again invaded from the west and gradually covered almost two-thirds of the State, and calcareous shales and limestone interfinger with nonmarine red beds from the uplifted areas in the east. By Late Triassic time the sea had withdrawn leaving a vast, gently sloping subaerial plain on which sand, silt, volcanic ash, and shale were deposited. Triassic strata thin northeastward across the plateau from more than 4,000 feet thick in the southern part to around 2,500 feet thick in the Wasatch area. Semiarid conditions on the plain in the Early Jurassic produced eolian dune sands, fluvial deposits and thick terrestrial sandstones. Marine invasion from the north in Middle and Late Jurassic time produced interfingering marine and nonmarine facies across the area, and playa lake deposits were common. Near the close of the Jurassic, the Sevier arch (Harris, 1959, p. 2639) in west-central Utah, altered the physiography and climate, and new eastward flowing rivers from the uplifted lands laid down vast sheets of sands, muds, and volcanic ash.

Cretaceous rocks.—Intermittent orogenic activity in the uplifted areas in western Utah supplied the vast amounts of debris that accumulated as coarse conglomerates up to 15,000 feet thick west of and along the hinge line. To the east in the plateau and mountain areas, these interfinger with continental, fluvial, and marine sand, siltstone, mudstone, fresh-water limestone, shale, and coal beds. Eastward-moving, often imbricate, thrust fault blocks composed of seaward rocks impinged on the hinge line area (fig. 5), and locally overrode and were overlapped by coarse Cretaceous sediments.

Cenozoic Era

Cenozoic deposits consist of thick continental deposits of the Tertiary (62 million year duration), and the thin superficial morainal, alluvial, eolian, and lacustrine sediments of the Quaternary (1 million year duration) Period. In central Utah deposition continued virtually uninterrupted across the Cretaceous-Tertiary boundary.[1]

Tertiary rocks.—Uplift and folding characterized the Laramide revolution, and coarse sediments and volcanic debris continued to be supplied from the northwest. During much of the Tertiary the Uinta basin was occupied by a lake, and up to 13,000 feet of sediments were deposited in the central part as the basin subsided. In northern and western Utah conglomerate, sandstone, and tuff, of mostly terrestrial origin, interfinger in the east and southeast areas with limestone, shale, and silt deposits of fluvial-marine origin. Volcanic sediments and welded tuffs are common in the upper parts of the Tertiary sequence.

Block faulting (and tilting) during the Miocene and Pliocene and perhaps earlier, west of the hinge line in Utah, largely produced the present-day Great Basin structure.

Quaternary rocks.—By the close of the Tertiary, the present physiographic character of Utah was established. The Quaternary deposits are mostly surficial and comprise alluvium, talus, lake beds, fanglomerates, tuffs, flood-plain deposits, terrace gravels, alluvial fans, landslide blocks, and local lava and basalt flows. Perhaps the most spectacular feature was a series of glacier-fed lakes, most prominent of

[1] The North Horn Formation, which spans this interval, has been included with the Cretaceous and Tertiary rocks on the geologic map, fig. 5.

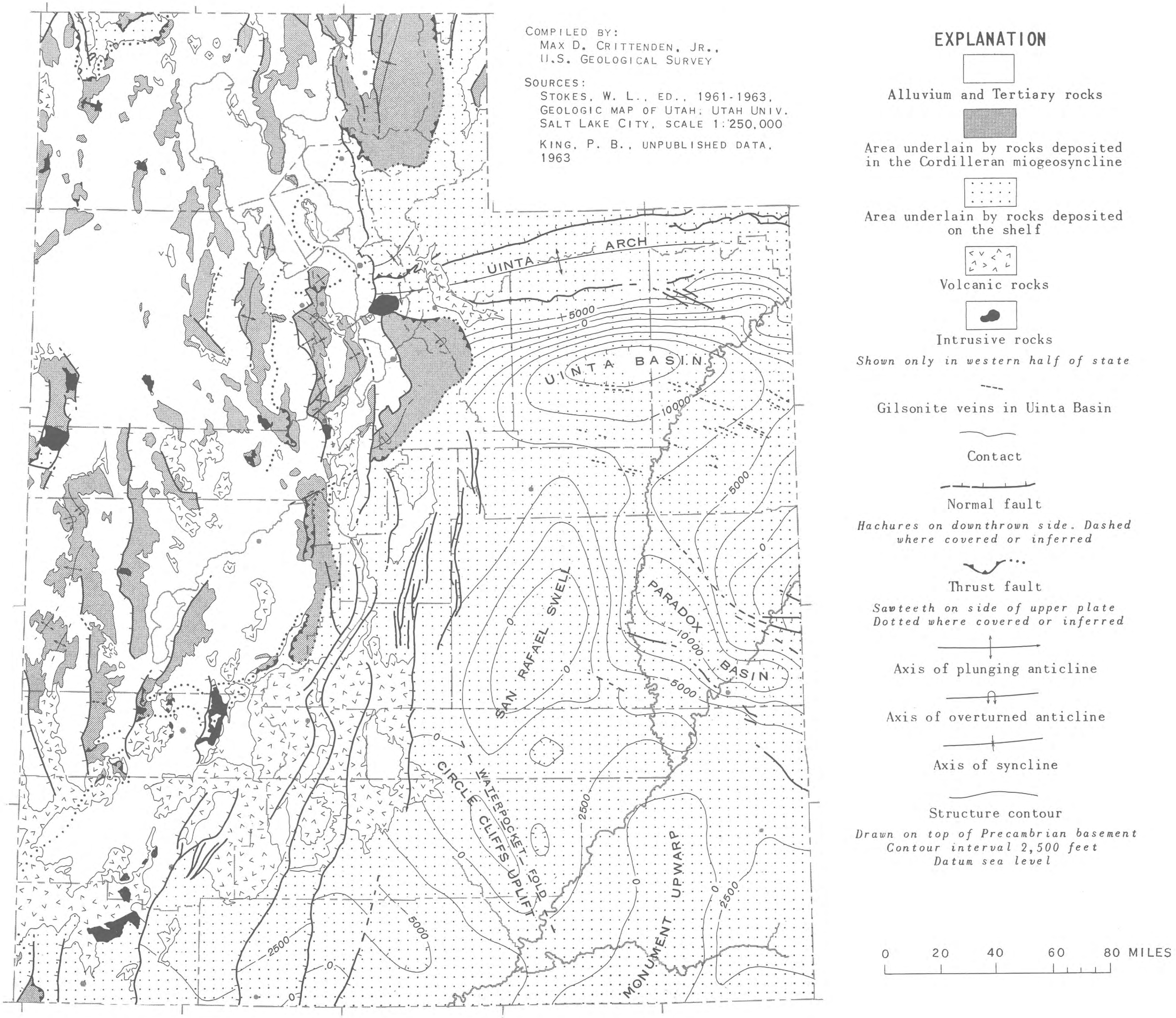


FIGURE 6.—The principal structural features of Utah.

26-803 O - 69 (Face p. 25)

which was Lake Bonneville (fig. 4). Shoreline deposits and wave-cut terraces developed at several different lake levels and are a conspicuous part of the modern physiography. In addition, finer grained lake-bottom sediments floor many of Utah's broad valleys.

IGNEOUS ROCKS

Intrusive rocks.—Intrusive igneous rocks are scattered throughout the Basin and Range province, in the western part of the Rocky Mountains province, and in the southern part of the Colorado Plateaus province. These intrusives are composed of porphyritic to granitoid rocks that occur in stocks, laccoliths, and dikes and sills; the laccoliths are principally in the plateau area and generally are dioritic; the intrusives in the southwest part of the Great Basin are mostly quartz monzonite porphyries; and in the northern Great Basin range from granite, quartz monzonite, granodiorite, and quartz diorite to syenite and diorite. The best dated intrusive igneous rocks are of Eocene through Pleistocene age and intrude rocks of all ages from the Precambrian through the Tertiary. Intrusive rocks related to metallization in the major mining districts are mostly of Eocene age; however, some, as at Marysvale and Iron Springs, are of Oligocene and Miocene age (Proctor and Bullock, 1963, p. 165). Some granitoid bodies occur in Precambrian terranes (not shown on map). At least some of these were deformed during the Precambrian Era and thus are Precambrian in age.

Extrusive rocks.—Volcanic rocks are most abundant in the central and southwest part of the State. Outcrops in the northern part of the Great Basin and the east margin of the mountains are scattered and less extensive. No significant volcanic rocks occur in the plateau. A general distribution of bands of Tertiary volcanic rocks occurs in the southern part of the Great Basin in association with the intrusive porphyries. In addition, in the southernmost part of the Great Basin there are Quaternary basalts and lavas. Volcanic eruptions, fissure flows, or combinations of these, produced rhyolite, trachyte, phonolite, quartz latite, latite, dacite, andesite, basalt, nepheline basalt, volcanic glass, tuff, andesite-latite, pyroclastic ryholite- to latite-welded tuffs, and Quaternary basalts.

STRUCTURE

(By M. D. Crittenden, Jr., Menlo Park, Calif.)

The structure of Utah (fig. 6), like its surface, exhibits strong contrasts from one physiographic province to another. For present purposes, the State may be divided into two major subdivisions: western Utah, which will be taken to include the Basin and Range province, and eastern Utah, which will include the Rocky Mountains and the Colorado Plateaus provinces. The separation between these two divisions was discernible in the pattern of deposition of younger Precambrian rocks as long as a billion years ago. It was clearly defined throughout most of the Paleozoic Era—western Utah being occupied by the Cordilleran geosyncline and eastern Utah by a slowly subsiding shelf. The boundary between the two—the Wasatch line—follows closely the edge of the Basin and Range province.

26 803 O 69 - 3

WESTERN UTAH

The western half of the State is an area of complex structures, in which the effects of the early episodes of earth deformation are partly destroyed by later structures and extensively covered by younger rocks. Yet each of these periods of deformation has had a part in shaping the present landscape, and in some degree has influenced the natural resources with which we are concerned.

The most clearly defined structures of western Utah are the youngest—fault blocks formed mainly within the last 10 million years—which have given rise to the present ranges and valleys. But discernible within these faulted blocks, locally crossing them at high angles, and traceable from one range to another, are older structures—faults and folds—that were produced during earlier episodes of deformation or "orogeny." The most significant such orogeny was the Laramide which took place in Late Cretaceous and early Tertiary time. The following paragraphs will describe some of these structures, beginning with the older ones.

One of the oldest structures in western Utah was a peninsulalike uplift, the Tooele arch, that extended from the present site of the Uinta Mountains at least as far west as the Stansbury Mountains. It rose above the sea in Late Devonian time and may have attained a height of 5,000 feet. How far this structure continued to the west is obscured by younger rocks and later structures.

The most extensive structures, and those involving the largest displacements of the earth's crust, evolved during the Laramide (fig. 7A). These structures consist mainly of arcuate belts of folds made up of the rocks deposited earlier in the rapidly subsiding Paleozoic basins and of thrust sheets that were moved eastward. The front of these structures, or thrust belt, generally lies along the Wasatch line, the former boundary between the geosynclinal basins and the shelf. Between Ogden and Logan, however, and between American Fork and Nephi, are lobes of basin rocks that have moved eastward across the edge of the shelf. From the vicinity of Nephi, the belt of thrusts can be traced southward to the Pavant Range, and thence southwestward diagonally across the State through isolated exposures in the Mineral Mountains, the San Francisco Mountains, and the Wah Wah Mountains. Still farther southwest, the thrust belt probably connects beneath later cover, as similar thrusts are exposed near Las Vegas, Nev. Thrust faults exposed in the Deep Creek and Confusion Ranges, and in the Raft River Mountains indicate that this episode of orogeny affected all of western Utah.

The rocks within the thrust belt are sheetlike and are flat or gently folded in places (as near Logan); in such places they seem to have moved forward without strong internal deformation; in other places (as in the Oquirrh Mountains and the Confusion Range) the rocks are thrown into arcuate folds overturned to the east like the wrinkles in a sheet of tar poured out of a barrel. Such structures, long assumed to have been caused by compressive stresses within the earth, are now seriously suspected to be the result of sliding or rolling of the upper layers of the crust down gentle slopes largely under the influence of gravity.

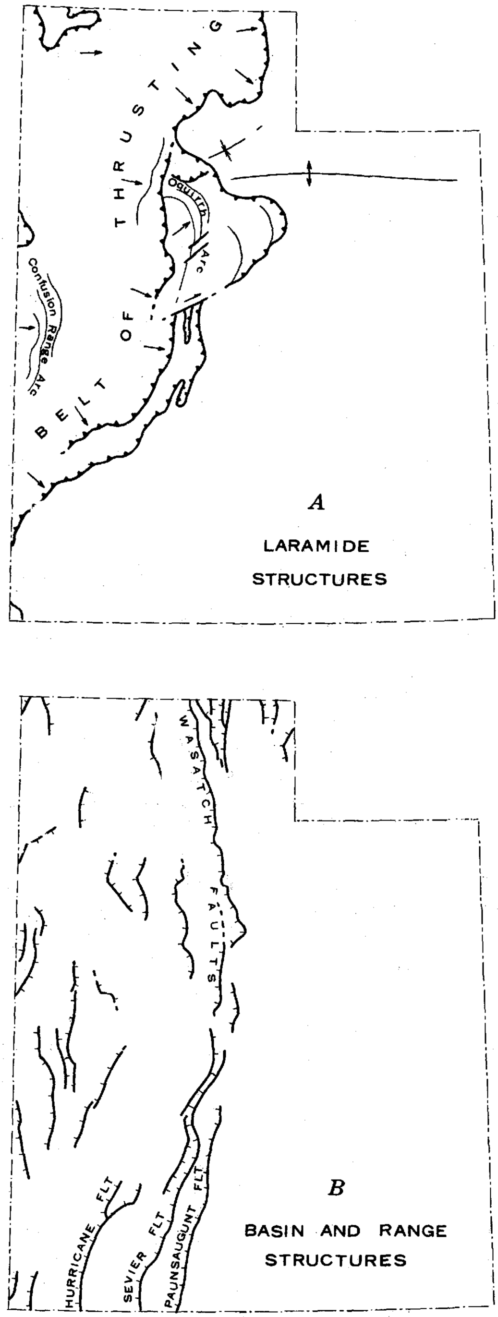


FIGURE 7.—Principal Laramide and Basin and Range structures of Utah.

The Laramide deformation continued in intermittent pulses for some 40 million years, from Cretaceous time until early in the Tertiary. Near the end of this episode of earth movements, igneous activity became widespread throughout western Utah. Surface outbreaks led to the formation of thick accumulations of volcanic rocks locally, and similar igneous material, cooling at depths of a few thousand feet, formed stocks of granitoid or porphyritic rock. Deposits of base and precious metals are widely associated with these bodies throughout western Utah.

Basin and Range structures (fig. 7B), though not directly responsible for the formation of ore deposits, are nevertheless of economic significance because most of the ore deposits now known are exposed in the uplifted blocks. Without this uplift, and the accompanying erosion which stripped off thousands of feet of rocks, both the discovery and exploitation of the ore deposits of western Utah would have been more difficult. Conversely, one of the outstanding problems is to find means of locating and mining the deposits concealed in the downthrown blocks.

EASTERN UTAH

In the Rocky Mountains which occupy the northeastern corner of Utah, the Laramide epoch of deformation was the principal one. In this area, the Laramide structures have not been obscured by later events, and are still dominant in shaping the topography. But here, the direction of folds as revealed in the Uinta arch (figs. 6 and 7A) and the adjoining Parleys Canyon syncline, are almost at right angles to those of the thrust sheets to the west.

In strong contrast to the history of mobility recounted above, the greater part of eastern Utah—the Colorado Plateau—was a stable element of the earth's crust. This is a broad platform, which except for localized downwarps like the Paradox Basin that formed during the Permian and the Uinta Basin that formed during the Tertiary, has remained as a stable shelf for much of the last 500 million years. This stability is reflected in vast areas of flat-lying strata. Linear monoclinal flexures and a few broad gentle domelike structures, as in the San Rafael Swell, record local but limited movements.

Igneous rocks have punched through or formed laccoliths in the Henry, La Sal, and Abajo Mountains, but base-metal deposits like those of the Basin and Range province are conspicuously absent.

ECONOMIC GEOLOGY

(By L. S. Hilpert, Salt Lake City, Utah, and R. J. Roberts, Menlo Park, Calif.)

The formation of Utah's mineral deposits was the result of a number of geologic events that have been reviewed in preceding sections and shown on figures 4, 5, 6, and 7. The resources in all physiographic provinces of the State are summarized here as to general geologic relations, distribution, and economic importance.

RESOURCES OF THE BASIN AND RANGE PROVINCE

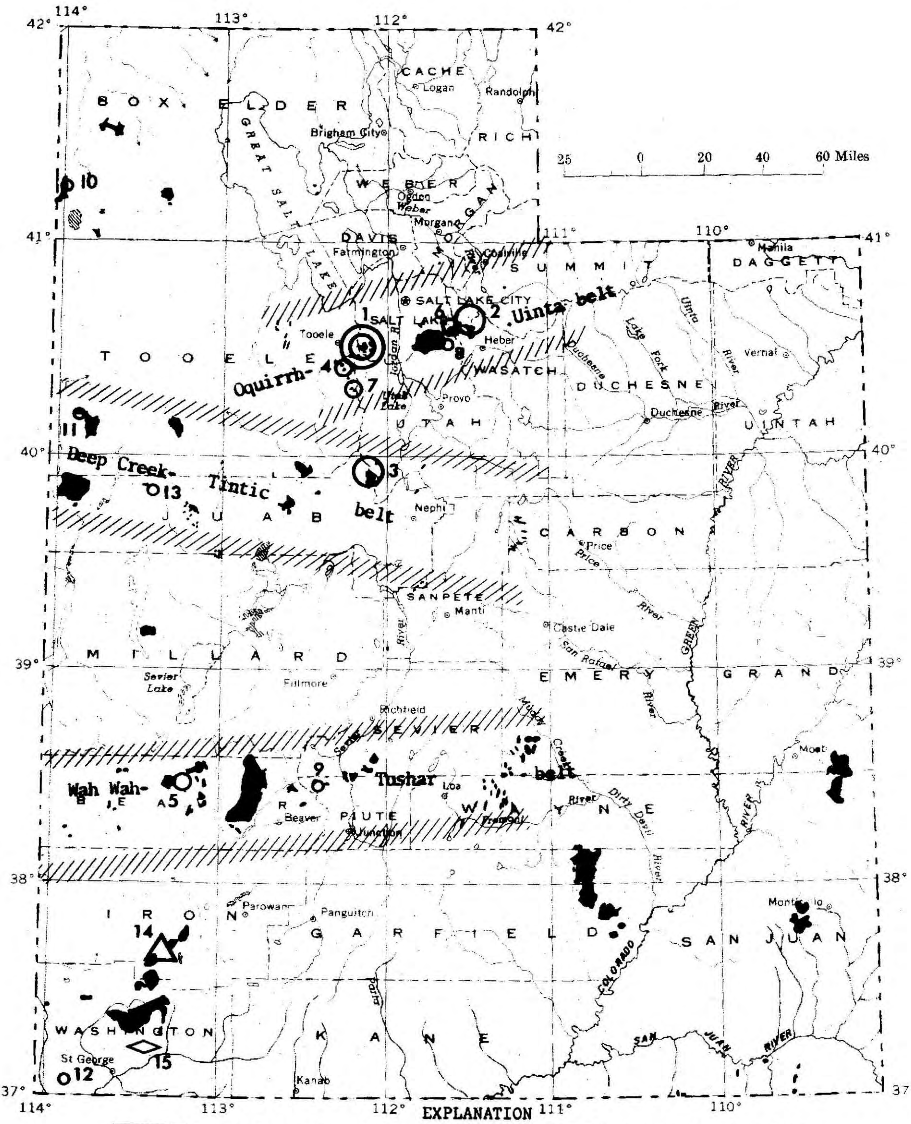
Deposits in the Basin and Range province and the western margins of the Colorado Plateaus and Rocky Mountains provinces have yielded nearly all of Utah's metallic mineral output, with the exception of uranium and vanadium, and have yielded substantial amounts of nonmetallic minerals. The principal deposits consist of replacement bodies in Paleozoic and Mesozoic carbonate rocks; contact metamorphic or tactite zones in carbonate rocks; veins, stockworks, and breccia pipes in rocks of various types and ages; and some bedded deposits in Mesozoic and Tertiary rocks. All these deposits, except the bedded ones, show a close spatial relation to intrusive igneous rocks, principally monzonitic and granitic stocks.

The deposits and the intrusive igneous rocks show a strong tendency to be arranged in elongate zones or belts. This has been noted by many geologists (Butler and others, 1920, pp. 100–105; Calkins and Butler, 1943, p. 53; Wilson, 1959, p. 183; and Morris and Lovering, 1961, p. 81). Butler referred to these alinements as uplifts, but as uplift is only important locally, it seems preferable to refer to them as mineral belts. The three principal belts are shown in figure 8. Included in the figure are the outcrops of the intrusive igneous rocks and the principal metal-mining districts in the State, excepting uranium and vanadium. Each of the districts shown has a total output of more than $1 million. The mineral belts are referred to as the Oquirrh-Uinta belt in the north, the Deep Creek-Tintic belt in the center, and the Wah Wah-Tushar belt in the south. These belts mark zones of weakness that extend deep into the earth's crust and served as channelways for the igneous rocks and related ore-forming solutions. Each of these belts is described briefly.

The Oquirrh-Uinta belt follows the axis of the Uinta arch (fig. 6). West of the Wasatch line the belt is less obvious, but it can be traced into western Utah by alinement of intrusives, alinement of various metal deposits, and other geologic features. The belt has undergone deformation during the Precambrian, Paleozoic (Morris and Lovering, 1961, pp. 78–81), Mesozoic and Tertiary (Eardley, 1951, pp. 325–331; and Hunt, 1956, pp. 59–61, 73). It is also reflected by regional gravity and aeromagnetic anomalies and is therefore a major structural lineament. The course of the belt west of the Stansbury Mountains is uncertain, but it may intersect the Deep Creek-Tintic belt near the Clifton district. The Oquirrh-Uinta belt contains the Ophir-Rush Valley, Camp Floyd (Mercur), Bingham, American Fork, Little and Big Cottonwood, Park City, and other smaller districts that have an aggregate metal output of about $4.8 billion.

The Deep Creek-Tintic belt extends from the Utah-Nevada line eastward into central Utah. It is characterized by east-west alinement of several intrusive bodies and both metallic and associated nonmetallic deposits. The most productive area in the belt is the Tintic district which has yielded about $432 million in silver, lead, gold, copper, and zinc. Other districts include the Clifton, Fish Springs, Detroit, and Erickson (mostly manganese), Thomas Range (fluorspar), and Spor Mountain (beryllium).

The Wah Wah-Tushar belt extends from the Nevada line eastward along an alinement of igneous intrusives into the south-central part



EXPLANATION

Approximate boundary of mineral belt

Outcrop of intrusive igneous rock

Base- precious-metal and iron districts with output for 1865-1961 > $1 million

Name	Total $ output	Name	Total $ output
1. Bingham	$ 4.25 billion	9. Gold Mountain	$ 3.8 million
2. Park City	470.0 million	10. Lucin	3.7 million
3. Tintic	432.0 million	11. Clifton (Gold Hill)	2.9 million
4. Ophir-Rush Valley	92.6 million	12. Tutsagubet	2.8 million
5. San Francisco	41.6 million	13. Fish Springs	2.6 million
6. Cottonwood	37.2 million	14. Iron Springs	282.0 million
7. Camp Floyd (Mercur)	26.0 million	15. Silver Reef	9.8 million
8. American Fork	6.4 million		

FIGURE 8.—Mineral belts, principal base- and precious-metal and iron mining districts, and outcrops of the intrusive igneous rocks in Utah.

of the State. The belt includes the San Francisco, Gold Mountain, Mount Baldy, Gold Springs, Stateline, Marysvale (alunite and uranium), Indian Peak and Pine Grove (fluorspar), Cove Creek-Sulphurdale (native sulfur), and several other districts. The greatest yield in the belt has come from the San Francisco district, which has produced about $41.6 million in lead, silver, copper, zinc, and gold.

The importance of these three belts is reflected in their mineral output. They account for 95 percent of the copper, lead, silver, gold, and zinc, largely from the districts listed on figure 8. They also account for all the molybdenum, largely from porphyry copper ores in the Bingham district; all the mercury, principally from veins in the Mercur and Mount Baldy districts, and from the Deep Creek Range; two-thirds of the manganese, principally from replacement deposits of manganese carbonate ores in the Detroit, Erickson, and Tintic districts; about three-fourths of the tungsten, principally from tactites in the Clifton and San Francisco districts and in the Mineral Range, and from a tactite zone and from narrow veins in a pendant of limestone in monzonite in the West Tintic district; important amounts of uranium, mostly from veins in monzonite in the Marysvale district; almost all of the minor metals that have been recovered as smelter byproducts, including antimony, arsenic, bismuth, cadmium, selenium, and tellurium; all of the alunite from vein and replacement deposits in Tertiary volcanic rocks in the Marysvale district; nearly all of the barite, mostly from vein deposits in western Juab County and the San Francisco district; all of the halloysite, mostly from replacement deposits in the Tintic district; nearly all of the fluorspar, principally from breccia pipes in the Thomas Range district and in part from fault breccias in the Indian Peak and Pine Grove districts, various gem materials; and nearly all the native sulfur, almost entirely in tuffaceous material in the Cove Creek-Sulphurdale area. In addition to the productive deposits in these belts, very large deposits of low-grade beryllium also occur in rhyolite tuff in the Spor Mountain area and in quartz veins in monzonite in the Clifton district.

In the Basin and Range province, but outside the three principal mineral belts, are some other important metallic mineral deposits. Foremost of these are the iron deposits of the Iron Springs district (fig. 8). These are hematite and magnetite replacements in Jurassic limestone. They have supplied nearly all of Utah's iron ore and constitute most of Utah's iron resources. The other principal occurrences of metallic minerals are in the Lucin, Tutsagubet, and Silver Reef districts. The deposits in the first two are similar to those in the other base- and precious-metal producing districts. The Silver Reef district, however, is unique, Most of its output has been silver and copper, from tabular impregnations of sulfides, chlorides, and carbonates in Triassic sandstone. These deposits are not directly associated with igneous rocks and are similar to the uranium-vanadium-copper deposits in the Colorado Plateau.

RESOURCES OF THE COLORADO PLATEAUS PROVINCE

In contrast to the complex geologic structures present in the Basin and Range province, much of the Colorado Plateaus province is characterized by nearly flat-lying strata that have been regionally warped into broad arches and basins. The mineral resources of this region, therefore, are primarily those that are associated with varied sequences of sedimentary rocks. Geologic processes that have resulted in the accumulation of such commodities as mineral fuels and saline resources are associated with the alternate advances and retreats of the seas across this area, as marked by the preservation of organic debris in the sediments and elsewhere by deposits of salts precipitated from isolated marine incursions. Intermittent uplift brought gradual emergence of the region into a continental environment. Some volcanic activity is indicated by the volcanic debris in some of the continental sandstones and mudstones. Uranium and vanadium now are concentrated in tabular deposits in these terrestrial rocks, principally in the Chinle and Morrison Formations of Mesozoic age, in linear zones or belts in San Juan, Grand, Emery, and Garfield Counties.

After the emergence of the region, a large lake occupied much of the northeastern part of the State and received thick accumulations of organic-rich debris. This debris is now represented by the extensive oil shale deposits of the Green River Formation in the Uinta Basin.

Coal-bearing strata are widely distributed, but the largest and more important deposits are in rocks of Cretaceous age in Carbon and Emery Counties, especially in the Book Cliffs coalfield where some of the coal has good coking properties.

Oil accumulations have been found in a number of formations, but principal production has come from Pennsylvanian carbonate rocks in the Greater Aneth area of the Paradox Basin, and in Tertiary terrestrial beds in the Uinta Basin. The major reserves of gas are associated with oil in the Paradox Basin and in separate gasfields in the Uinta Basin, Wasatch Plateau, and Green River Basin.

Several types of solid hydrocarbons, other than coal and oil shale occur in the Uinta Basin. Gilsonite, ozokerite, and wurtzilite occur mostly in veins in Tertiary sediments. Rock asphalt occurs principally in the Sunnyside area, Carbon County, and near Vernal, Duchesne County, in Tertiary and Cretaceous sandstone beds.

OTHER RESOURCES

A number of mineral commodities are widely distributed in the State such as clays, building stone, sand and gravel, phosphate rock, and saline deposits. A relatively limited amount of these widely distributed materials has been developed because of superior qualities, ease of mining, favorable location, or a combination of such factors. Other mineral commodities such as thorium and rare earth minerals, are rather sparsely distributed, but have high unit values. Still other mineral commodities, of interest to the public because they are easy to identify and have high unit values, include such materials as gem stones, and pegmatite minerals. Finally, a number of mineral commodities are briefly discussed that have limited potential or are not known to occur in Utah.

Abundant resources suitable for construction materials can be found in most parts of the State. Building stone and clays suitable for many purposes are found in a variety of rock strata. Special purpose clays, such as halloysite, used as a catalyst in petroleum refining, are much more limited. The halloysite deposits are mainly located in the

Tintic mining district, where they were formed by solutions related to the formation of the metallic mineral deposits. Phosphate resources are present in two upper Paleozoic formations in many places in northern Utah. Certain beds of phosphate rock in Rich and Uintah Counties are favorable because of thickness and phosphate content at suitable mining sites. A variety of saline resources are available throughout Utah, including bedded deposits of common salt, potash, gypsum, anhydrite, and sodium carbonate, as well as modern and fossil brine resources associated with Great Salt Lake and earlier lakes, and crusts of common salt on the surface of Great Salt Lake Desert. Additional development of all of these resources can be expected, as demand for each continues to increase.

Among the most interesting mineral resources of the State are some of the gem materials. Although the total commercial value of these materials has not been great, the individual satisfaction from discovery of attractive minerals insures continued exploitation. Most noteworthy of the gem materials are petrified wood, agate, and dinosaur bone from Mesozoic formations in southeastern Utah, obsidian in Millard County, variscite in Box Elder and Tooele Counties, and topaz and morganite from Tertiary rhyolite in the Thomas Range, Juab County. Known resources of high-temperature refractory minerals in Utah are limited; kyanite and andalusite occur in a few places in areas of Precambrian metamorphic rocks, but for the most part deposits of these minerals have not been intensively sought. A small amount of magnesite has been produced, but large deposits have not yet been found. Environments suitable for the formation of magnesite deposits exist in Utah, where dolomitic rocks have been intruded by igneous rocks.

A number of mineral commodities are recovered currently as byproducts in the processing of other mineral materials, including antimony arsenic, bismuth, cadmium, cobalt, fluorine, nickel, platinum, sulfur, and selenium. Other potential byproducts such as chromium, fluorine, molybdenum, nickel, selenium, silver, vanadium, uranium, zinc, zirconium, and some rare earths are present only in minor amounts in phosphate rock, but they constitute a large resource that might be recovered in the future. Similarly, lithium, magnesium, boron, and possibly bromine might be commercially recoverable from processing of saline brines. Several elements including rhenium, thallium, and tellurium are known to be present in small amounts in sulfide ores but are not now recovered.

Minor occurrences of a number of less abundant but useful minerals have been reported, including asbestos, celestite, graphite, and vermiculite. Most of these occurrences are only of academic interest, however, as the amount of material represented is too small for commercial development. Resources of tin, bauxite, and diamonds are not apt to be found in Utah because of the unfavorable geologic environments.

In summary, the western part of the State is geologically complex and is characterized by a great variety of faulted and folded metamorphic, sedimentary, and igneous rocks. It contains the principal metalliferous provinces and most of Utah's metallic minerals resources. These resources and many associated nonmetallic resources are largely in three easterly trending mineral belts. A combined estimate of the known reserves and potential resources of the principal base and precious metals in western Utah indicate that remaining resources of gold, silver, copper, and lead are as great as have been mined to date and the remaining resource of zinc is about three times as great as has been mined to date. At current prices, these metals would be worth $10 billion. This estimate is based on available mine reserve data, production records, and geologic inference. In addition, the western part of the State contains abundant nonmetallic resources such as clays, lightweight aggregate, cement rock, salines, sand and gravel, and stone.

The eastern part of the State is essentially a sedimentary province characterized by flat-lying sedimentary rocks, few intrusive igneous rocks, and relatively simple fault and fold structures. It contains nearly all of the State's mineral fuels, principally coal, petroleum, and oil shale; large nonmetallic minerals resources, principally salines and phosphate; and most of the State's uranium and vanadium.

Utah has a great variety and abundance of mineral resources. Much of this plentiful supply, however, is far from potential markets and many technologic and economic problems must be solved before some of the materials can be mined and marketed. Even before these problems can be faced, however, much geologic effort will be required to evaluate the known resources and find those that are hidden. Deposits are becoming harder to find. Those near or at the surface have largely been found and, as mining continues, exploration will be forced to seek for hidden deposits and to search for those at greater depths. To find such deposits will require a better understanding of the geology, and the development of more effective exploration techniques. Recent discoveries in the Tintic district demonstrate the value of increased effort using modern methods of exploration (Lovering and Morris, 1960; and Bush and Cook, 1960).

Geologic mapping is fundamental to developing a better understanding of mineral and water resources, and modern-scale topographic maps are fundamental to geologic mapping as well as for other uses in the minerals industry and for other segments of the State's economy. As shown on figure 9, modern topographic maps are available for only a part of the State. Similarly, as shown on figure 10, much detailed geologic mapping remains to be done, mapping that is needed to better evaluate the resources of Utah (fig. 10)[1]

The expected continued growth in the economy of the State and Nation will demand an ever-increasing mineral output. Utah has the potential resources to help satisfy the many needs, but much effort will be required to find, develop, and win the various commodities, which are summarized in ensuing sections of this report.

Selected References

Andrews, D. A., and Hunt, C. B., 1948, Geologic map of eastern and southern Utah: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 70.

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.

[1] For more complete information on topographic and geologic mapping coverage see: Boardman, Leona, 1954, Geologic map index of Utah: U.S. Geological Survey Index to Geologic Mapping in the United States; and Index to Topographic Mapping in Utah.

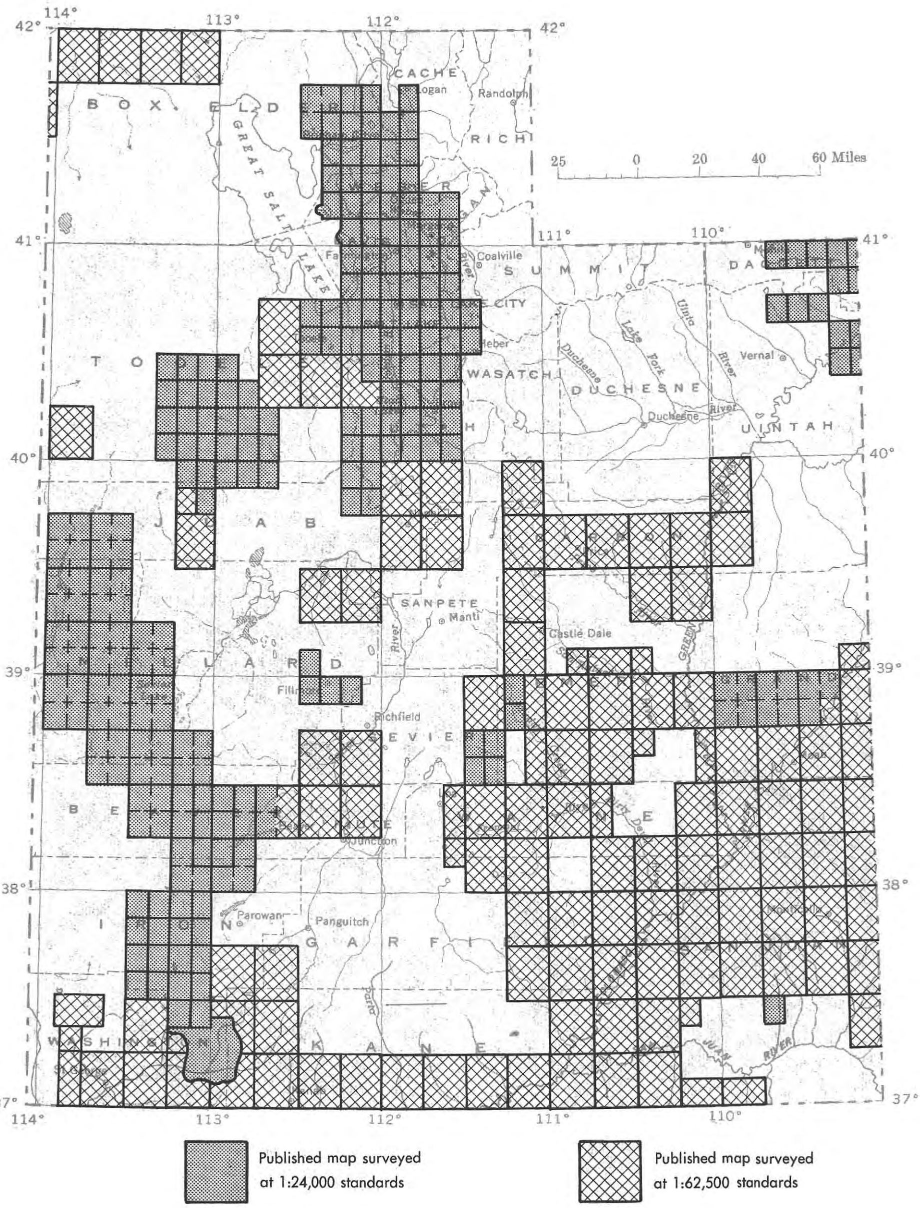


Figure 9.—Published topographic mapping in Utah, October 1963.

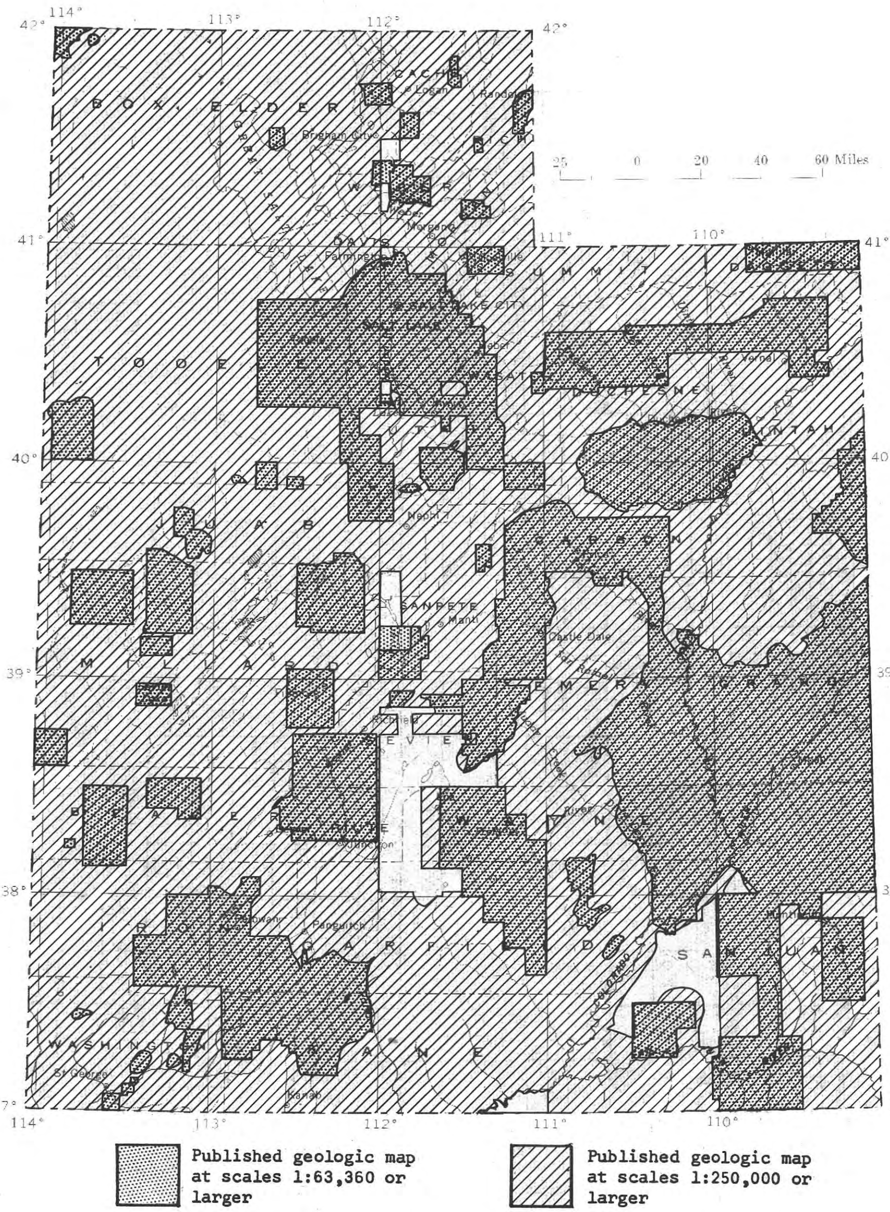


FIGURE 10.—Published geologic mapping in Utah, October 1963.

Boutwell, J. M., 1905, Economic geology of the Bingham mining district, Utah: U.S. Geol. Survey Prof. Paper 38.

———, 1912, Geology and ore deposits of the Park City district: U.S. Geol. Survey Prof. Paper 77.

Bush, J. A., and Cook, D. R., 1960, The Chief Oxide-Burgin area discoveries, East Tintic district, Utah; a case history. Part II. Bear Creek Mining Company studies and exploration: Econ. Geology, v. 55, no. 7, p. 1507–1540.

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., Loughlin, G. F., Heikes, V. C., and others, 1920, The ore deposits of Utah: U.S. Geol. Survey Prof. Paper 111.

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.

Christiansen, F. W., 1963, Cambrian rocks of Utah, *in* Crawford, A. L., ed., Surface, structure, and stratigraphy of Utah: Utah Geol. and Mineralog. Survey Bull. 54a, p. 45–49.

Crawford, A. L., ed., 1963, Surface, structure, and stratigraphy of Utah: Utah Geol. and Mineralog. Survey Bull. 54a.

Crittenden, M. D., Jr., (in press), General geology of Salt Lake County: Utah Geol. and Mineralog. Survey Bull.

———, 1963, New data on the isostatic deformation of Lake Bonneville, U.S. Geol. Survey Prof. Paper 454–E.

Eardley, A. J., 1951, Structural geology of North America: Harper and Bros., New York.

Fenneman, N. M., 1931, Physiography of Western United States: McGraw-Hill Book Co., Inc., New York and London.

Gilbert, G. K., 1890, Lake Bonneville: U.S. Geol. Survey Mon. 1.

Hansen, W. R., 1963, Absolute age of the Red Creek Quartzite (Precambrian) exceeds 2 billion years [abs.]: Geol. Soc. America Rocky Mountain Sec., and New Mexico Geol. Soc. 16th Ann. Mtg. Program, Albuquerque, N. Mex., May 15–18, 1963, p. 26.

Harris, H. D., 1959, Late Mesozoic positive area in western Utah: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 11, p. 2636–2652.

Hunt, C. B., 1956, Cenozoic geology of the Colorado Plateau: U.S. Geol. Survey Prof. Paper 279.

Hunt, R. N., 1924, The ores in the limestone at Bingham: American Inst. of Mining Eng. Trans., vol. 70, p. 857–883.

James, Allan, Smith, Wilbur, and Bray, Eldon, 1961, Bingham district, a zoned porphyry ore deposit, *in* Geology of the Bingham Mining District and the Northern Oquirrh Mts., Cook, D. R., ed., Utah Geol. Society Guidebook no. 16: p. 82–100.

Kulp, J. L., 1961, Geologic time scale: Science, v. 33, no. 3459, p. 1111.

Lovering, T. S. and Morris, H. T., 1960, The Chief Oxide-Burgin area discoveries, East Tintic district, Utah; a case history. Part I. U.S. Geological Survey studies and exploration: Econ. Geology, v. 55, no. 6, p. 1116–1147.

Morris, H. T., and Lovering, T. S., 1961, Stratigraphy of the East Tintic Mountains: U.S. Geol. Survey Prof. Paper 361.

Odekirk, J. R., 1962, Lead-alpha age determinations of five Utah rocks: Utah Univ., Salt Lake City, M.S. thesis, p. 12–27.

Proctor, P. D., and Bullock, K. C., 1963, Igneous rocks of Utah, *in* Crawford, A. L., ed., Surface, structure, and stratigraphy of Utah: Utah Geol. and Mineralog. Survey Bull. 54a, p. 155–170.

Stokes, W. L., ed., 1961, Geologic map of Utah, NE ¼: Utah Univ., Salt Lake City.

———, 1963, Geologic map of Utah, NW¼: Utah Univ., Salt Lake City.

———, (in press), Geologic map of Utah, SW ¼: Utah Univ., Salt Lake City.

Tooker, E. W., and Roberts, R. J., 1962, Comparison of Oquirrh Formation sections in the northern and central Oquirrh Mountains, Utah: Art. 188 *in* U.S. Geol. Survey Prof. Paper 424–E, p. E32–E36.

Wilson, C. L., 1959, Park City mining district, *in* Guidebook to the Geology of the Wasatch and Uinta Mountains, N. C. Williams Ed., Tenth Ann. Field Conference, Intermountain Assoc. of Petroleum Geologists: p. 182–188.

MINERAL FUELS AND ASSOCIATED RESOURCES

INTRODUCTION

(By L. S. Hilpert, Salt Lake City, Utah)

Utah's mineral fuel resources are almost entirely in the eastern part of the State and, through 1961, have produced about 18 percent of the value of the State's total mineral yield. In 1961, the value of all mineral fuels produced in Utah totaled about $139 million, approximately one-third of the State's total mineral output. For many years, coal provided almost the entire fuels output and, through 1961, had contributed $914 million in total value, ranking second to copper in the State's mineral commodities. In recent years petroleum has come to the forefront and supplanted coal in value of annual yield. In 1959, petroleum output was valued at $117 million. Oil shale constitutes a great potential petroleum resource, but it has not yet been exploited. Other bituminous substances, principally gilsonite and lesser amounts of rock asphalt and other bitumens, have been produced in modest amounts for many years. Since the late 1950's, the output of gilsonite has increased substantially. The production of mineral fuels in Utah will probably increase in the near future. Recent interest in the development of steampower from coal may stimulate coal output; oil output may continue near present levels; gas output will probably continue to rise with the expanding market demands for the fuel; and gilsonite and other bitumens may continue near present levels. Utilization of the oil shale resources is dependent on the solution to many technologic and economic problems and the time when the shales will be developed cannot be predicted. Until such development they will remain as an important resource that can be used in case of national emergency. Production of fluid hydrocarbon fuels from coal is technically feasible, and can be initiated when necessary or economically feasible. The mineral fuels coal, oil and gas, oil shale, and other bituminous substances will be discussed in that order in the following sections.

COAL

(By Paul Averitt, Denver, Colo.)

Coal is widespread and abundant in Utah. The vast coal field areas shown in figure 11 cover 15,000 square miles, or about 18 percent of the total area of the State. Coal is present in 17 out of Utah's 29 counties, but resources and most of the mining activity are concentrated in Carbon and Emery Counties in the central part of the State.

Most of the coal in Utah occurs in rocks of Cretaceous age, and the largest and most important deposits occur in rocks of the Mesaverde Group of latest Cretaceous (Montana) age. Smaller and less important deposits occur in the underlying Mancos Shale and equivalent rocks of the early Late Cretaceous (Colorado and Montana) age. Other minor deposits occur in still older rocks of the Dakota Formation

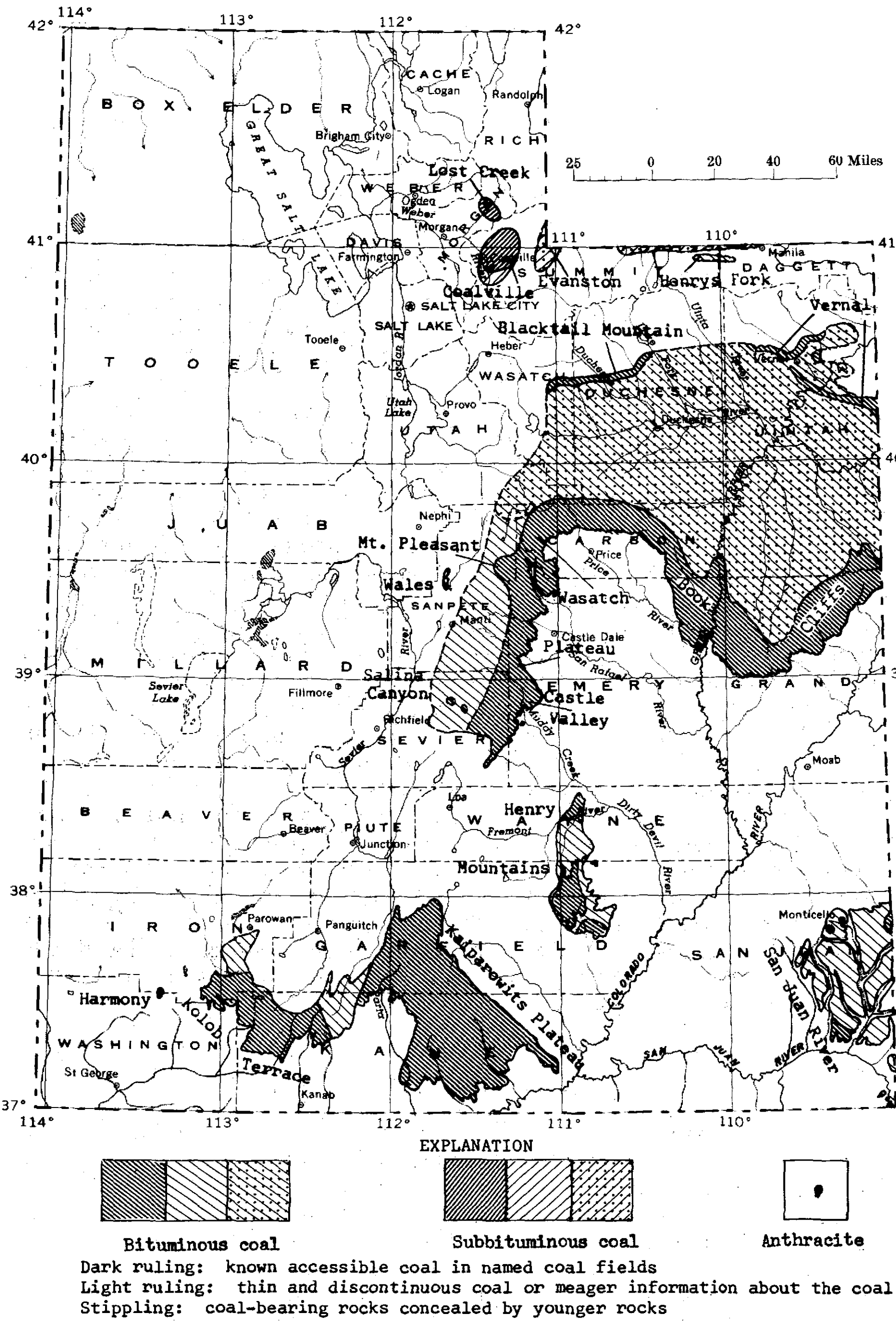


FIGURE 11.—Coalfields of Utah.

of Early and early Late Cretaceous age. A few deposits are in the Wasatch Formation of early Tertiary age.

The great bulk of Utah coal is of bituminous rank and is relatively high in heat value (Aresco, Haller, and Abernethy, 1962; and U.S. Bureau of Mines, 1925). Small, insignificant quantities are of subbituminous and anthracite ranks. Coal is classified by rank according to percentage of fixed carbon and heat content. In general, the percentage of fixed carbon and the heat content increase and the moisture and volatile matter decrease from lignite, the lowest rank, to anthracite, the highest rank (American Society for Testing Materials, 1954). These changes took place progressively during the slow, coal-forming process. Rank is, therefore, both a measure of the degree of coal metamorphism and a useful index of the utility and value of the coal.

In the Carbon County portion of the Book Cliffs field much of the coal, and specifically the Upper and Lower Sunnyside beds, is of high volatile bituminous A rank, and has good coking properties. This coal, blended with small amounts of low volatile bituminous coal from Colorado, Arkansas, or Oklahoma, is used in the manufacture of coke for the production of iron and steel in Utah and California, as well as providing the basis for many coke byproducts industries.

PRODUCTION

Utah is the leading coal-producing state west of the Mississippi River. In 1962 Utah produced 4,297,000 tons as compared to 3,379,000 tons for Colorado, the No. 2 State; and to 2,896,000 tons for Missouri, the No. 3 State. In spite of a long-term continuing decline in national coal production, Utah's dominant position in the West is because of the need for Utah coal in the manufacture of coke to supply the western iron and steel industry. The conspicuous fluctuations in annual Utah production shown on figure 12 are due largely to fluctuations in production of iron and steel.

The mining of coal is the fourth largest extractive industry in Utah, being exceeded in annual value of the product only by petroleum and natural gas, copper, and uranium. In 1961 the coal industry employed an average of 2,206 men daily and produced 5,159,000 tons of coal valued at $31,126,000. This figure is 7.4 percent of the value of all mineral commodities produced during the year.

Because of its high heat content and coking properties, Utah coal is regularly shipped in quantity to other western states. In 1962, for example, 989,000 tons was shipped to California, and 671,000 tons was shipped to Washington and Oregon.

Coal production in Utah began in 1854 near Cedar City in the Kolob Terrace field, Iron County, but soon extended to other parts of the State. The new industry grew slowly at first and by 1870 the recorded annual production was only about 6,000 tons. After 1870, however, annual production increased steadily to a total of 3,576,000 tons in 1940. Then, in response to the greatly increased demands of World War II and the postwar boom, production increased very rapidly to 7,119,000 tons in 1944, and to an all-time high of 7,429,000 tons in 1947. In the 11-year period, 1947–57, production ranged generally between 6 and 7 million tons. Since 1957 production has declined

26-803 O-69- 4

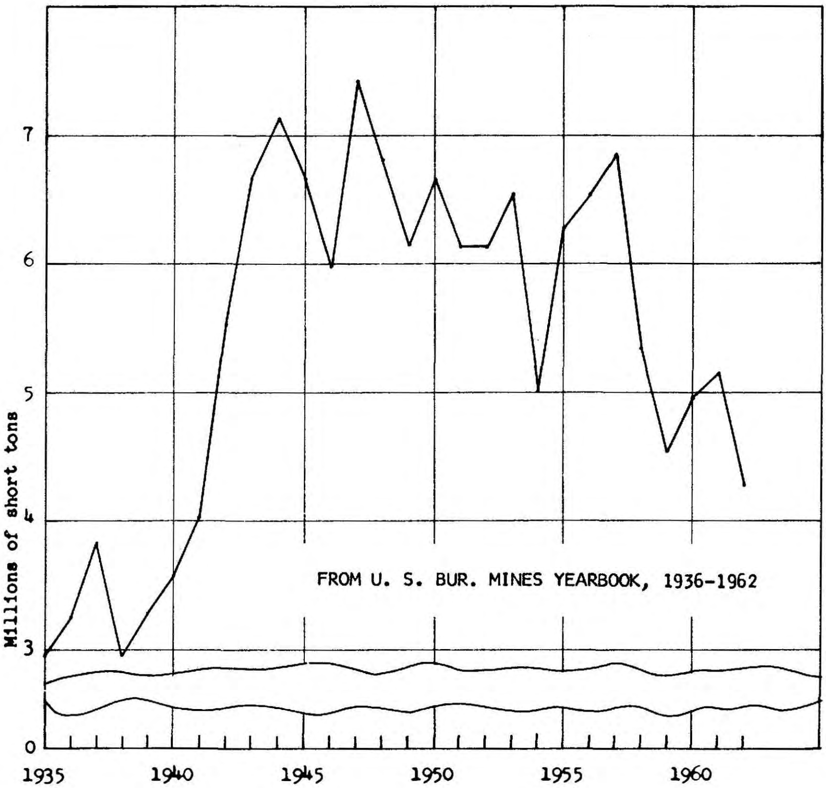


FIGURE 12.—Coal production in Utah, 1935–62.

markedly. The 4,297,000 tons produced in 1962 was the lowest figure recorded since 1941. This decline has been brought about by the decline and essential cessation of exports to Asia, and by the great increase in availability and use of natural gas.

About 98 percent of Utah coal production is obtained in Carbon and Emery Counties. Carbon County typically produces about 74 percent of the total, and Emery County about 24 percent. Most of the production in Carbon County is from a few large mines. Large modern mines are operated by the Kaiser Steel Corp.; the Columbia-Geneva Division, United States Steel Corp.; the Independent Coal & Coke Co.; and the U.S. Fuel Co., a subsidiary of the United States Smelting, Refining & Mining Co. The remaining 2 percent of production is obtained from small mines in Sevier, Summit, and Iron Counties.

The percentage of Utah coal production used in the manufacture of coke has increased in recent years although overall coal production has declined. In 1954 and 1955, for example, 38 and 40 percent, respectively, was coked; whereas, in 1960 and 1961, the respective proportions were 49 and 51 percent.

Of the total amount used in the manufacture of coke, a little less than half is shipped to southern California, and the remainder is used in Utah.

The quality of coke made from Utah coal is greatly improved by admixing small amounts of low-volatile bituminous coal and anthracite obtained from Colorado, Arkansas, and Oklahoma. In 1962 Utah imported 268,000 tons of such coal from Colorado, and 169,000 tons from Arkansas and Oklahoma.

For convenience in study and description the Utah coal areas have been divided into 16 smaller areas or fields, which are summarized below.

COALFIELDS

Henrys Fork field

The Henrys Fork field, which has been examined in reconnaissance by Gale (1910b), lies on the north flank of the Uinta Mountains in Daggett and Summit Counties, Utah, and Sweetwater County, Wyo., The only coal of consequence in this field occurs in the Mesaverde group and in the underlying Frontier formation. Where exposed along the Green River north of Flaming Gorge, these units contain several coalbeds of bituminous rank that range in thickness from less than a foot to 10 feet. The coal-bearing rocks are broken by faults and locally dip as much as 85° south, which greatly reduces the quantity and value of the available coal. Thin and impure beds of bituminous coal have also been observed in underlying rocks of Pennsylvanian age, but these beds also are disturbed by faulting. Thin and impure beds of subbituminous coal have been observed in overlying rocks of Teritary age.

Blacktail (Tabby) Mountain field

The Blacktail (Tabby) Mountain field lies on the south flank and near the west end of the Uinta Mountains in Wasatch and Duchesne Counties. The coal in this field occurs in the Mesaverde Group and in the underlying Mancos Shale. As described by Lupton (1912), these beds trend east-west for 32 miles and dip south at angles ranging from 20° to 58°. Two subsequent maps by Huddle and McCann (1947), and by Huddle, Mapel, and McCann (1951), present more recent detailed geologic data on the field.

The Mesaverde Group contains 21 coal beds ranging in thickness from 7 inches to 28 feet in a stratigraphic sequence 1,650 feet thick. The thickest of these beds, the Fraughton, ranges from 15 to 28 feet thick in four exposures. The other beds range from 7 inches to 15 feet. The underlying Mancos Shale contains four coalbeds ranging in thickness from 6 inches to 18 feet in a statigraphic sequence 250 feet thick. All the coal is of high volatile C bituminous rank; it is mined only on a small scale for local use.

The coal-bearing rocks of the Blacktail (Tabby) Mountain field continue eastward through eastern Duchesne County under a cover of younger sediments of Tertiary age to join those of the Vernal field in Uintah County.

Vernal field

The Vernal field lies on the south flank and near the east end of the Uinta Mountains in Uintah County. The field is divided into two districts—a western, described by Kinney (1955), and an eastern, described by Gale (1910a). The coal in this field occurs primarily in the upper part of the Frontier Sandstone Member of the Mancos Shale. Thin and impure beds also occur in the overlying Mesaverde Group and in underlying beds of Mississippian age.

The coal in the Vernal field is of high volatile C bituminous rank and is moderately high in heat value. In the past it was mined on a modest scale for local use.

Western district.—The western district, known also as the Deep Creek or Uinta River-Brush Creek district, extends from a few miles west of Deep Creek on the west side of T. 3 S., R. 19 E. of the Salt Lake meridian eastward several miles beyond Brush Creek to the northwest corner of T. 3 S., R. 23 E., and includes an arc-shaped area on the westward extension of the Split Mountain anticline in T. 4S., R. 22 E. In these areas the coal-bearing rocks dip southward at angles ranging generally between 15° and 30°, but are steeper locally near faults and on the crests of folds.

A single coal horizon is present at most places in the Frontier Sandstone Member. However, the horizon drops progressively eastward from the top of the Frontier Member in the Deep Creek area, to 65 feet below the top in the Brush Creek area, to 90 feet below the top on the westward extension of the Split Mountain anticline. This relation suggests that the coal occurs as discontinuous lenses. Locally, the coal-bearing rocks are broken by faults, or concealed by younger deposits, and in places the coal horizon may have been removed by erosion in late Frontier time. At most places where coal is exposed the thickness ranges from about 2 feet to about 7 feet. Coal in the general range of 2 to 4 feet is abundant.

Eastern district.—The eastern district extends eastward from the Green River to the Colorado State line, and includes T. 5 S., R. 23 E., and T. 6 S., Rs. 23, 24, and 25 E. The coal-bearing Frontier Sandstone Member of the Mancos Shale, and the Mesaverde Group extend across these townships, but exposures are poor, and very little coal is visible. However, a coalbed 7 feet thick is present about 700 feet above the base of the Mesaverde Group in T. 6 S., R. 24 E. The beds in the eastern district dip southward at angles ranging from 30° to 70°.

Book Cliffs field

The Book Cliffs form a bold, southward-facing, S-shaped escarpment 1,000 to 2,000 feet high extending eastward from Price River into Colorado—a distance in Utah of about 140 miles measured along the base of the cliffs. The west half of the field in Carbon County is described in a report by Clark (1928) and the east half in Emery and Grand Counties in a report by Fisher (1936).

West half.—In the west half of the field coal occurs near the base of the cliffs in the Blackhawk Formation of the Mesaverde Group, which dips gently north and east. The coal-bearing part of the formation is about 500 feet thick. A maximum of nine coalbeds more than 14 inches thick are present in this sequence at one locality, and four or five beds more than 4 feet thick are present at most localities. The coalbeds at the west end of the area near Castlegate are older than those at the east end near Sunnyside. These older beds thin progressively eastward and pinch out. Concomitantly, younger beds appear higher in the sequence, and these in turn first thicken and then pinch out eastward. The most important bed in the sequence is the Lower Sunnyside bed, which thickens eastward from about 2 feet near the west edge of the Wellington quadrangle to about 14 feet near Sunnyside, and then thins southward and eastward. Most of the mining in Carbon County and in Utah is concentrated in this bed and in the overlying Upper Sunnyside bed in a small area between the town of Sunnyside and Horse Canyon near the south edge of the Sunnyside quadrangle. This coal is of high volatile A bituminous rank and has good coking properties. It is, therefore, in demand for the manufacture of coke to supply the western iron and steel industry.

East half.—The east half of the Book Cliffs field extends generally south from Sunnyside to the Green River, then east and northeast to Colorado. Between Sunnyside and the Green River the rocks in the cliffs dip 3° to 12° east or north and are broken locally by several small normal faults with maximum vertical displacements of 200 feet. From Green River to the Colorado State line the rocks dip 2° to 4° north or northeast but the dip of the beds and the trend of the cliffs are modified locally by small faults and flexures.

The pattern of coal deposition noted in the west half of the field continues uniformly across the east half. The coals in the Blackhawk Formation of the Sunnyside area thin and pinch out southward, and from the Green River eastward they are relatively unimportant. As these coals pinch out other coals appear higher in the sequence; east of the Green River the important coals are in the Neslen Formation of the Mesaverde Group, which in this area overlies the Blackhawk Formation. The Neslen Formation contains five coal zones in a stratigraphic sequence 250 to 410 feet thick, but in most townships east of the Green River only two or three coals of economic interest are present. These coals average 2 to 4 feet in thickness. The Chesterfield bed is locally as much as 5 feet thick, and in the past was mined on a small scale near Sego.

The coal in the east half of the field is of slightly lower rank than in the west half and is not suitable for coking.

Wasatch Plateau field

In the Wasatch Plateau field, Carbon, Emery, and Sevier Counties, the coal-bearing Blackhawk Formation lies near the base of the Wasatch Cliffs, which are a southward continuation of the Book Cliffs. As described by Spieker (1931), the formation ranges in thickness between 700 and 1,000 feet, and typically contains in the lower part 4 to 7 coalbeds, each of which is of minable thickness over a considerable area, though none is continuous over the entire field. The Hiawatha bed, the most extensive and best known bed in the field, is more than 5 feet thick, and locally as much as 20 feet thick, over a large area around the town of Hiawatha, where it is mined extensively.

Throughout most of the field the coal-bearing rocks dip westward at angles ranging between 1° and 3°. Locally, dips of as much as 20° have been noted along faults. Three major fault zones that strike essentially parallel to the Wasatch Cliffs disrupt the strata. All the faults are normal and the fault planes are vertical or nearly so with displacements of about 100 to 1,000 feet.

The coal resources in the Wasatch Plateau field are larger than those of any other field in Utah and annual production is second only to the very large production from the Book Cliffs field.

Mount Pleasant field

The Mount Pleasant field, which has been described by Duncan (1944), is in Sanpete County on the east side of Sanpete Valley and on the west flank of the Wasatch Plateau. In this field the top of the coal-bearing Blackhawk Formation crops out locally where it has been uplifted to the surface by faulting, but the coalbeds generally are 1,000 feet below the surface. Because these beds are a westward extension of beds in the Wasatch Plateau field they were drilled during World War II in an intensive search for coking coal. The drilling showed 5 coalbeds ranging in thickness from 3 feet to 5 feet 8 inches at depths of 955 to 1,151 feet below the surface. The coke made from these coals was inferior to that made from Sunnyside coal, and in part for this reason and in part because the coal is deeply buried, no attempt has been made to develop the deposit.

Wales field

The small and unimportant Wales field in west-central Sanpete County has been described by Clark (1912). It is on the west side of Sanpete Valley at the base of the Gunnison Plateau, which rises several thousand feet above the valley. A major fault lies due east of and parallel to the coal outcrop. Near the fault the coal dips steeply but it flattens to about 15° within a short distance.

The coal is of bituminous rank and is in a single bed 2 to 7 feet thick containing about equal parts of coal and shale. The bed includes benches of coal 1½ to 2½ feet thick that are free of partings, but even these benches are high in ash. The poor quality of the coal has prohibited development of the deposit.

Salina Canyon field

The Salina Canyon field is in Sevier County at the southwest end of the Wasatch Plateau field. It is in the drainage of Salina Creek, a tributary of the Sevier River, and thus is readily accessible from the west. The coal is in the Blackhawk Formation (Spieker and Baker, 1928) and is exposed in Salina Canyon in five small areas along a group of north-south normal faults spaced 1 to 3 miles apart. In the blocks between faults, beds dip 10° to 15° over large areas but may be steeper locally. The Blackhawk Formation is believed to be 800 to 900 feet thick in the field, but only the upper 550 feet of the formation is exposed. This sequence includes 3 coalbeds that are thick enough locally to be mined, and several additional thin beds. Other beds of unknown thickness are undoubtedly present below drainage. The Ivie bed, the lowest in the exposed sequence, is 6 feet thick over a considerable area and is considered suitable for large-scale mining. The overlying Sevier and Wilson beds are 2½ to 3 feet thick in most places, and are of subordinate interest.

The coal is of bituminous rank and is relatively high in heat value, low in sulfur, and contains low to moderate amounts of ash.

Castle Valley field

The Castle Valley field, which has been described by Lupton (1916), is largely in Emery and Sevier Counties. Coal in this field is in the Ferron Sandstone Member of the Mancos Shale. The Ferron Sandstone Member forms a low ridge parallel to and about 10 miles east of the Wasatch Cliffs. Beds in this ridge dip gently northwestward at angles generally less than 5°, but locally as much as 11°. The sandstone thins from about 800 feet in the southwest end of the field to 75 feet at the northeast end. Most of the coal is at the southwest end near and southwest of the town of Emery. Fourteen coalbeds ranging in thickness from 14 inches to 20 feet have been observed in this restricted area. Several beds, each more than 5 feet thick, are present in most townships. The coal is of bituminous rank and is of good quality. It is mined only on a small scale because of competition from large mines in the nearby Wasatch Plateau field.

Henry Mountains field

The Henry Mountains field in Wayne and Garfield Counties is remote from means of transportation and centers of use. As described by Hunt and others (1953), coal in this field occurs in both the Ferron and the overlying Emery Sandstone Members of the Mancos Shale in a shallow structural basin on the west side of the Henry Mountains. A coal in the upper part of the Ferron Sandstone Member is 2 to 6 feet thick including a few thin partings at the south end of the basin; and locally 7 feet thick including a few partings at the north end of the basin where it is mined on a small scale for local use. Elsewhere it is generally less than 2 feet thick. The Emery Sandstone Member includes near the top a coal zone locally 20 feet thick composed of several benches of coal and shale. The coal benches range in thickness from 2 to 6 feet and a bench 4 feet thick or more is present in most exposures. The coal is of high volatile C bituminous rank.

Kolob Terrace field

The Kolob Terrace field is in Iron, Washington, and Kane Counties. In this field the coal occurs in the Tropic Formation and the Straight Cliffs sandstone, both correlatives of the Mancos shale of Late Cretaceous age. These coal-bearing rocks dip very gently eastward and few widely spaced normal faults of moderate to large displacement are present but do not and will not hamper mine development. The western part of the field has been described in a report by Averitt (1962), and the eastern part in a report by Cashion (1961). Regional studies have been made by Gregory (1950a, 1950b), and by Robison (1963).

In the western part of the field the only coal of consequence occurs in two zones at the top of the Tropic Formation—an upper zone 10 to 14 feet thick, and a lower zone 7 to 13 feet thick, separated by a sequence of barren rock 11 to 34 feet thick. The best coal is contained in the upper part of the upper zone, which at most localities exhibits about 6 feet of coal separated by several shale partings. Three small commerical mines developed in this part of the sequence near Cedar City were active in 1963. The coal in the western part of the field is of high volatile C bituminous rank. It has a moderate heat content, moderate to high ash content, and a relatively high sulfur content.

In the eastern part of the field the coal of consequence also occurs in two zones—one near the base and the other near the middle of the Tropic Formation. The lower coal zone is 5 to 35 feet thick and contains several benches of coal and shale. The coal benches range in thickness from 1 to 7 feet, but typically are 2 or 3 feet thick and are discontinuous. The zone contains some coal suitable for local mining, but nowhere in the area does it exhibit a continuous bench of coal thick enough to encourage large-scale mining. The upper zone is 6 to 34 feet thick and contains near the top a bench of coal that is believed to average about 5 feet thick over a large area. The coal in the eastern part of the field is also of high volatile C bituminous rank and contains less ash and sulfur than that in the western part. The coal in the eastern part is mined only on a very small scale for local use.

Kaiparowits Plateau field

The Kaiparowits Plateau field, in Garfield and Kane Counties, is the least explored of Utah coal fields. Coal in this field occurs in the Dakota Sandstone, the Tropic Formation, and the Straight Cliffs Sandstone (Gregory and Moore, 1931; Gregory, 1951). The coal in the Dakota Sandstone and the Tropic Formation is generally thin and discontinuous, but a few pockets of minable thickness occur locally.

Four thick and continuous beds and several thin and discontinuous beds occur in the Straight Cliffs Sandstone in a sequence 300 to 600 feet above the base. Bed A, 310 feet above the base of the Straight Cliffs sandstone, contain 2 feet 7 inches, to 3 feet 3 inches of good coal in the several sections examined. Bed B, 460 to 480 feet above the base, ranges in thickness from 1 to 20 feet, and is typically about 2 to 4 feet thick. Bed C, about 500 feet above the base, contains several local areas of coal 9 to 12 feet thick. Bed D, about 600 feet above the base, is 11 feet thick in one exposure and 4 feet thick in another.

The Kaiparowits Plateau field is in a large shallow synclinal basin bordered on the west by a steep monoclinal flexure and modified on the south by several parallel anticlines and synclines. Except for the bordering monoclinal flexure the dips are gentle and exceed 10° only locally.

The coal in the Kaiparowits Plateau field is of high volatile C bituminous rank and is relatively low in ash and sulfur. The construction of the Glen Canyon dam has focused attention on the field and much mapping and exploration was in progress in the summer of 1963.

San Juan River field

In the San Juan River field, San Juan County, coal occurs in short, discontinuous lenses in the Dakota Sandstone. These lenses are thick enough locally to permit mining on a small scale. Gregory (1938) cites several localities where the coal attains a maximum thickness of 2 feet 10 inches. The coal-bearing rocks are nearly flat-lying and are readily accessible. The coal is of high volatile bituminous rank, but is typically high in ash.

Lost Creek field

In the Lost Creek field, Morgan County, coal occurs in the middle of an 1,800-foot sequence of beds correlated with the Wasatch Formation of early Tertiary age. The coal lies on top of a 700- to 900-foot thick conglomerate in a single, relatively thin sequence of carbonaceous rock. According to Clark (1918), the only coal of consequence occurs in T. 5 N., R. 5 E. Of 13 coal sections measured in this township, 4 showed coal 4 to 6 feet thick, and the remainder showed coal 2 feet thick or less.

The coal-bearing rocks are nearly flat-lying. Throughout most of the township the dip is 5° or less, but locally the dip attains a maximum of 10°. The coal is of subbituminous rank and is relatively high in ash.

Coalville field

The Coalville field is in Summit County, about 30 miles northeast of Salt Lake City. This field has been a small but continuing source of coal for Salt Lake City and nearby communities since the earliest days of settlement. Coal occurs in three zones in the lower part of a 9,000-foot stratigraphic sequence of Late Cretaceous age (Wegemann, 1915). The Spring Canyon zone is 850 feet above the base of the sequence; the Wasatch bed is about 1,700 feet above the base; and the Dry Hollow bed about 3,800 feet above the base. The Wasatch bed is the thickest and most important bed. It is 5 to 13 feet thick and continuous throughout the field. The Dry Hollow bed is somewhat less continuous, but where mined and prospected is 2 to 4 feet thick. The coals in the Spring Canyon zone are of less importance.

The coal-bearing rocks are folded into a northeast-trending anticline with a broad, flat top. On the northwest flank of the anticline the beds dip 15° to 30° northwest; on the southeast flank they are vertical to overturned. The anticline is broken by many small normal faults both parallel to and normal to the anticlinal axis, which locally complicate mine development.

The coal in the field is of subbituminous rank and is relatively low in ash and sulfur.

Harmony field

The Harmony field is in Iron and Washington Counties about 4 miles northwest of the village of New Harmony. The coal is in rocks of Late Cretaceous age that are correlatives of those in the nearby Kolob Terrace field. As described by Lee (1907) and by Richardson (1909), the rocks in the Harmony field have been deformed by a nearby intrusive stock and the beds dip at angles ranging from 45° eastward to vertical. Because of the deformation and the heat of the intrusive the coal is semianthracite.

Six coal and carbonaceous shale zones have been observed in the lower 560 feet of the Cretaceous sequence, but no significant thickness of clean coal is present. Analyses of beds exposed by prospecting show 23 to 34 percent ash, and small samples handpicked in an effort to obtain low ash values showed a minimum of 9 percent ash. The coal is also highly sheared and tends to break into small granules. Because of the steep dip, high ash, and fine texture of the coal no mining has been undertaken in the field (Cook, 1957, p. 101–102).

RESOURCES

Utah's coal resources may be considered from two points of view. The more conservative and certainly the more practical includes coal determined by present mapping and exploration; the more generous attempts by extrapolation to account for all coal above a minimum thickness potentially present in the full thickness and extent of coal-bearing rocks.

As determined by mapping and exploration, the original coal resources of Utah total 28,378 million tons, including 28,222 million tons of bituminous coal and 156 million tons of subbituminous coal. This estimate is the sum of 12 estimates for individual fields prepared by geologists who have studied and mapped in those fields. The accompanying table modified slightly from Averitt (1961, p. 79) gives

TABLE 2.—*Estimated original coal resources of Utah as determined by exploration and mapping*

[In millions of short tons]

Field and county	Estimated resources	Source of estimate	Remarks
BITUMINOUS COAL			
Henrys Fork field, Daggett and Summit Counties			Insignificant resources in Frontier Formation and Mesaverde Group. (See Gale, 1910b.)
Blacktail (Tabby) Mountain field, Duchesne and Wasatch Counties.	1,858	Lupton (1912) [1]	Estimate is high compared to recent estimate for Vernal field.
Vernal field (west end only), Uintah County	143	Kinney (1955) [2]	Insignificant additional resources in east end of field. (See Gale, 1910a.)
Book Cliffs field, Carbon, Emery, and Grand Counties:			
Castlegate quadrangle	1,275	Clark (1928) [2]	Resource area covers 43 square miles.
Wellington and Sunnyside quadrangles	2,629	do	Resource area covers 237 square miles.
Book Cliffs south and east of Sunnyside quadrangle	518	Fisher (1936) [2]	Resources within 2 miles or less of outcrop.
Wasatch Plateau field, Carbon, Emery, and Sevier Counties	13,000	Spieker (1931) [2]	Includes 7,800,000,000 tons in beds more than 30 inches thick.
Mount Pleasant field, Sanpete County			Modest resources 1,000 feet below surface. (See Duncan, 1944.)
Wales field, Sanpete County			Small resources. (See Clark, 1912.)
Salina Canyon field, Sevier County	170	Spieker and Baker (1928) [2]	Resource area covers 30 square miles.
Castle Valley field, Emery and Sevier Counties	1,429	Lupton (1916) [1]	Coal in Ferron sandstone. Estimate may be high.
Henry Mountains field, Wayne and Garfield Counties	200	Provisional gross estimate by writer	Data from Hunt and others (1953).
Kolob Terrace field, Iron, Washington, and Kane Counties	4,000	Estimate by W. B. Cashion and writer by extrapolation from work in 2 parts of the field.	(See Cashion, 1961; Averitt, 1962.)
Kaiparowits Plateau field, Garfield and Kane Counties	3,000	Provisional gross estimate by writer	Data from Gregory and Moore (1931).
San Juan River field, San Juan County			Small resources. (See Gregory, 1938.)
Total, bituminous coal	28,222		
SUBBITUMINOUS COAL			
Lost Creek field, Morgan County			Insignificant resources. (See Clark, 1918.)
Coalville field, Summit County	156	Campbell (1917)	Data from Wegemann (1915).
SEMIANTHRACITE			
Harmony field, Iron and Washington Counties			Insignificant resources of highash coal. (See Richardson, 1909.)
Total, all ranks	28,378		

[1] Report contains breakdown of resources by townships only.

[2] Report contains breakdown of resources by beds and by townships.

the source and amount of these individual estimates. These estimates include coal to a minimum thickness of 14 inches, but the major emphasis is on the thicker and more persistent beds. They are conservative in part for this reason, but largely because they include only coal near the outcrops.

The total of 28,378 million tons is for original resources in the ground before mining began. The accumulative production in Utah from the beginning of mining to January 1, 1963, is about 274 million tons. Assuming that past and future losses in mining will equal production, the recoverable resources as of January 1, 1963, total roughly 14,000 million tons. By comparison, production in 1962 was a little more than 4 million tons.

Working on a more generalized basis and from a broader point of view, Campbell (1929) estimated that the original coal resources of Utah total 93,340 million tons. This estimate includes coal in beds to a minimum thickness of 14 inches and to a maximum depth of 3,000 feet below the surface. In the writer's opinion, this figure is large for the stated parameters, and would be more appropriate if it were considered to include coal to a maximum depth of 6,000 feet below the surface, which would allow for much deeply buried coal in the Uinta Basin and in the Wasatch Plateau field. Although no special accuracy is claimed for the Campbell figure it is indicative of the vast amount of coal that is potentially present in the full thickness and extent of coal-bearing rocks in Utah.

OIL AND NATURAL GAS

(By W. C. Gere, G. W. Horton, J. N. Harstead, and D. F. Russell, Salt Lake City, Utah)

Through 1962, Utah has produced some $553 million worth of oil and gas, almost entirely from fields in the eastern part of the State (fig. 13). More than 90 percent of this has been produced since 1956, when pipeline facilities became available to the major fields (fig. 14). Oil has accounted for almost 90 percent of the total value, and in 1961, Utah ranked 11th in the Nation in oil production and 14th in gas production. Output has declined somewhat since 1959, as the result of depletion of reserves in southeastern San Juan County, together with lessened exploration activity.

Utah's petroleum refineries can process as much as 104,500 barrels of crude oil daily into a wide variety of products ranging from aviation fuel to stove oil. These products are marketed mainly in Utah, Idaho, and Washington with lesser markets in other western states. In addition, crude oil and natural gas are sent by pipeline to Texas, New Mexico, and California for refining and marketing.

Some 90 percent of the State is underlain by sedimentary rocks that are potentially valuable for oil and gas, including some areas in western Utah where the favorable rocks are covered by later volcanic rocks. In the other 10 percent of the State, intrusive igneous rocks and Precambrian rocks are present, and these are not considered favorable for petroleum.

The oil and gas in Utah's fields have been derived by decay and distillation from organic debris that accumulated along with rock-forming debris in a variety of geologic environments. Plant and

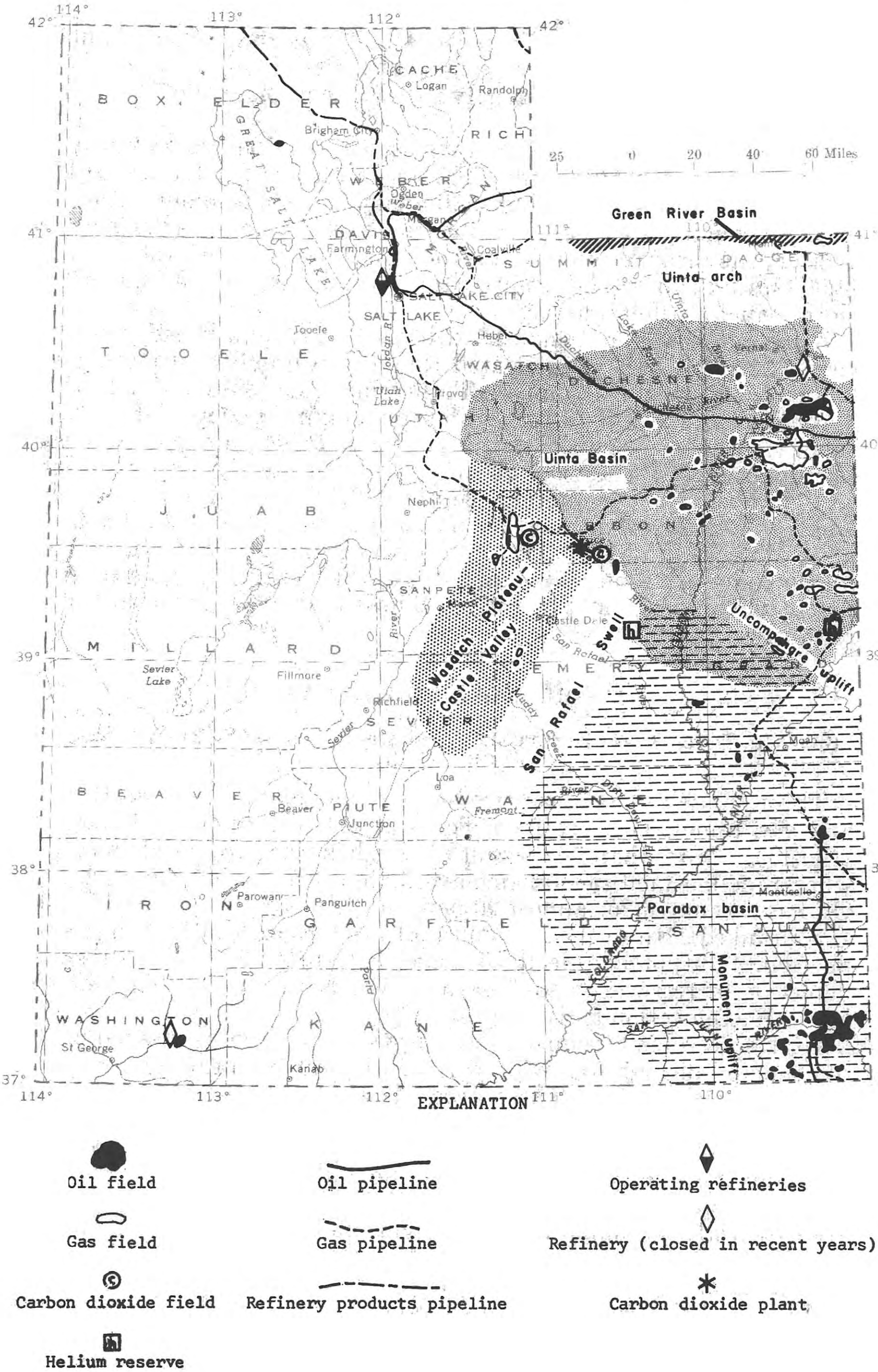


FIGURE 13.—Oil and gas fields in Utah.

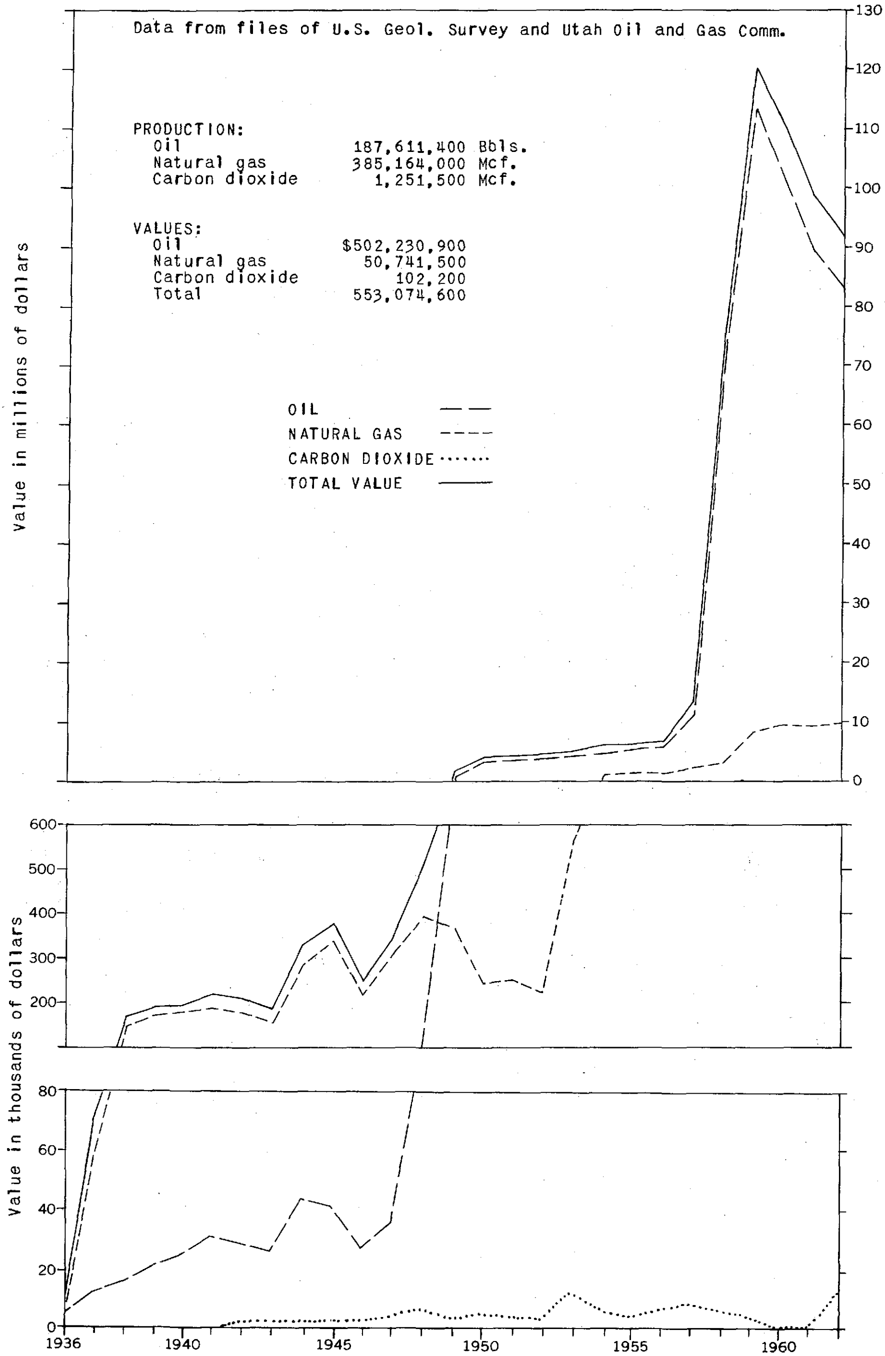


FIGURE 14.—Production and value of oil and gas in Utah.

animal remains buried on the floors of oceans, lakes, and swamps have been subsequently compacted, folded, and subjected to widely different conditions of heat and pressure for differing periods of time. Gaseous and fluid hydrocarbons that developed in these processes tended to migrate into pore spaces and fractures, and ultimately when an impermeable barrier was encountered, they accumulated in reservoirs of many kinds. Gas and lighter oils move most easily, thus in part separating from the more viscous hydrocarbons. Entrapment may have been structural, in that a barrier was formed by folding or faulting of the rocks, or it may have been stratigraphic by decreases in porosity because of vertical and horizontal changes in rock composition. Subsequent breaching of the barrier in some reservoirs by erosion or by earth movements may have allowed the escape of oil and gas to the surface, as indicated by oil seeps and bituminous sandstones. The driving force that moves oil or gas through rocks may be gravity, or water or gas pressure, and, in oilfield usage, this force is called drive.

Crude oil is classified as asphalt base, napthene base, paraffin base, aromatic, and mixed; these oils are highly fluid to highly viscous, colorless to amber, green, or black and no oils occurring in different reservoirs are exactly alike. Industry rates crude oil on the basis of its gravity under standards adopted by the American Petroleum Institute (API). The lighter gravity oils are more valuable because of their use in fuel, especially gasoline, for which the demand is great. Oils containing sulfur compounds are less valuable because they are toxic, corrosive to equipment, and are more difficult to handle and refine. The standard unit of production is the barrel, equivalent to 42 U.S. gallons.

Industry applies the term "natural gas" to all varieties of gases produced from rock in which the paraffin series of hydrocarbons predominates (U.S. Bur. of Mines, 1960, p. 595). Methane (CH_4) is the principal constituent along with some ethane, propane, butane, pentane, and hexane, and contaminants such as nitrogen, carbon dioxide, hydrogen sulfide, helium, and other rare gases. The standard volumetric unit used by the gas industry is a thousand cubic feet (Mcf). Owing to decreasing pressure during production, some of the gases liquefy and are collected separately at the wellhead as condensate. Condensate and the low volatile refinery products are referred to as liquefied petroleum gas or L.P.G. Gases are classified as "dry" or "wet" according to the amount of contained liquid, and are further classified as "sweet" or "sour" according to the relative absence or presence of hydrogen sulfide. The presence of hydrogen sulfide, nitrogen, and carbon dioxide are generally deleterious to natural gas, because of the reduced heat value and the higher temperature required for combustion. However, when any of these gases occur in sufficient quantity or purity they are recoverable and marketable. Hydrogen sulfide is indirectly marketable as sulfur, its principal constituent, which is used mostly in the manufacture of sulfuric acid. Nitrogen is utilized principally in the manufacture of ammonia, and carbon dioxide is utilized principally in the manufacture of dry ice. Helium is the most abundant of the so-called noble or highly inert gases and occurs in low concentration in natural gas. It presently is used mainly for welding and for other industrial and medicinal purposes.

Sporadic search for oil and gas in Utah was not significantly successful until intensive exploration following World War II resulted in major production. Because of its late arrival in the ranks of major producing states, Utah has benefitted greatly from production and conservation practices developed over many years in other states. A large number of wells have been drilled under unit agreements, in which two or more interested parties vest their operating rights in a single oil or gas field to a single operator, thus eliminating waste and expense. These unitization agreements greatly simplify the installation of production regulating systems and secondary recovery systems which facilitate and extend production.

The first discovery of gas was accidental when, in 1891, it was encountered in the Farmington Bay area, Davis County, during the drilling of a water well. Gas from the Farmington field was delivered to the Salt Lake City area by means of a wooden pipeline during 1895 and 1896. Early exploration for oil in Utah, however, was guided by the location of oil seeps. Attempts to develop the Rozel Point seep were initiated in 1904 and other attempts to develop other seeps had been established, by 1907, in the Virgin and Mexican Hat fields. These early ventures proved uneconomical and later oil and gas exploration was guided by concepts that evolved largely through subsequent experience. Three requirements were recognized as necessary for oil and gas reservoirs: source beds for the generation of the hydrocarbons; porous rocks to serve as reservoirs; and structures such as anticlinal folds, domes, and stratigraphic pinchouts to effect the entrapment of oil and gas. Later successful developments in various fields are described progressively from north to south, by petroleum provinces, in accordance with the approximate chronology of the development of oil and gas in the state. (See table 3.)

Table 3.--Summary of oil and gas fields in Utah

[API, American Petroleum Institute; bbls, barrels; Mcf, thousand cubic feet]

Field index No.	Province, field, county, township and range[1]	Discovery date	Date shut in ( ) or abandoned	Total production through 1962: Oil (bbls)	Distillate (bbls)	Natural gas (Mcf)	Gravity° (API)	Btu	Reservoir formation ( )[2] and number of productive wells	Average depth of pay	Deepest penetration	Deepest formation tested ( )[2]	Type of trap[3]	Rock type[4]	Type of drive[5]
	Green River Basin														
1	Clay Basin, Daggett (3 N., 24 E.)	1927	---------	0	244,990	94,840,897	55	1,090	Frontier (K) 2	5,395	9,355	Weber IP	Stl	Ss	G&W
		1935	---------				55	1,080	Dakota (K) 8	5,603	-------	---------	do.	do.	Do.
	Uinta Basin														
2	Agate, Grand (20 S., 24 E.)	1961	---------	35,370	0	0	No data	-------	Morrison (J) 4	1,550	1,612	Morrison (J)	Sta	do.	SG
3	Agency Draw, Uintah (13 S., 21 E.)	1962	---------	1,202	0	0	No data	-------	Wasatch (T) 1	3,810	7,433	Mesaverde (K)	do.	do.	Do.
4	Ashley Valley, Uintah (5 S., 22 E.)	1925	1941	0	0	536,366	-------	No data	Morrison (J) 2	4,100	6,393	Madison (M)	Stl	do.	G
		1948	---------	13,068,018	0	0	30.0-30.8	-------	Park City-Weber (IP&P) 29	-------	-------	---------	do.	Do & Ss	W
5	Bar-X, Grand (17 S., 25-26 E.)	1955	---------	0	0	7,395,953	-------	1,045	Dakota (K) 6	3,252	5,530	Granite (pЄ)	Sta	Ss	G
		1955	---------				-------	1,045	Cedar Mtn. (K) 8	3,159	-------	---------	do.	do.	Do.
		1954	---------				-------	1,005	Morrison (J) 6	3,314	-------	---------	do.	do.	Do.
		1948	---------				-------	486	Entrada (J) 2	3,551	-------	---------	Stl	do.	W
6	Bend, Uintah (7 S., 22 E.)	1959	(1959)	0	0	0	-------	997	Uinta (T) 1	2,875	2,945	Uinta (T)	Sta	do.	G
7	Bitter Creek area, Uintah (8 S., 21-22 E. & 9 S., 20-23 E. & 10 S., 18-22 E.)	1955	---------	0	10,683	7,237,971	-------	1,100	Wasatch (T) 58	5,500	11,500	Mancos (K)	do.	do.	Do.
		1956	(1956)				28.2	-------	Green River (T) 1	3,570	-------	---------	do.	do.	Do.
		1953	---------				48.0	No data	Mesaverde (K) 2	7,845	-------	---------	do.	do.	Do.

8	Bluebell, Duchesne (1 S., 2 W., USM)	1954	(1958)	0	0	39,016	-------	1,057	Green River (T) 1	8,000	9,728	Green River (T)	do.	do.	Do.
9	Book Cliffs, Grand (18 S., 22 E.)	1961	(1961)	0	0	0	-------	No data	Dakota (K) 2	5,267	5,700	Morrison (J)	do.	do.	Do.
10	Brennan Bottom, Uintah (7 S., 20 E.)	1954	---------	436,327	0	0	31-33	-------	Green River (T) 4	7,100	8,000	Wasatch (T)	do.	Ls	SG
11	Buck Canyon, Uintah (12 S., 21-22 E.)	1961	---------	0	0	41,000	-------	No data	Wasatch (T) 5	5,204	8,294	Mancos (K)	do.	Ss	G
12	Castle Peak, Duchesne (9 S., 15 E.)	1962	---------	1,319	0	0	No data	-------	Green River (T) 3	4,600	8,816	Wasatch (T)	do.	do.	SG
13	Chokecherry, Duchesne (7 S., 4 W., USM)	1959	1961	6,620	0	0	37.2	-------	Green River (T) 1	4,100	8,559	Mesaverde (K)	do.	do.	W
14	Cisco Dome, Grand (20 S., 21-22 E.)	1925	1944	0	0	3,137,948	-------	1,083	Dakota (K)	2,000	4,744	Granite (p6)	do.	do.	G
							-------	1,090	Cedar Mtn. (K) 16	2,130	-------	---------	do.	do.	Do.
							-------	1,100	Morrison (J)	2,300	-------	---------	do.	do.	Do.
15	Cisco Townsite, Grand (21 S., 23 E.)	1954	1961	1,735	0	8,379	34.8	1,088	Morrison (J) 9	619	1,500	Entrada (J)	do.	do.	No data
16	County, Duchesne (3 S., 5 W., USM)	1953	1954	32,757	0	0	23.7	-------	Green River (T) 2	4,850	5,257	Green River (T)	do.	Sh & St	SG & W
17	Coyote Wash, Uintah (8 S., 24 E.)	1960	(1960)	0	0	0	-------	No data	Wasatch (T) 1	4,910	8,530	Mancos (K)	do.	Ss	G
18	Diamond Ridge, Grand (17 S., 22 E.)	1960	(1960)	0	0	0	-------	No data	Cedar Mtn. (K) 1	7,269	7,700	Morrison (J)	do.	do.	Do.
		1961	(1961)	0	0	0	-------	-------	Morrison (J) 1	7,400	-------	---------	------	do.	------

Table 3.--Summary of oil and gas fields in Utah--Continued

[API, American Petroleum Institute; bbls, barrels; Mcf, thousand cubic feet]

Field index No.	Province, field, county, township and range[1]	Discovery date	Date shut in ( ) or abandoned	Total production through 1962: Oil (bbls)	Distillate (bbls)	Natural gas (Mcf)	Gravity° (API)	Btu	Reservoir formation ( )[2] and number of productive wells	Average depth of pay	Deepest penetration	Deepest formation tested ( )[2]	Type of trap[3]	Rock type[4]	Type of drive[5]
	Uinta Basin--Continued														
19	Duchesne, Duchesne (4 S., 4 W., USM)	1963	---------	0	0	0	-------	No data	Uinta (T) 1	1,900	-------	Green River-Wasatch transitional zone (T)	Sta	Ss	G
		1958	---------		0	0	21.5-23.6	-------	Green River (T) 4	3,070	-------		do.	Sh & St	SG & W
		1951	1958	216,224	0	0	41.7-42.9	-------	Green River-Wasatch (T) 2	7,550	7,596		do.	do.	Do.
20	Eight Mile Flat, Duchesne (10 S., 17 E.)	1962	---------	8,702	0	0	37	-------	Green River (T) 1	5,210	8,200	Wasatch (T)	do.	Ss	SG
21	Farnham Dome[6], Carbon (15 S., 11-12 E.)	1924	---------	0	0	2,251,557	-------	(6)	Navajo (J) 4	3,000	8,509	Granite (pЄ)	Stl	do.	G
							-------	(6)	Moenkopi (TR) 1	4,498	-------	---------	do.	do.	Do.
22	Fence Canyon, Uintah (15 S., 22 E. & 15½ S., 23 E.)	1960	(1960)	0	0	0	-------	No data	Dakota (K) 3	8,167	10,350	Granite (pЄ)	Sta	do.	Do.
		1961	(1961)	0	0	0	-------	No data	Cedar Mtn. (K) 2	8,249	-------	---------	do.	do.	Do.
		1961	(1961)	0	0	0	-------	No data	Morrison (J) 1	8,520	-------	---------	do.	do.	Do.
23	Flat Mesa, Duchesne (3 S., 5 W., USM)	1952	1958	50,890	0	0	41.8	-------	Green River (T) 1	8,860	9,103	Green River (T)	do.	do.	SG
24	Flat Rock, Uintah (14 S., 20 E.)	1963	---------	0	0	0	50.0	-------	Wasatch (T) 1	3,805	6,792	Mancos (K)	do.	do.	Do.
25	Grassy Trail, Emery (15-16 S., 12 E.)	1961	---------	31,996	0	0	38.7-40.1	-------	Moenkopi (TR) 5	3,900	7,930	Madison (M)	Stl	Ca	Do.

26	Gusher, Uintah (5 S., 19 E. & 6 S., 20 E.)	1949	1960	29,695	0	0	32.8-35.4	-------	Green River (T)	2	8,000	9,757	Wasatch (T)	Fr	Sh & St	Do.
27	Harley Dome[7/], Grand (18 S., 24-25 E., 19 S., 25 E.	1959	1962	638	0	0	36.8	-------	Mancos (K)	1	2,494	2,518	Mancos (K)	Fr ?	Ss	G
		1925	1925	0	0	0	-------	(7)	Entrada (J)	No data	No data	-------	---------	No data	do.	No data
28	Horse Point, Grand (16 S., 23 E.)	1962	(1962)	0	0	0	-------	No data	Dakota (K)	1	7,985	8,774	Entrada (J)	Sta	do.	G
29	Jack Canyon, Carbon (12 S., 16 E.)	1954	---------	2,651	0	0	28-34	-------	Wasatch (T)	2	3,077	3,621	Wasatch (T)	do.	do.	SG
30	Moon Ridge, Grand (16 S., 21 E.)	1962	(1962)	0	0	0	-------	No data	Cedar Mtn. (K)	1	10,205	10,301	Morrison (J)	Fr ?	do.	G
31	Nine Mile Canyon, Carbon (12 S., 15 E.)	1962	(1962)	0	0	0	-------	No data	Wasatch (T)	1	3,913	8,450	Mesaverde (K)	Sta	do.	Do.
32	Oil Springs, Uintah (12 S., 24 E.)	1962	(1962)	0	0	0	-------	No data	Wasatch (T)	2	2,978	5,735	Mancos (K)	do.	do.	Do.
33	Pariette Bench, Uintah (9 S., 19 E.)	1962	---------	19,170	0	0	29	-------	Green River (T)	2	7,894	6,660	Wasatch (T)	do.	do.	SG
34	Pear Park, Grand (18 S., 23 E.)	1961	(1961)	0	0	0	-------	No data	Dakota (K)	1	6,854	6,174	Morrison (J)	do.	do.	G
35	Peters Point, Carbon (12-13 S., 16-17 E.)	1953	(1953)	0	0	0	-------	1,026	Wasatch (T)	3	3,619	5,140	Wasatch (T)	Sta & Stl	do.	Do.
36	Red Wash, Uintah (7-8 S., 21-24 E.)	1951	---------	24,687,801	0	31,491,392	20.0-32.6	1,050	Green River (T)	250	5,500	11,288	Mancos (K)	Sta	do.	G & SG

Table 3.--Summary of oil and gas fields in Utah--Continued

[API, American Petroleum Institute; bbls, barrels; Mcf, thousand cubic feet]

Field index No.	Province, field, county, township and range[1]	Discovery date	Date shut in ( ) or abandoned	Total production through 1962: Oil (bbls)	Distillate (bbls)	Natural gas (Mcf)	Gravity° (API)	Btu	Reservoir formation ( )[2] and number of productive wells	Average depth of pay	Deepest penetration	Deepest formation tested ( )[2]	Type of trap[3]	Rock type[4]	Type of drive [5]
	Uinta Basin--Continued														
37	Rock House, Uintah (11 S., 22-24 E.)	1960	---------	0	4,349	1,925,207	No data	No data	Wasatch (T) 14	4,200	7,384	Mancos (K)	Sta	Ss	G
		1960	---------				-------	-------	Mesaverde (K) 5	5,200	-------	---------	do.	do.	Do.
38	Roosevelt, Uintah 1 S., 1 W., USM)	1949	---------	2,211,778	0	0	30.0-36.4	-------	Green River and Wasatch (T) 9	9,515	11,888	Wasatch (T)	do.	Ss, Sh, St	SG & W
39	San Arroyo, Grand (16 S., 24-26 E.)	1963	---------	0	156	662,749	34.5	-------	Mancos (K) 2	2,871	5,810	Granite (p€)	Fr	Ss	No data
		1955	---------				-------	1,085	Dakota (K) 18	5,032	-------	---------	Sta	do.	G
		1959	---------				-------	No data	Cedar Mtn. (K) 12	5,802	-------	---------	do.	do.	Do.
		1962	---------				-------	No data	Morrison (J) 5	5,802	-------	---------	do.	do.	Do.
		1955	---------				-------	633	Entrada (J) 5	5,664	-------	---------	Stl	do.	Do.
40	Segundo Canyon, Grand (16-17 S., 21 E.)	1962	(1962)	0	0	0	50	-------	Mancos (K) 1	6,725	9,900	Morrison (J)	No data	do.	Do.
		1963	(1963)	0	0	0	-------	No data	Cedar Mtn. (K) 1	9,849	-------	---------	------	------	------
41	Seiber Nose, Grand (20 S., 24 E.)	1955	1961	13,513	0	0	38.0	-------	Morrison (J) 1	1,434	1,439	Morrison (J)	Sta	do.	SG
42	Southman Canyon, Uintah (10 S., 23-24 E.)	1955	---------	0	0	2,620	57-61	No data	Wasatch (T) 2	4,670	8,502	Mancos (K)	do.	Ss	G
		1957	---------				-------	No data	Mesaverde (K) 2	6,133	-------	---------	do.	do.	Do.
43	Starr Flat, Duchesne (1 N., 2 W., USM)	1959	1960	11,027	0	0	31.5	-------	Green River (T) 1	10,100-10,160	13,354	Mesaverde (K)	do.	do.	SG
44	Stone Cabin, Carbon (12 S., 14 E.)	1958	---------	0	0	230,795	-------	1,190	Wasatch (T) 2	4,705	5,515	Wasatch (T)	do.	do.	W

45	Sweetwater Creek, Uintah (14 S., 22 E.)	1963	---------	0	0	0	45	No data	Wasatch (T) 1	1,827	2,165	Wasatch (T)	do.	do.	G
46	Walker Hollow, Uintah (7 S., 23 E.)	1955	(1955)	0	0	0	-------	No data	Uinta (T) 4	2,750	6,004	Wasatch (T)	do.	do.	Do.
47	West Pleasant Valley, Duchesne (8 S., 16 E.)	1952	1955	2,192	0	0	44	-------	Green River (T) 1	6,000	7,240	Wasatch (T)	Sta & Stl	do.	SG
48	Westwater-Bryson Canyon, Grand (17 S., 23-24 E.)	1957	---------	0	35,742	4,762,371	-------	1,130	Castlegate (K) 11	1,092	6,471	Entrada (J)	Stl	do.	W
		1957	---------				-------	1,086	Dakota (K) 10	5,078	-------	---------	Sta	do.	G
		1959	---------				-------	No data	Cedar Mtn. (K) 4	4,520	-------	---------	do.	do.	Do.
		1959	---------				-------	1,034	Morrison (J) 5	5,102	-------	---------	do.	do.	Do.
		1959	---------				-------	785	Entrada (J) 4	5,986	-------	---------	Stl	do.	W
	<u>Wasatch Plateau-Castle Valley</u>														
49	Clear Creek, Carbon & Emery (12-14 S., 7 E.)	1951	---------	0	0	106,899,375	-------	910	Ferron (K) 16	4,700	7,010	Morrison (J)	do.	do.	G&W
50	Ferron, Emery (20-21 S., 7 E.)	1957	(1957)	0	0	0	-------	1,040	Ferron (K) 4	726	3,386	Entrada (J)	Stl & Sta	do.	SG & W
51	Flat Canyon, Emery (16 S., 6 E.)	1953	---------	0	0	678,730	-------	1,086	Ferron (K) 3	5,900	7,580	Dakota (K)	do.	do.	G
		1953	1958				-------	1,151	Dakota (K) 1	7,020	-------	---------	do.	do.	Do.
52	Gordon Creek[6/], Carbon (14 S., 7-8 E.)	1952	(1952)	0	0	0	-------	966	Ferron (K) 1	3,500	12,293	Hermosa (IP)	Stl	do.	No data
		1948	(1948)	0	0	0	-------	(6)	Moenkopi (TR) 2	10,900	-------	---------	do.	Ca	Do.
		1948	(1948)	0	0	0	-------	(6)	Coconino (P) 1	11,858	-------	---------	do.	Ss	Do.
53	Joe's Valley, Sanpete (15 S., 6 E.)	1955	(1961)	0	0	2,980,498	-------	No data	Ferron (K) 1	6,784	7,800	Dakota (K)	do.	do.	G
		1957	(1961)	0	0	0	-------	No data	Dakota (K) 1	8,040	-------	---------	do.	do.	Do.

Table 3.--Summary of oil and gas fields in Utah--Continued

[API, American Petroleum Institute; bbls, barrels; Mcf, thousand cubic feet]

Field index No.	Province, field, county, township and range1/	Discovery date	Date shut in ( ) or abandoned	Total production through 1962: Oil (bbls)	Distillate (bbls)	Natural gas (Mcf)	Gravity° (API)	Btu	Reservoir formation ( )2/ and number of productive wells	Average depth of pay	Deepest penetration	Deepest formation tested ( )2/	Type of trap3/	Rock type4/	Type of drive 5/
	Paradox Basin														
54	Akah, San Juan (42 S., 22 E.)	1955	---------	296,096	0	0	34	-------	Hermosa (ℙ) 2	5,045	5,975	Ouray (D)	Stl & Sta	Ls	W & SG
55	Aneth area, San Juan (40-41 S., 23-25 E. & 42 S., 24 E.)	1956	---------	135,367,019	0	109,318,147	31.2-43.5	1,450-1,485	Hermosa (ℙ) 548	5,540	7,885	Unnamed (p€)	do.	Ls & Do	SG
56	Anido Creek San Juan (43 S., 23-24 E.)	1960	---------	396,500	0	0	41.8-42.7	-------	Hermosa (ℙ) 4	5,266	6,611	Leadville (M)	Sta	Ls	Do.
57	Barlett Flat, Grand (25 S., 19 E.)	1962	---------	117,172 (57 and 58 combined)	0	0	43	-------	Hermosa (ℙ) 1	7,230	7,243	Hermosa (ℙ)	FrS	Sh	Do.
58	Big Flat, Grand (26 S., 19 E.)	1957	---------				40.3-43.9	-------	Leadville (M) 3	7,734	8,600	Unnamed (€?)	Stl & Sta	Do & Ls	W&G
59	Big Indian, San Juan (29 S., 24 E.)	1961	(1961)	0	0	0	68.6	-------	Leadville (M) 1	10,150	11,143	Ignacio (€)	Stl	do.	SG
60	Bluff, San Juan (40 S., 23 E.)	1956	---------	409,150	0	411,151	38.8-42.3	1,100	Hermosa (ℙ) 6	5,515	7,156	Leadville (M)	Sta	Ca	Do.
61	Bluff Bench, San Juan (40 S., 22 E.)	1957	1961	22,755	0	0	37-41	-------	Hermosa (ℙ) 3	5,453	6,780	do.	do.	Ls	Do.
62	Boundary Butte, San Juan (43 S., 22 E.)	1948 1948	--------- ---------	104,578	0	1,248,580	36-42 36-48	No data 800-900	Coconino (P) 7 Hermosa (ℙ) 9	1,549 4,479	6,129 -------	Unnamed (€) ---------	Stl Stl & Sta	Ss Ls	W G
63	Broken Hills, San Juan (40 S., 22 E.)	1960	---------	19,347	0	0	35	-------	Hermosa (ℙ) 1	5,730	5,884	Hermosa (ℙ)	Sta	Ca	SG

64	Cane Creek, Grand (26 S., 20 E.)	1959	(1959)	0	0	0	42	-------	do.	6,656	8,005	Elbert (D)	FrS	Sh	Do.
65	Chinle Wash, San Juan (43 S., 21 E.)	1957	(1957)	0	0	0	-------	No data	Hermosa (ℙ) 2	4,890	6,385	Leadville (M)	Sta	Ca	G
66	Cleft, San Juan (43 S., 21 E.)	1962	1963	2,102	0	548	39.3	No data	Leadville (M) 1	5,916	6,218	Leadville (M)?	No data	do.	SG
67	Cone Rock, San Juan (42 S., 26 E.)	1959	1960	877	0	0	40.0	-------	Hermosa (ℙ) 1	6,125	6,200	Hermosa (ℙ)	No data	do.	No data
68	Desert Creek, San Juan (41 S., 23 E.)	1954	---------	302,805	0	97,100	40.0-40.1	1,425	Hermosa (ℙ) 2	5,386	7,230	Leadville (M)?	Sta	Ls & Do	SG
69	Gothic Mesa, San Juan (40 S., 22 E. & 41 S., 22-23 E.)	1956	---------	220,501	0	0	39.5-44.5	-------	Hermosa (ℙ) 22	5,639	5,985	Hermosa (ℙ)	do.	Ca	G
70	Grayson, San Juan (38 S., 22 E.)	1959	1963	4,818	0	0	38-41.8	-------	Hermosa (ℙ) 2	5,800	6,120	Hermosa (ℙ)	do.	do.	SG
71	Hatch, San Juan (38 S., 24 E.)	1957	---------	14,505	0	0	42.4	-------	Hermosa (ℙ) 1	5,977	6,234	do.	do.	do.	Do.
72	Hogan, San Juan (41 S., 22 E.)	1962	1963	0	0	0	42.0	-------	do.	5,479	5,715	do.	do.	do.	Do.
73	Ismay, San Juan (40 S., 25-26 E.)	1956	---------	3,646,993	0	3,847,882	37-46.4	No data	Hermosa (ℙ) 50	5,667	7,410	Leadville (M)	do.	Ls	Do.
74	Lisbon, San Juan (30 S., 24 E.)	1960	---------				46.5	No data	Hermosa (ℙ) 1	5,061	10,706	(Probable Є)	Fr	Sh	G
		1959	---------				50-71	835-1,207	Leadville (M) 20	8,531	-------	---------	Stl	Do	SG & W
		1960	---------	2,294,529	0	4,875,087 7/	46-53	No data	Ouray (D) 2	9,181	-------	---------	do.	Ls	No data
		1960	---------				54	No data	Elbert (D) 1	8,853	-------	---------	do	Do	Do.
		1959	---------				45.1-45.2	No data	McCracken (D) 2	8,304	-------	---------	do.	Ss	G
75	Little Valley, San Juan (30 S., 25 E.)	1963	---------	0	0	0	-------	No data	Hermosa (ℙ) 1	4,324	9,560	Leadville (M)	No data	Ca	SG
		1961	1961	0	0	0	46	-------	Leadville (M) 1	9,367	-------	---------	------	Ls & Do	Do.

Table 3.--Summary of oil and gas fields in Utah--Continued

[API, American Petroleum Institute; bbls, barrels; Mcf, thousand cubic feet]

Field index No.	Province, field, county, township and range[1]	Dis-covery date	Date shut in ( ) or abandoned	Total production through 1962			Gravity° (API)	Btu	Reservoir formation ( )[2] and number of productive wells	Average depth of pay	Deepest pene-tration	Deepest formation tested ( )[2]	Type of trap[3]	Rock type[4]	Type of drive[5]
				Oil (bbls)	Dis-tillate (bbls)	Natural gas (Mcf)									
	Paradox Basin--Continued														
76	Long Canyon, Grand (26 S., 20 E.)	1962	---------	30,572	0	0	41.5	No data	Hermosa (IP) 2	6,866	8,132	Leadville (M)	Fr	Sh	SG
77	Mexican Hat, San Juan (42 S., 19 E.)	1908	1956	17,292	0	0	36.9-40.7	-------	Rico (P) 3	500	1,425?	Hermosa (IP)	Sta	Ss	Gr
							38.4	-------	Hermosa (IP) 10	600	-------	---------	do.	do.	Do.
78	Recapture Creek, San Juan (40 S., 23 E.)	1956	---------	375,364	0	538,323	41-42	No data	Hermosa (IP) 4	5,436	7,050	Leadville (M)	do.	Ca	SG
79	Salt Wash, Grand (23 S., 17 E.)	1961	---------	100,925	0	0	50.4-56.2	-------	Leadville (M) 6	8,795	9,528	Lynch (Є)	Stl & Sta	Ls & Do	W&G
80	Shafer Canyon, San Juan (27 S., 20 E.)	1962	---------	8,013	0	0	39.7	-------	Hermosa (IP) 2	5,995	6,198	Hermosa (IP)	No data	Sh	SG
81	Tohonadla, San Juan (41 S., 21-22 E. & 42 S., 21 E.)	1957	---------	884,880	0	6,413	36-41	No data	Hermosa (IP) 12	5,257	6,345	Elbert (D)	Sta	Ca	Do.
82	Turner Bluff, San Juan (40 S., 22 E.)	1957	1961	14,009	0	1,749	46	No data	Hermosa (IP) 1	5,416	5,795	Hermosa (IP)	do.	do.	Do.
83	Tenneco USA Harris 1, San Juan (39 S., 21 E.)	1962	---------	196	0	0	No data	-------	do.	5,404	5,547	do.	do.	do.	Do.
84	Alco Cottonwood Creek A1, San Juan (39 S., 22 E.)	1962	1963	406	0	0	No data	-------	do.	5,608	5,836	do.	do.	do.	Do.

85	Kingwood Oil Lime Ridge Unit 1, San Juan (40 S., 20 E.)	1958	(1958)	0	0	0	-------	No data	do.		1,294	3,357	Ophir (Є)	do.	do.	G
	Basin and Range and other fields															
86	Farmington, Davis (3 N., 1 W.)	1891	1898	0	0	150,000	-------	833	Lake beds (Q)	No data	400-700	3,525	Salt Lake (T)	do.	Ss	Do.
87	Last Chance, Emery (26 S., 7 E.)	1934	1949	0	0	0	-------	840	Moenkopi (TR)	1	2,650	6,704	Lynch (Є)	Stl	do.	Do.
88	Rozel Point, Box Elder (8 N., 7 W.)	1904	1952	No data	0	0	1.1	-------	Salt Lake (T)	No data	125-300	3,600	Salt Lake (T)	No data	Ba & Ls	No data
89	Virgin, Washington (41 S., 11-12 W.)	1907	---------	199,569	0	0	30-35.7	-------	Moenkopi (TR)	27	610	4,538	Redwall (M)	Sta	Ca	Gr
90	Woodside[8], Emery (19 S., 13-14 E.)	1924	1926	0	0	0	-------	(8)	Coconino (P)	1	142	8,431	Tintic (Є)	Stl	Ss	No data

1/ Refers to Salt Lake Meridian except where Uinta Special Meridian (USM) is noted.

2/ Geologic ages are coded: Q, Quaternary; T, Tertiary; K, Cretaceous; J, Jurassic; TR, Triassic; P, Permian; IP, Pennsylvanian; M, Mississippian; D, Devonian; S, Silurian; O, Ordovician; Є, Cambrian; pЄ, Precambrian.

3/ Trap types are coded: Stl, structural; Sta, stratigraphic; Fr, fracture; and FrS, fracture system.

4/ Rock types are coded: Ss, sandstone; Sh, shale; St, siltstone; Ls, limestone; Do, dolomite; Ca, carbonate; and Ba, basalt.

5/ Types of drives are coded: G, gas; W, water; SG, solution gas; and Gr, gravity.

6/ Carbon dioxide field.

7/ May include recycled gas.

8/ Helium field.

GREEN RIVER BASIN PROVINCE

The Green River Basin province is a large sedimentary and topographic basin in southwestern Wyoming, with a thin strip extending into northeast Utah along the north flank of the Uinta Mountains (fig. 13). The stratigraphic section in Utah is about 11,000 feet thick in the eastern part of the basin and probably thickens to 13,000 feet to the western part. Paleozoic rocks of the basin are primarily limestone with some sandstone and shale. The overlying Mesozoic and Tertiary rocks consist of interbedded sandstone shale and carbonate rocks. The regional dip is northward, but this is complicated by several faults and folds.

The Clay Basin gasfield, in the northeast corner of Daggett County, is the only producing field in the Utah part of the Green River Basin. The field was discovered in 1927 and production started in 1937, with completion of a pipeline to the Salt Lake Valley. Gas and distillate are structurally trapped, with production coming from sandstones in the Frontier and Dakota Formations of Late Cretaceous age. The deepest test penetrated the Weber Sandstone of Pennsylvanian age, and encountered a high amount of nitrogen and carbon dioxide. Decline in reservoir pressure exhibited at Clay Basin gasfield indicates the drive is due to gas expansion (Fidlar, 1963, p. 182). Except for a few scattered wells, only the eastern part of the Utah portion of the Green River Basin has been explored, and generally it has not been tested below the Cretaceous rocks.

UINTA BASIN PROVINCE

The Uinta Basin is in the northern part of the Colorado Plateaus province (see fig. 4), and generally it is restricted within eroded edges of the Tertiary rocks, but it is extended here to include the surface outcrops of the underlying Cretaceous rocks, which also reflect the basin structure. This extension along the southern margin allows the inclusion of the oil and gas fields in the "Mancos shelf" area (see figs. 6 and 13), which are related to the basin structure.

The maximum thickness of the stratigraphic section in the Uinta Basin is about 26,000 feet. The Paleozoic rocks are predominantly limestone with lesser amounts of shale and sandstone. The Mesozoic rocks consist of interbedded sandstone and shale, and, in the western part of the basin, some limestone. Tertiary rocks include sandstone, shale, and some carbonate rock. The asymmetric Uinta Basin formed during the early Tertiary. The northern part is deepest and the axis trends easterly irregularly. Folds and faults generally are rather local features except for the Uncompahgre uplift (fig. 13), a large anticlinal structure that extends northwesterly under the southern part of the basin.

The first discovery in the Uinta Basin was a carbon dioxide field in the Jurassic and Triassic(?) Navajo Sandstone in the Farnham dome, Carbon County, made in 1924. The gas was not produced, however, until the early "forties." At Harley dome gasfield, discovered in 1925, a show of gas in the Jurassic Entrada Sandstone, contains as much as 7 percent helium. The structure was made a Federal helium reserve in 1932 but has not produced. In 1925, gas production from nonmarine sandstones of the Jurassic Morrison Formation was established in the Ashley Valley anticline, Uintah County, and from the Morrison and Cretaceous Dakota and Cedar Mountain Formations at Cisco dome, Grand County. Gas was delivered to the Vernal area from the Ashley Valley field until depletion of gas in the reservoir in 1941. Gas transmission from the Cisco dome area was not feasible, and, except for some local use, the production was used to make carbon black, a powdery form of carbon that is utilized principally in the rubber industry. The field was abandoned in 1944. Deeper drilling in the Ashley Valley anticline in 1948 resulted in the discovery of oil in the Pennsylvania Weber Sandstone and in the overlying Permian Park City Formation. This became Utah's first oilfield of much economic importance.

The emphasis in exploration changed in the late 1940's after oil and gas had been found in nonmarine sedimentary rocks in other states and after the importance of stratigraphic entrapment of oil and gas became apparent. This new emphasis was applied to exploration in the Uinta Basin with resulting discoveries of oil in the Tertiary Green River Formation in the Gusher and Roosevelt fields in 1949, and the discovery of oil and gas in the noteworthy Redwash field in 1951. Subsequently, oil has also been found in commercial quantities in the Triassic Moenkopi Formation, Jurassic Morrison, the Cretaceous Dakota, Mancos, and Mesaverde Formations, and the Teritary Wasatch Formation. Also, gas has been found in the Jurassic Entrada and Morrison Formations; in the Cretaceous Cedar Mountain, Dakota, Mancos, and Mesaverde Formations; and in the Tertiary Wasatch, Green River, and Uinta Formations. (See table 3.)

Accumulation is largely in sandstones, except for carbonate rocks in the Park City, Moenkopi, and part of the Green River Formations. The entrapment is effected largely by stratigraphic conditions, but to some extent also by structural conditions. Solution gas and water drives are active in most oil pools, and gas depletion drives are typical of most of the gas pools. The Uinta Basin is the second most productive oil and gas province in Utah. The largest output of oil and gas has come from the Redwash field, the gas being produced both with the oil and from separate gas reservoirs. Ashley Valley is the second largest producer of oil followed by Roosevelt field, Uintah County. The Bar X-San Arroyo-Westwater gas area, Grand County, is second largest in gas production followed by the Bitter Creek field, Uintah County.

The oils from the Green River Formation in the Uinta Basin are generally waxy and have a high pour point, solidifying at temperatures as high as 130° F. (Wegner and Ball, 1963, p. 501). These characteristics create many problems in the production and transportation of the crude oil. Producing wells must be treated with hot oil or reamed to prevent paraffin from clogging the well bores. The crude must be dewaxed or mixed with a low pour point oil to prevent it from solidifying in the pipeline.

The natural gas in the Uinta Basin is of good quality except for that found in the Entrada Sandstone, which is contaminated by varying amounts of carbon dioxide and nitrogen. Gas from the Entrada Formation of the San Arroyo field is treated to remove the carbon dioxide, which raises the Btu value enough to be blended with other gas and accepted at the pipeline. In the Westwater field the Btu value is higher and the Entrada gas can be blended without treatment. Another problem in gas production is the rapid decline in reservoir pressure when the wells are placed on flow.

Throughout most of the basin the Cretaceous and older formations have not been tested, except around the margins, and large areas of Tertiary rocks also are still untested especially in the western part of the basin.

WASATCH PLATEAU-CASTLE VALLEY AREA PROVINCE

The Wasatch Plateau-Castle Valley province, in central Utah (fig. 13), is an extensive area of Tertiary and Cretaceous rocks that extends southwesterly from the southwestern part of the Uinta Basin. This area is arbitrarily separated from the Uinta Basin along the drainage of the Price River and Spanish Fork Creek. The stratigraphic column in the area has a maximum thickness of about 19,000 feet and consists of Paleozoic, Mesozoic, and Tertiary rocks that are predominantly sandstone and some limestone and shale. It is a structurally complex area of numerous north-trending horsts and grabens that generally cut older structures.

In 1948, the Gordon Creek structure was drilled and substantial quantities of carbon dioxide were found in the Triassic Moenkopi and Permian Coconino Sandstone none of which has been produced. First commercial discovery of natural gas in the Cretaceous Ferron Sandstone Member of the Mancos Shale was established in the Clear Creek structure in 1951. This was followed by the discovery of gas in the Dakota Sandstone in the Flat Canyon structure and in both horizons of the Joe's Valley field. The Ferron Sandstone Member also was found to be productive of gas in the Ferron field in Castle Valley. The Clear Creek, Flat Canyon, and Joe's Valley gasfields have delivered gas to Utah Valley and the Salt Lake City distribution center.

The gas occurs in faulted folds and is in contact with a water-drive pressure system. Porosities and permeabilities of the lenticular Cretaceous Dakota Sandstone and Ferron Member vary but are generally low. The relatively large production from the Clear Creek field is attributed in part to the fractured reservoir rocks.

Future potential rests with deeper drilling of known structures to test the Paleozoic and Mesozoic rocks. Although most of the major faulted blocks appear to have been explored, a search for additional faulted structures is warranted.

PARADOX BASIN PROVINCE

The Paradox Basin province is defined as the area underlain by the Hermosa Formation, which outlines the extent of the Paradox sea of Pennsylvanian time. In addition to southeast Utah, the basin extends into parts of Colorado, New Mexico, and Arizona. The stratigraphic section in the basin in Utah is about 24,000 feet thick and is mainly salt, anhydrite, carbonate rock, shale, and sandstone. There is considerable faulting in the central and northern parts of the basin, in the area of the salt accumulations, along northwesterly trending faults. This area and the area immediately to the northeast contain the thickest accumulations of sedimentary rocks. The southern part of the basin is folded locally and contains some faults.

Of major importance is the Hermosa Formation which consists of a variety of carbonate rocks, sandstone, carbonaceous shale, and evaporites that intertongue along the northeast side of the basin with arkosic rocks of the Cutler Formation. The Hermosa rocks are rich in organic material, and represent deposition of sediments in a restricted marine environment. While salt was being deposited in the central part of the basin, fossil debris accumulated in the southern part along with fine-grained carbonates. The faulting in the northern part of the basin began prior to the deposition of the Hermosa formation, and continued throughout most of Hermosa time, modifying the salt thickness and resulting in the formation of salt anticlines.

The productive history commenced in 1907 with the output of oil at the Mexican Hat field from sandstone in the Hermosa and overlying Rico Formations. Minor success was experienced, commencing in 1923, in exploring the Boundary Butte anticline near the Arizona State line where small quantities of oil were found in the Triassic Shinarump Member of the Chinle Formation and large quantities of low Btu gas in the Hermosa formation. Difficult access and lack of market outlet precluded further development until about 1948. Discovery of the small Desert Creek field in 1954 and the Akah field in 1955 greatly stimulated exploration effort in the southern part of the basin leading to the discovery of the important Aneth field in 1956. The accumulation of oil and gas in the Aneth field is a function of stratigraphic entrapment in porous carbonate rocks. The porosity is determined in part by either the clastic texture or the result of dolomitization of the limestones. The reservoir pressures result from solution gas and water drives. (See table 3.) Combination investigation of well log data and surface geologic investigations are largely responsible for success of drilling in the southern part of the basin. Since the "twenties," the central and northern part of the basin also received attention, especially the salt anticlines. Although early drilling of these structures revealed the highly petroliferous nature of the rocks penetrated, no great success was realized except for the discovery of potash deposits in the evaporite facies of the Paradox Member of the Hermosa Formation. (See section on salines.) Oil was encountered at the north end of Salt Valley anticline, but sustained production could not be established. Later, oil and gas found in the Big Flat and Cane Creek areas added further stimulus to exploration. As more exploration wells were drilled and geologic data accumulated, it became apparent that a great potential of oil and gas would be in fault blocks and folds where pre-Hermosa porous rocks are adjacent to the thick, organic-rich Hermosa Formation. Although the structural grains of the pre-Hermosa tectonic elements paralleled and influenced the development of the salt anticlines, the two are not superimposed, and the crests of the older structures are located on the flanks or between the surface expression of the salt anticlines. This knowledge, with the aid of geophysical investigations, led to the discovery of Lisbon and Salt Wash fields and further development of the Big Flat field. The accumulations in these fields formed by the migration of oil and gas from the Hermosa into porous rocks of Devonian to Pennsylvanian age. Unfortunately, effective porosity has been lacking in some of the more promising structures. Solution gas and water are effective drive mechanisms throughout the central and northern part of the basin.

The Paradox basin is presently the largest producer of oil and gas in Utah. Much of the area remains to be explored and only the Hermosa rocks have been tested widely. Problems in the joint development of oil and gas and potash mining may be anticipated in the northern and central parts of the basin (Hite, 1963).

BASIN AND RANGE PROVINCE AND OTHER FIELDS

Accumulations of oil and gas are found at widely separated places outside of the major fields. The Farmington gasfield and reported gas in wells in the Salt Lake and Cache valleys indicated the presence of gas in the Quaternary and upper Tertiary rocks. The gas is in small sand lenses, however, and sustained production of significant volumes is not anticipated. The asphaltic seep deposits at Rozel Point in northwestern Utah probably formed in the Quaternary lakebeds about 4,000 years ago as indicated by the carbon 14 age (Heylmun, 1961), and are not likely important. The deposits have a very high content of sulfur combined in the organic molecules, however, and are valued at a large price per barrel by the rubber industry. The small production from the Virgin field in Washington County is of little economic importance. It does, however, establish the accumulation of oil in southwestern Utah, and has encouraged exploration effort in this part of the State. At the Last Chance field in Emery County, two wells encountered gas trapped in lenticular sandstones in the Triassic Moenkopi Formation. An exploration potential in the southern San Rafael Swell and Henry Mountains area is indicated by shows of oil and gas. The Coconino Sandstone in the Woodside field in Emery County contains natural gas with 1.3 percent helium. It was made into a Federal helium reserve in 1924 and no attempts have been made to develop it until recently. It has not produced any gas to date.

OIL AND GAS RESOURCES

The estimated "proved recoverable resources" in Utah as of 1961 were 218 million barrels of oil (Kirby, Messner, and Moore, 1961, p. 365) and 1,526,140,000 Mcf of natural gas (Avery and Harvey, 1961, p. 315). Most of these reserves are in the Paradox and the Uinta basins, although minor gas reserves occur in the Green River Basin and the Wasatch Plateau-Castle Valley area. These reserves, however, are only a small part of Utah's total oil and gas resources, which may be as much as 10 times the production to date. These resources also are mostly in the Paradox and Uinta basins, with perhaps an appreciable amount in the Great Basin, and less significant amounts in the Wasatch Plateau-Castle Valley area and in the Green River Basin.

Economic factors will control the rate of development of these resources. Some factors that tend to slow development are the large expense of drilling to some of the deep deposits, the inaccessability of some parts of the favorable regions west of the Paradox basin, and the lack of detailed structural and stratigraphic information in some undeveloped areas such as some parts of the Great Basin. Other factors tend to stimulate development of these resources, especially basic geologic data outlining the favorable areas and the availability of pipeline, refinery, and marketing facilities. Wise conservation practices that are in effect throughout the State will assure maximum utilization of the resources.

Utah's future as an oil and gas producing state is assured, for in addition to the resources discussed above, it has a wealth of other fossil fuels that may ultimately be converted to liquid hydrocarbons, including oil shale, coal, and other bituminous materials.

OIL SHALE

(By W. B. Cashion, Denver, Colo.)

Oil shale is a dense, fine-grained sedimentary rock that is rich in organic matter which can be converted to oil by applying heat. The organic material is composed chiefly of minute particles which are the remains of plants and animals. Oil shale contains little or no free oil that can be extracted by solvents or mechanical methods, but appreciable amounts of oil can be formed by thermal decomposition of the organic matter. The method of converting the organic material to shale oil is called retorting.

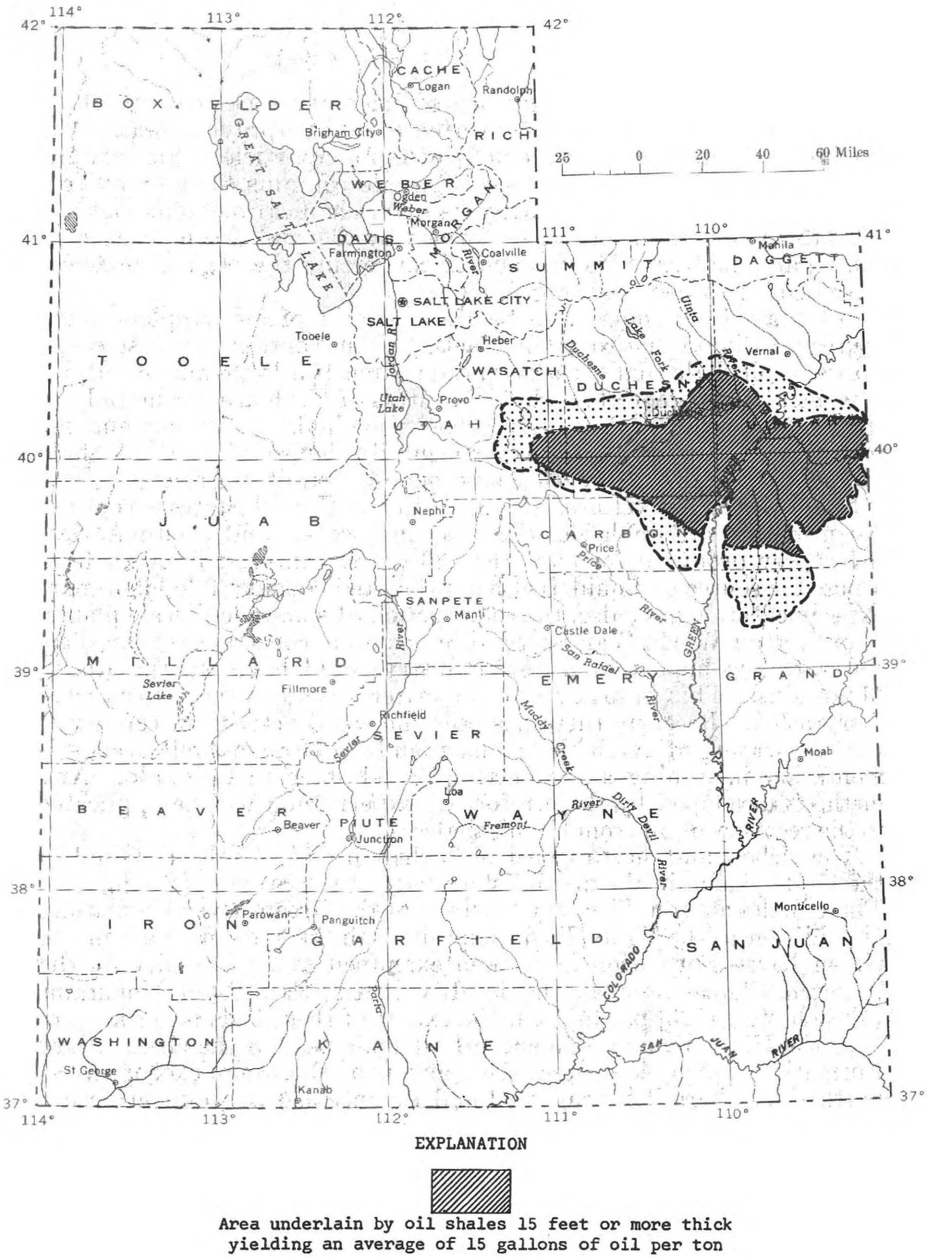
Oil shale is considered to be the Nation's prime supplementary source of liquid hydrocarbon fuels. Utah contains extensive deposits of oil shale that are a potential source of a large amount of oil. The estimated potential oil-shale resources of Utah are second only to those of Colorado. Relatively efficient methods of mining and retorting oil shale have been experimentally devised and an oil-shale industry in Utah will develop as economic conditions change.

Shale oil has not yet been produced in the United States except experimentally, although elsewhere, as in Sweden and South Africa, it has been produced for more than 30 years. Interest in oil shale as a possible source of liquid fuel has prompted considerable laboratory experimentation and, also, the construction of some small-scale plants. Shortly after World War I several retorts were constructed near Watson with the hope that a new industry could begin in the Rocky Mountains. This industry did not materialize and the retorts were dismantled. Recently there has been increased activity in core drilling and leasing of available oil-shale lands in Utah, as well as experimentation in mining and retorting of oil shale in Colorado. Any methods developed by these retorting experiments will be applicable in the recovery of oil from Utah's shales.

The richest and most extensive oil-shale beds in Utah are found in the Uinta Basin, in the northeastern part of the State. (See fig. 15.) These shales occur as Tertiary lakebeds of the Green River Formation. In addition to the Uinta Basin deposits, thin beds of oil shale in the Green River Formation have been examined at one locality on the Wasatch Plateau and at one locality in the San Pitch Mountains (Winchester, 1923, p. 114), but the extent of these beds is not known.

In the Uinta Basin a sequence of oil-shale beds of the Green River Formation is exposed around the margins of the basin, except on the north side, where it is truncated and is concealed by younger strata. These beds dip toward the central part of the basin, where they are thickly covered. Within the oil-shale sequence, the highest potential oil yield is in the Mahogany ledge, a series of resistant, blue-gray-weathering oil shales, the richest of which is called the Mahogany bed. Shales of the ledge crop out in many canyons in the southern and eastern parts of the basin. The Mahogany ledge is thickest in the east-central part of the basin, along an east-west-trending strip near the 40th parallel, where it may lie as much as 2,500 feet below the surface. In the central part of the basin other oil shales, of lower potential yields, extend hundreds of feet above and below the Mahogany ledge, but the sequence of beds thins near the margin of the basin.

Samples of the Green River Formation taken from many core holes



EXPLANATION

Area underlain by oil shales 15 feet or more thick yielding an average of 15 gallons of oil per ton

Area underlain by oil shales which are low grade or unappraised

FIGURE 15.—Oil shale in Utah.

and exploratory wells in the Uinta Basin have been assayed for oil yield by the U.S. Bureau of Mines. The results of these assays are used here to estimate the amount of shale oil resources in the Uinta Basin. Oil yields of samples from the Green River Formation, representing units at least 1 foot thick, range from a fraction of a gallon per ton to 95 gallons per ton of shale.

An oil-shale sequence 15 feet or more thick that will yield an average of 15 gallons of shale oil per ton underlies an area of about 3,000 square miles in the Uinta Basin. (See fig. 15.) It is estimated that this sequence has a potential oil yield of 320 billion barrels. That part of the sequence described above, which is 15 feet or more thick and will yield 25 gallons of oil per ton, contains 120 billion barrels of oil (Duncan, 1958, p. 50). This part of the sequence underlies an area of 1,200 square miles in the east-central part of the basin.

The estimates of shale oil resources given in this report are for total potential yield and do not indicate the amount of oil recoverable. Because of a scarcity of exploratory wells in some parts of the Uinta Basin the data for these resource estimates are not complete. The estimates, however, are conservative and data from future drilling will probably indicate larger resource figures.

OTHER BITUMINOUS SUBSTANCES

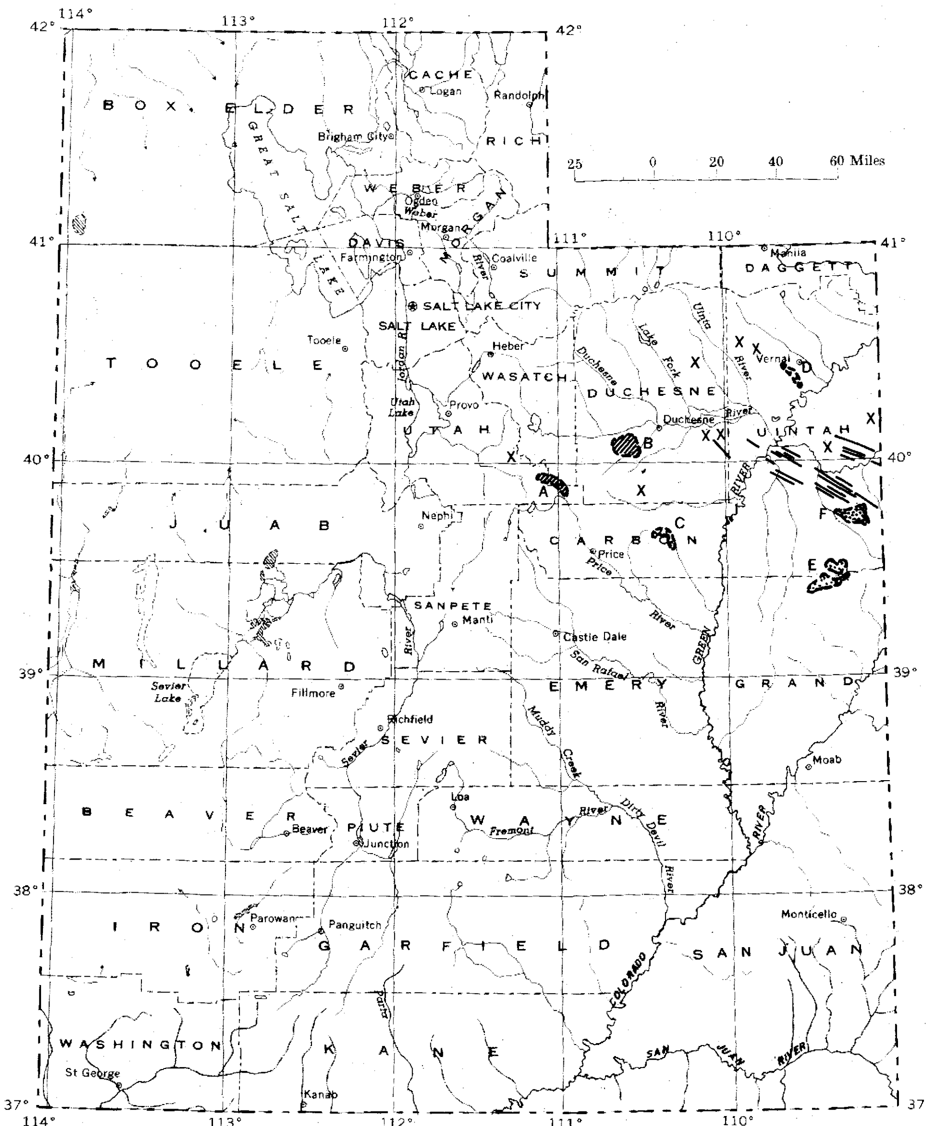
(By W. B. Cashion, Denver, Colo.)

Bituminous substances other than the hydrocarbon fuels already discussed (coal, oil shale, and petroleum and natural gas), include two groups of materials, the solid hydrocarbons and rock asphalts (Abraham, 1945, pp. 66–67). In both groups, the organic material appears to have changed from an earlier form, and to have migrated from the original site of accumulation. The many varieties of these bituminous substances reflect differences in source materials and subsequent history. A number of the varieties appear to represent residues left after partial volatilization of hydrocarbons.

SOLID HYDROCARBONS

Utah contains numerous unusual deposits of solid hydrocarbons which are the result of the metamorphosis of petroleum. These comparatively hard substances are brown to black in color and have a tarry or waxy appearance. They are used in a great variety of products ranging from high-quality varnishes to insulation. Gilsonite, wurtzilite, and ozokerite are the most important solid hydrocarbons found in Utah and each of these mineraloids will be discussed separately below. Glance pitch, tabbyite, and albertite are found in minor amounts and are of little economic significance. Gilsonite, wurtzilite, and ozokerite occur in the Uinta Basin in the northeastern part of the State. (See fig. 16.) Only gilsonite is being produced commercially at the present time, but significant amounts of wurtzilite and ozokerite also have been produced. The amount of solid hydrocarbons produced in Utah from 1888 through 1961 is estimated to be about 3,880,000 short tons valued at about $90,300,000.

26-803 O-69—6



EXPLANATION

Gilsonite vein

Area containing bituminous sandstone deposits

Area containing solid hydrocarbon deposits (other than gilsonite)

X Bituminous sandstone or limestone locality

Letters refer to areas described in text

FIGURE 16.—Solid hydrocarbons and rock asphalts in Utah.

Gilsonite.—Gilsonite is a black, lustrous substance having the appearance of solidified tar. It is characterized by a high fusing point (over 230° F.) and is almost completely soluble in carbon disulfide (Abraham, 1945, p. 250). A major part of the gilsonite produced is converted to metallurgical-grade coke and gasoline. Gilsonite also is used in ink, floor tile, brake linings, paint, electrical insulation, battery boxes, fiberboard, and numerous other products. Gilsonite is also sent to foreign markets.

Utah is the only state that produces gilsonite, and is the only state that contains major deposits of this solid hydrocarbon. Gilsonite is important to the economy of northeastern Utah, as evidenced by the 1961 output which totaled 422,294 short tons valued at $9,916,000.

Gilsonite production began about 1888 and has increased through the years in response to growing markets, creation of new products, and improvements in mining and transportation techniques. An industry which began with pick-and-shovel mining and wagon train transportation has evolved into one which is highly mechanized. Specially designed equipment allows the mining of large tonnages of material, and watersprays settle the highly explosive gilsonite dust which otherwise creates hazardous mining conditions. Gilsonite is mined by American Gilsonite Co., G. S. Ziegler & Co., and Standard Gilsonite Co. in the area near Bonanza, in eastern Uintah County, and the latter two companies also have mining operations in western Uintah County and eastern Duchesne County. A large percentage of the gilsonite mined by American Gilsonite Co. is transported by slurry pipeline to their refinery near Grand Junction, Colo., where it is converted to metallurgical-grade coke, gasoline, and other products. All other gilsonite is transported by trucks to railheads in Utah and western Colorado.

Gilsonite occurs in northeastern Utah in Uintah and Duchesne Counties (see fig. 16) as veins in northwest-trending vertical fractures that cut gently dipping beds of the Tertiary Duchesne River, Uinta, Green River, and Wasatch Formations. These smooth-walled, linear veins range in width from a fraction of an inch to about 18 feet and the maximum length is about 14 miles. The widest veins, which occur in eastern Uintah County, have their maximum width in massive sandstones in the Uinta and the Green River Formations. The veins thin, however, when they pass from sandstone into shale. Information on the veins at depth is limited, but mining in eastern Duchesne County has reached a depth of about 1,500 feet.

It is estimated that the original gilsonite reserves of Utah amounted to about 45 million tons. This estimate is for total original reserves in place; no allowance is made for gilsonite that may not be minable because of limitations of vein width or other factors. Gilsonite produced to date amounts to about one-tenth of the estimated original reserves.

Ozokerite.—Ozokerite is a native mineral wax that occurs in deposits usually associated with paraffinaceous petroleum (Abraham, 1945, p. 140). It may be as soft as tallow or as hard as gypsum; it melts easily between about 58° and about 80° C.; and is soluble in carbon disulfide. Ozokerite is a nonconductor of electricity and is used in insulation. It is also used in high-quality candles, polishes, rubber additives, and wax figures. Much ozokerite is converted to ceresin, a highly purified product, which is used to replace or adulterate beeswax, and has a variety of other uses (Robinson, 1916, p. 11).

Development of ozokorite deposits began in 1886, and by 1914 there were 17 small mines and prospects. Utah's ozokerite production has been sporadic and there has not been any mined in several years, although there is a continuing demand for the substance and the deposits are near transportation and other facilities. The small size of the veins and the irregular, unpredictable shape of the bodies discourage their exploitation.

Ozokerite occurs in an area of about 25 square miles in Wasatch and Utah Counties in central Utah. (See area A, fig. 16.) As described by Robinson (1916, pp. 3–16), the deposits are in the Wasatch Formation in a stratigraphic sequence of shale, sandstone, and limestone, about 600–700 feet thick. The beds dip 1° to 25° northward toward the axis of the Uinta Basin. The ozokerite occurs as veins and as fillings in brecciated zones; the wall rock is not impregnated. The principal fissures trend about N. 10° W. and contain the largest deposits of ozokerite. Thicknesses of the veins range from a fraction of an inch to 3 feet. The deposits are irregular in size, and thicknesses and lengths of veins cannot be predicted far from exposures. For this reason no estimate of ozokerite reserves has been made.

Wurtzilite.—Wurtzilite is a black, lustrous, sectile substance which has an elasticity similar to mica and is only slightly soluble in carbon disulfide (Abraham, 1945, p. 291). Wurtzilite is used in calking and waterproofing compounds and preservative paints.

Information concerning the mining of wurtzilite is scarce. Production figures indicate that wurtzilite mining began about 1900 and was carried on, discontinuously, until about 1950. Mining operations were on a relatively small scale and total production was probably less than 25,000 short tons.

Wurtzilite deposits are found in an area between Avintaquin and Antelope Canyons, in Duchesne County. (See area B, fig. 16.) The deposits occur as vertical veins in gently dipping limestone and shale beds in the Green River Formation (Eldridge, 1901, pp. 358–360; Davis, 1959, pp. 55–61). The veins are generally narrow and have uneven walls; some wurtzilite also occurs in brecciated zones. The widest vein has a maximum width of 4 feet and the longest has a maximum length of about 3 miles, but most of the veins are 10 to 12 inches wide and about 1 mile long. Outcrops of the veins are mostly restricted to steep slopes and cliff faces. Total resources of wurtzilite have not been estimated.

ROCK ASPHALTS

Rock asphalts are bitumen-impregnated porous rocks, such as sandstone and limestone, containing from a few percent to as much as 13 percent bituminous substances. The rock asphalt, after crushing, is used primarily for paving, and for other purposes such as a mastic for flooring, roofing, and waterproofing. In addition, the bitumen may be extracted from the associated mineral material by solvents or by mechanical means.

The most important rock asphalt deposits are in the northeastern part of Utah (fig. 16). Data on production are incomplete, but total output is estimated at about 400,000 tons. Nearly all the production has been bituminous sandstone from deposits near Sunnyside and at

Asphalt Ridge, and has been used for paving. A small production of bituminous limestone is reported, but the deposits have not been studied in detail. Some beds described as bituminous limestones, for example, may be oil shales. Many localities containing small deposits of bituminous sandstones and limestones are known, and a number of these are shown on figure 16.

Sunnyside deposits.—The Sunnyside bituminous sandstone deposits are about 5 miles north of the town of Sunnyside, Carbon County. (See area C, fig. 16.) The bituminous sandstone beds crop out in cliffs and steep slopes in the upper part of the Wasatch Formation and the lower part of the Green River Formation, with the bulk of them being in the Wasatch Formation (Holmes and others, 1948). The strata dip gently northeastward toward the axis of the Uinta Basin. Individual beds range in thickness from a few inches to 350 feet and extend as much as several thousand feet along the strike. These beds are numerous in a stratigraphic sequence 1,000 feet thick and occur along the outcrop for a distance of about 9 miles.

Bitumen content of beds in the Sunnyside area ranges from a few percent to a little over 13 percent by weight. Holmes (1948) estimated that the area includes about 1,600 million cubic yards of bituminous rocks in which beds with 9 percent or more bitumen by weight contain 728 million barrels of bitumen. From 1892 through 1945 intermittent quarrying operations removed about 335,000 tons of rock from the Sunnyside deposits. Shortly after 1945 mining ceased and has not resumed.

Asphalt Ridge deposits.—The Asphalt Ridge bituminous sandstone deposits lie a few miles southwest of Vernal, Uintah County. (See area D, fig. 16.) Impregnated beds of sandstone crop out along a northwest-trending strip about 14 miles long and less than a mile wide (Spieker, 1930). The bitumen occurs in beds of the Cretaceous Mesaverde and Tertiary Duchesne River Formations (Covington, 1963, p. 229). Dip of the beds is southward and southwestward and exploratory drilling has encountered bitumen-impregnated beds in the subsurface about 2 miles down dip from the outcrop. Thicknesses of impregnated sandstone sequences at the outcrop range from a few feet to about 200 feet.

Samples analyzed from various sandstone beds show that the bitumen content ranges from about 8 percent to a little more than 15 percent by weight. The area within 1½ miles of the outcrop is estimated to include about 1,970 million tons of bituminous rock containing 1,150 million barrels of bitumen (Spieker, 1930, pp. 96–97). The Asphalt Ridge deposits have been quarried for many years to obtain paving material for streets and roads in and near Vernal; however, the amount of material quarried is not known.

PR Springs-Evacuation Creek deposits.—The PR Springs bituminous sandstone deposits (see area E, fig. 16) and the Evacuation Creek bituminous sandstone deposits (see area F, fig. 16) occur on the southeast flank of the Uinta Basin, Uintah and Grand Counties. The main portions of these similar deposits lie along minor northwest-trending anticlinal noses that plunge toward the structurally low part of the basin.

The impregnated beds occur in the Green River Formation and crop out as cliffs or steep slopes in a well-dissected region. Maximum thicknesses of individual beds is about 40 feet in the Evacuation Creek area and about 120 feet in the PR Springs area.

In the Evacuation Creek area there is usually only one impregnated sandstone bed, but in the PR Springs area there may be as many as four within a stratigraphic sequence 200 feet thick. Much of the area between the two deposits contains sandstone beds that also are impregnated, although to a much lesser degree than the two main deposits. Impregnation of individual beds within the main deposits is quite irregular.

Bitumen content of analyzed samples from the sandstone beds range from about 6 to about 23 gallons per ton . Impregnated sandstone beds underlie an area of at least 100 square miles, but because of the irregular nature of the impregnation no attempt was made to estimate the bitumen reserves. The deposits have not been mined, probably because of their remoteness.

Miscellaneous deposits.—Numerous small deposits of bituminous sandstone and limestone in Utah have been reported by various authors (Abraham, 1945; Barb and Ball, 1944; Boutwell, 1904; Covington, 1963; Eldridge, 1901), but few of these have been described in detail. From the available information, they are apparently of minor significance.

Most of the deposits are in beds of Tertiary age and lie within the Uinta Basin. The only exceptions are a deposit in sandstone of Jurassic age about 22 miles northwest of Vernal, and a deposit in limestone of Quaternary age on the shore of Great Salt Lake. Some of the deposits are associated with faults or unconformities but most are in undisturbed conformable rock sequences.

The impregnated sandstone beds of Jurassic age are in steeply dipping strata near the mouth of Whiterocks Canyon, Uintah County. Covington (1963, pp. 237-238) has estimated that this deposit contains 50 million barrels of bitumen.

Boutwell (1904, pp. 473–476) described thin bituminous limestones of Quaternary age that occur near Rozel Point, Box Elder County. These limestones are in lakebeds near the shore of Great Salt Lake and are impregnated with bituminous material that seeps up through fractures in the lakebeds. Some of the bituminous material permeates porous rock and some floats to the lake surface (Eardley, 1963). The limestone beds have not been worked but a small amount of the material on the lake surface was marketed for use in paving mixture. The bituminous material is believed by Eardley to derive from oil occurring in Tertiary limestone interbedded with basalt.

A review of the literature has revealed only one report of the mining of bituminous limestone in Utah. Eldridge (1901, pp. 363–364) describes a deposit about 8 miles northwest of the Gilluly rail siding, Utah County, that was mined about 1900. The deposit is in a limestone sequence of beds in the Green River Formation. The beds dip northeastward into the Uinta Basin.

SELECTED REFERENCES

Abraham, Herbert, 1945, Asphalts and allied substances: v. 1, 5th ed., 887 p., D. Van Nostrand Co., Inc., Princeton, N.J.

American Society for Testing Material, 1954, Standard specifications for classification of coals by rank: A.S.T.M. Standards on coal and coke, p. 79–84.

Aresco, S. J., Haller, C. P., and Abernethy, R. F., 1962, Analyses of tipple and delivered samples of coal (collected during the fiscal year 1961): U.S. Bur. Mines Rept. Inv. 6086, p. 21, 23.

Averitt, Paul, 1961, Coal reserves of the United States—a progress report, January 1, 1960: U.S. Geol. Survey Bull. 1136.

———, 1962, Geology and coal resources of the Cedar Mountain quadrangle, Iron County, Utah: U.S. Geol. Survey Prof. Paper 389.

Avery, I. F., and Harvey, L. V., 1961, Natural gas *in* Minerals Yearbook, v. II: U.S. Bur. Mines, p. 313–356.

Barb, C. F., and Ball, J. O., 1944, Hydrocarbons of the Uinta Basin of Utah and Colorado: Quarterly of the Colo. School of Mines, v. 39, no. 1, 115 p.

Boutwell, J. M., 1904, Oil and asphalt prospects in Salt Lake Basin, Utah: U.S. Geol. Survey Bull. 260, p. 468–479.

Campbell, M. R., 1917, Coal fields of the United States, General introduction: U.S. Geol. Survey Prof. Paper 100–A.

———, 1929, Coal resources of the United States: U.S. Geol. Survey Press Release.

Cashion, W. B., 1961, Geology and fuel resources of the Orderville-Glendale area, Kane County, Utah: U.S. Geol. Survey Coal Inv. Map C–49.

Clark, F. R., 1912, Coal near Wales, Sanpete County, Utah: U.S. Geol. Survey Bull. 541, p. 478–489.

———, 1918, Geology of the Lost Creek coal field, Morgan County, Utah: U.S. Geol. Survey Bull. 691–L, p. 311–322.

———, 1928, Economic geology of the Castlegate, Wellington, and Sunnyside quadrangles, Carbon County, Utah: U.S. Geol. Survey Bull. 793.

Cook, E. F., 1957, Geology of the Pine Valley Mountain, Utah: Utah Geol. and Mineralog. Survey Bull. 58, 111 p.

Covington, R. E., 1963, Bituminous sandstone and limestone deposits of Utah, *in* Utah Geol. and Mineralog. Survey Bull. 54, p. 225–247.

Crawford, A. L., ed. 1963, Oil and gas possibilities of Utah, re-evaluated: Utah Geol. and Mineralog. Survey Bull. 54, 564 p.

Davis, L. J., 1951, The characteristics, occurrences and uses of the solid bitumens of the Uinta Basin, Utah: M.S. thesis, Bringham Young Univ., 93 p.

Duncan, D. C., 1944, The Mount Pleasant coal field, Sanpete County, Utah: U.S. Geol. Survey coal map.

Duncan, D. C., 1958, Known reserves—oil shale deposits in the United States: Independent Petroleum Assoc. America, v. 29, no. 4, p. 22, 49–51.

Eardley, A. J., 1963, Oil seeps at Rozel Point: Utah Geol. and Mineralog. Survey Spec. Study 5.

Eldridge, G. H., 1901, The asphalt and bituminous rock deposits of the United States: U.S. Geol. Survey 22nd Ann. Rept., pt. 1, p. 209–452.

Fisher, D. J., 1936, The Book Cliffs coal field in Emery and Grand Counties, Utah: U.S. Geol. Survey Bull. 852.

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.

Four Corners Geological Society, 1960, Geology of the Paradox basin fold and fault belt, 3rd annual field conference, K. G. Smith, ed. 1960: 173 p.

Gale, H. S., 1910a, Coal fields of northwestern Colorado and northeastern Utah: U.S. Geol. Survey Bull. 415, p. 204–219.

———, 1910b, Coal fields of northwestern Colorado and northeastern Utah: U.S. Geol. Survey Bull. 415, p. 233–239.

Gregory, H. E., and Moore, R. C., 1931, The Kaiparowits region: U.S. Geol. Survey Prof. Paper 164, p. 148–153 and pl. 30.

———, 1938, The San Juan country: U.S. Geol. Survey Prof. Paper 188, p. 110.

———, 1950a, Geology of eastern Iron County, Utah: Utah Geol. and Mineralog. Survey Bull. 37.

Gregory, H. E., 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, Utah: U.S. Geol. Survey Prof. Paper 226.

Hansen, G. H., and Scoville, H. C., 1955, Drilling records for oil and gas in Utah: Utah Geol. and Mineralog. Survey Bull. 50, 110 p.

Huddle, J. W., Mapel, W. J., and McCann, F. T., 1951, Geology of the Moon Lake area, Duchesne County, Utah: U.S. Geol. Survey Oil and Gas Inv. Map 115.

Huddle, J. W., and McCann, F. T., 1947, Geologic map of Duchesne River area, Wasatch and Duchesne Counties, Utah: U.S. Geol. Survey Oil and Gas Inv. Map 75.

Heylmun, E. B., 1961, Rozel Point, *in* Preston, D. A., A symposium of the oil and gas fields of Utah: Intermountain Association of Petroleum Geologists, Salt Lake City, Utah.

Holmes, C. N., Page, B. M., and Averitt, Paul, 1948, Geology of the bituminous sandstone deposits near Sunnyside, Carbon County, Utah: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 86.

Hunt, C. B., and others, 1953, Geology and geography of the Henry Mountains region, Utah: U.S. Geol. Survey Prof. Paper 228, p. 216–217 and pl. 22.

Intermountain Association of Petroleum Geologists, 1950, Petroleum geology of the Uinta Basin, first annual field conference, A. J. Eardley, ed., 1950: Salt Lake City, Utah, 151 p.

Intermountain Association of Petroleum Geologists, 1954, Geology of portions of the high plateaus and adjacent canyon lands, central and south central Utah, 5th annual field conference, 1954, A. W. Grier, ed.: Salt Lake City, Utah, 145 p.

———, 1956, Geology and economic deposits of east central Utah, 7th annual field conference, J. A. Peterson, ed., 1956: Salt Lake City, Utah, 225 p.

———, 1957, Guidebook to the geology of the Uinta Basin, 8th annual field conference, O. G. Seal, ed., 1957: Salt Lake City, Utah, 224 p.

———, 1958, Guidebook to the geology of the Paradox Basin, 9th annual field conference, A. F. Sanborn, ed., 1958: Salt Lake City, Utah, 308 p.

———, 1961, A symposium of the oil and gas fields of Utah, D. A. Preston, ed.

Kirby, J. G., Messner, W. G., and Moore, B. M., 1961, Crude petroleum and petroleum products, *in* Minerals Yearbook, v. 2: U.S. Bureau of Mines, p. 357–486.

Kinney, D. M., 1955, Geology of the Uinta River-Brush Creek area, Duchesne and Uintah Counties, Utah: U.S. Geol. Survey Bull. 1007.

Lee, W. T., 1907, The Iron County coal field, Utah: U.S. Geol. Survey Bull. 316-E, p. 372–374.

Lupton, C. T., 1912, The Blacktail (Tabby) Mountain coal field, Wasatch County, Utah: U.S. Geol. Survey Bull. 471, p. 595–628.

———, 1916, Geology and coal resources of Castle Valley in Carbon, Emery, and Sevier Counties, Utah: U.S. Geol. Survey Bull. 628.

Richardson, G. B., 1909, The Harmony, Kolob, and Kanab coal fields, southern Utah: U.S. Geol. Survey Bull. 341–C, p. 384–388.

Robinson, H. M. 1916, Ozokerite in central Utah: U.S. Geol. Survey Bull. 641–A, p. 1–16.

Robinson, R. A., 1963, A reconnaissance survey of the coal resources of southwestern Utah: Utah Geol. and Mineralog. Survey Spec. Studies no. 3.

Spieker, E. M., 1930, Bituminous sandstone near Vernal, Utah: U.S. Geol. Survey Bull. 822–C, p. 77–98.

———, 1931, The Wasatch Plateau coal field, Utah: U.S. Geol. Survey Bull. 819.

Spieker, E. M., and Baker, A. A., 1928, Geology and coal resources of the Salina Canyon district, Seiver County, Utah: U.S. Geol. Survey Bull. 796–C.

U.S. Bureau of Mines, 1925, Analyses of Utah coals: U.S. Bur. Mines Tech. Paper 345.

U.S. Bureau of Mines, 1960, Mineral facts and problems: U.S. Bur. Mines Bull. 585.

Wegemann, C. H., 1915, The Coalville coal field, Utah: U.S. Geol. Survey Bull. 581, p. 161–184.

Winchester, D. E., 1923, Oil shale in the Rocky Mountain region: U.S. Geol. Survey Bull. 729, 204 p.

METALLIC MINERAL RESOURCES

INTRODUCTION

(By L. S. Hilpert, Salt Lake City, Utah)

The metallic mineral resources, which are mostly in the western part of the State, have been the bulwark of Utah's mineral industry for the past 100 years. Through 1961, they have accounted for three-fourths of the value of the total minerals output, and they have been instrumental in the establishment of a major mining, smelting, milling, refining, and manufacturing complex, and have played a great part in the development of the State's economy since about 1870. The major metals have been copper, lead, silver, gold, and zinc, in the order named. Copper greatly outranks all other mineral commodities, having a total yield through 1961 valued at more than $3.3 billion, which is about 40 percent of the State's total mineral output. Iron, which has a total yield valued about the same as zinc is of much greater value to the State because of its part in establishing a steel manufacturing complex. Other minerals of considerable importance in recent years are uranium, mostly from the eastern part of the State, and molybdenum, a byproduct of prophyry copper ores at Bingham Canyon. The metallic mineral resources will continue in the future to play about as important a part in the State's mineral economy as in the past. Although some metals may decline in output, others may take their place. The strength of the State's mineral economy is supported by a variety of mineral commodities and the metals are no exception. The recently discovered large resources of beryllium, for example, may be brought into production within the near future. The variety and extent of the metallic resources is brought out in the following sections.

BERYLLIUM

(By W. R. Griffitts, Denver, Colo.)

Within the past 3 years, the world's largest known beryllium deposits have been discovered in Utah. Large deposits have not previously been known, and Utah's beryllium industry is still in the early development stage, but rapid expansion appears to be assured.

Beryllium is a metal that has received much attention during the last 15 years, because it possesses unique properties that might be useful in the construction of nuclear reactors, of airframes for aircraft and space capsules, as well as the importance of many older uses. Traditionally, about three-fourths of the beryllium consumed is alloyed with copper to make hard fatigue-resistant and nonrusting springs, diaphragms, tools, and other devices. Beryllium oxide combines high electrical resistance, high thermal conductivity, and a high melting point (4658° F), which makes it a very useful refractory material. Both beryllium metal and its oxide are useful as moderators and reflectors of neutrons in atomic reactors. The use of beryllium as a structural metal in manned aircraft and in missiles has been handicapped by its brittleness; however, this property has not prevented important use in guidance mechanisms of missiles and in nose cones and manned space capsules. Alloys of beryllium with nickel, aluminum, and magnesium have been used in rather small amounts: beryllium-rich alloys with aluminum were reported in 1963 to have a potentially large-scale use in aircraft manufacture. Speculative uses include the incorporation of beryllium metals into missile fuels and explosives.

Beryllium is a minor commodity in terms of the amounts actually used, as the U.S. consumption of ore increased from 1,013 tons in 1946 to an all-time high of only 9,692 tons in 1960, but the industrial importance of beryllium is far greater than the amount used might suggest.

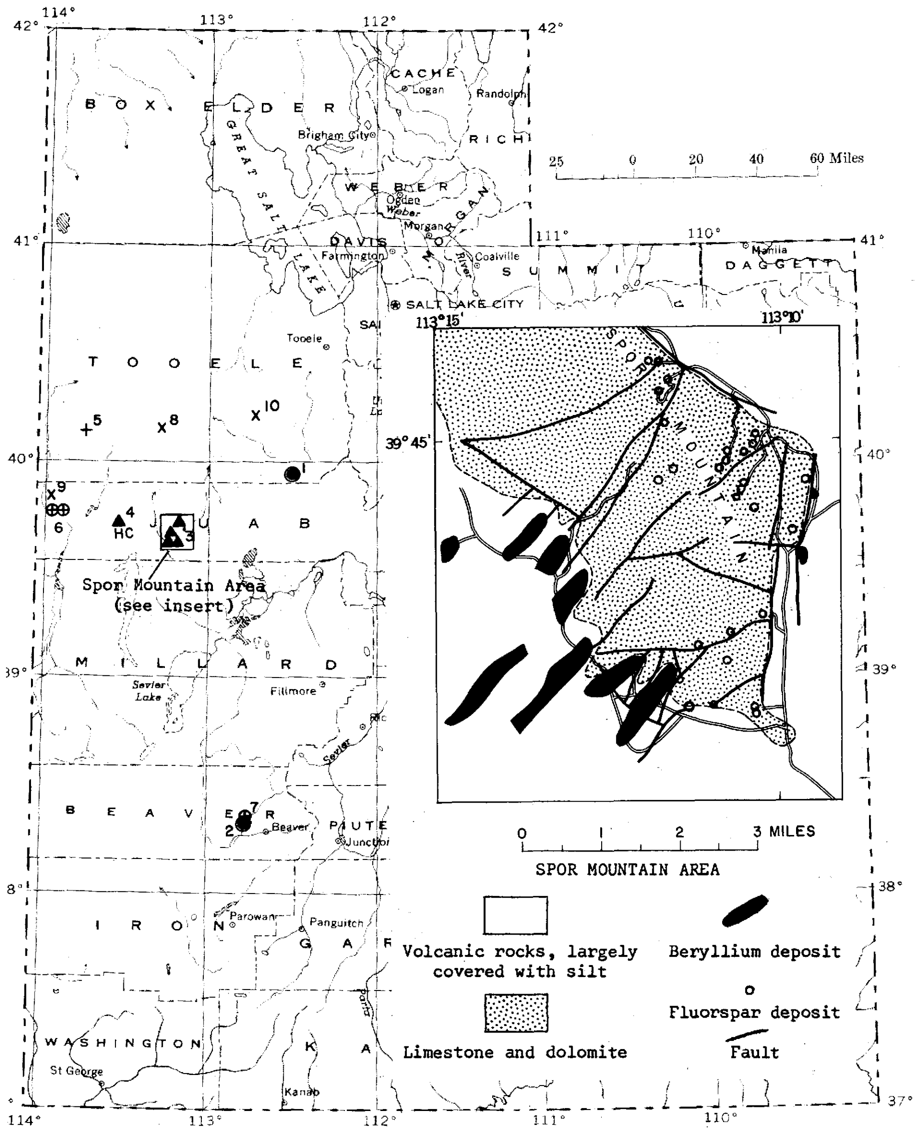
There is no substitute for it in some nuclear uses, and beryllium-copper alloy springs that are used in many switches and other electrical contacts are critical components of computers, aircraft, and other delicate and costly machines, in which equipment failures must be avoided. A factor that limits the choice of beryllium for many potential uses has been the unavailability of dependable large sources of supply.

The supply of beryllium ore has been maintained at an adequate and increasing level mainly by importation of the mineral beryl, which contains 10 to 14 percent BeO. This rather high-grade beryl ore is obtained from pegmatite deposits that are rather small; no more than 15 in the United States have yielded as much as 100 tons of ore, and the largest mine in the world has produced a total of less than 4,000 tons.

Since 1950 the search for domestic deposits and deposits large enough to sustain mining operations for several years has turned from pegmatite deposits to those of other types. The deposits of disseminated beryl in the Sheeprock Mountains, Tooele County, Utah, were among the first to attract attention. The discovery in 1960 of multi-million ton deposits at Spor Mountain, Juab County and in 1962 near Gold Hill, Tooele County, has shown that Utah contains the world's largest known beryllium deposits. As a result of the successful exploration of the Spor Mountain deposits, the beryllium industry is beginning a shift from the use of imported high-grade ore to the use of domestic low-grade ore. Such a shift will permit greatly expanded consumption of beryllium and will provide a stable domestic source of ore. Thus great changes in the structure of the industry and in the amount and diversity of use of the metal and its compounds can be expected soon, largely based upon Utah resources.

Beryllium minerals have been found in many places in west-central Utah, particularly in Tooele and Juab Counties (fig. 17). This area is the eastern end of a beryllium-rich province that extends westward from the Sheeprock Mountains, near Eureka, Utah to Austin, Nev. Part of this province has been described by Cohenour (1963a).

In the Sheeprock Mountains (No. 1, fig. 17), the easternmost deposits in the province, blue beryl crystals form radiating clusters or rosettes embedded in light gray to reddish brown granite (Cohenour,



EXPLANATION

▲ Fine-grained replacement bodies in volcanic rocks

\+ Fine-grained veins

⊕ Coarse-grained veins

● Beryl in granite

X Beryl-bearing pegmatite

1. Sheeprock Mountains
2. Mineral Range granite
3. Spor Mountain
4. Honeycomb Hills
5. Gold Hill area
6. Trout Creek area
7. Mineral Range veins
8. Granite Mountain
9. Goshute Indian Reservation
10. Skull Valley

Numbers refer to localities described in text

FIGURE 17.—Beryllium in Utah.

1963b). These clusters of crystals are distributed nearly at random over an area larger than a square mile; most abundantly in Hard-to-beat and Sheeprock Canyons. Individual clusters may exceed a foot in width. These may be separated from the neighboring clusters by a few feet or several tens of feet. Inasmuch as the intervening granite generally contains little beryllium, the beryllium content of large rock masses is determined largely by the number and size of clusters of crystals.

A somewhat similar occurrence is on the east side of the Mineral Range, Beaver County, where blue beryl forms thin veinlets in granite (No. 2).

The beryllium deposits at Spor Mountain (No. 3) are most unusual both in size and in geologic setting (Staatz, 1963; Staatz and Griffitts, 1961). Spor Mountain consists of limestones and dolomites, with minor amounts of sandstone or quartzite. These rocks have been intensely faulted and are overlain, along both the eastern and western sides of the mountain, by beds of silicic volcanic ash or tuff. These in turn are overlain by massive rhyolite. Above this rhyolite layer is more interlayered tuff and rhyolite. One particular tuff bed found under the basin west of the mountain is the host of the beryllium ore bodies. It commonly lies directly upon dolomite and below the lowest rhyolite and contains abundant pebbles and cobbles of dolomite and limestone. This bed thins from 100 feet near the center of the district to about 30 feet in the southernmost deposit, where it is separated from the rhyolite by 20 or more feet of tuff that does not contain limestone and dolomite pebbles.

Beryllium-rich rock is found near the top of the pebble-rich tuff bed. The principal ore bodies appear to be hundreds of feet wide, thousands of feet long, and 10 to 20 feet thick. They are parallel to and near long faults in the sedimentary rocks that probably are the channels through which the beryllium entered the tuff. The ore is a soft, earthy gray or tan material that contains hard white, gray, and purple nodules, a fraction of an inch to a foot in width. The purple color that characteristically spots the ore is due to fluorite, which constitutes a few percent of the ore. The beryllium is present in an acid-soluble mineral that forms minute particles both in the nodules and in the earthy matrix. The two deposits east of Spor Mountain are similar to those west of the mountain and are in pebble-bearing tuff near faults. They are thinner and less extensive than the deposits west of the mountains, inasmuch as the pebble layer is thinner and most of it has been removed by erosion.

Beryllium-bearing tuff also has been found below a rhyolite cap in the Honeycomb Hills (No. 4). These deposits are similar to those at Spor Mountain but are small.

Another group of exceptionally large beryllium deposits was found by the Vanguard Research Co. in 1962 in the Rodenhouse Wash area about 3 miles southeast of Gold Hill, Utah (No. 5). In this area, near the center of a stock of quartz monzonite, beryllium-bearing veins are numerous in a belt about 2 miles long. Individual veins are tens of feet in thickness and hundreds of feet in length. The veins are a fine-grained mixture of quartz, calcite, adularia, and a beryllium mineral, apparently the silicate, bertrandite. The veins are in the northeast-trending fracture zone shown by Nolan (1935).

Coarse-grained beryl-bearing veins have been found in many places near Trout Creek, Juab County (No. 6). The beryl in these veins forms white crystals one-eighth inch to at least 2 inches in length, which are in quartz or mica-rich veins and associated with the tungsten mineral scheelite. Some veins are several feet thick. Few have been extensively explored to determine the length and vertical extent.

A different type of coarse-grained beryllium-rich vein is on the east side of the Mineral Range and just east of an area in which the granite contains veinlets of beryl (No. 7). The beryllium mineral is helvite, a rather uncommon mineral that has been considered a potential ore of beryllium (Sainsbury, 1962). In the Mineral Range prospect, helvite is exceptionally abundant and is associated with marble, magnetite, and altered porphyry.

Pegmatite deposits, which have provided nearly all of the world's beryl ore, have not been productive in Utah. Perhaps the largest resources of beryl in pegmatite are on Granite Mountain, in the southern part of the Dugway Proving Grounds, Tooele County (No. 8). The beryl here forms blue crystals as much as 2½ inches in diameter that are in pegmatite and composite pegmatite-aplite dikes (Hanley and others, 1950). Associated minerals are albite, potash feldspar, quartz, and muscovite. The beryl content of the rock is estimated to be one-hundredth to one-tenth percent. The masses of pegmatite range from a few inches to several tens of feet in thickness.

Pegmatite in the southern part of the Goshute Indian Reservation, Juab County, forms dikes in granite (No. 9). One zoned dike has been prospected, to reveal a core of vuggy gray to white quartz, an intermediate zone containing potash feldspar and muscovite, and an outer zone of feldspar, quartz, and mica. Blue beryl was found in the outer and intermediate zones.

A few beryl crystals were found in pegmatite in Skull Valley (No. 10).

Resources to support active mining are assured, as at least 15 million tons of material averaging at least one-half percent BeO are available in the Spor Mountain and Gold Hill areas. In addition, the same districts probably contain an equal amount of material averaging 0.1 to 0.5 percent. Enormous tonnages of rock averaging 0.01 to 0.1 percent BeO are available in the Sheeprock Mountains and Gold Hill area.

Large as the estimated resources are, they may well be increased by additional discoveries in the west-central part of the State.

The exceptionally large resources and potential production of beryllium ore in Utah contrast markedly with the small past production of beryl ore. The impending large-scale production awaits, primarily, an expansion of markets for beryllium products to a level that will permit sustained operation and reasonably rapid amortization of costly industrial plants. This level of consumption appears assured within 10 years.

COPPER

(By R. J. Roberts, Menlo Park, Calif.)

Since the industrial revolution, copper has been a vital necessity to our economy. In 1962, 1,347,000 short tons were used by U.S. industry; about half of this went into the electrical industry; 10 percent each was used in the auto and building industries; 9 percent in munitions; and the remainder in miscellaneous uses. Copper has high electrical and thermal conductivity; it also has high tensile strength, ductility, malleability, and corrosion resistance.

The early history of copper production in Utah is the history of the Bingham (West Mountain) district. Copper was discovered in Bingham Canyon in 1862 by John Lowder (Hansen, 1963, p. 263), but he did not file on the discovery. Early in September 1863, George B. Ogilvie found lead ore in the canyon now known as Galena Gulch (Hammond, 1961, p. 121). On September 17 the first claim, the Jordan, was staked and the West Mountain Quartz Mining District was organized. Other claims were staked later that year and early in 1864, but development lagged and the first shipment of copper ore was not made until June 1868 (Arrington, 1963, pp. 199, 206).

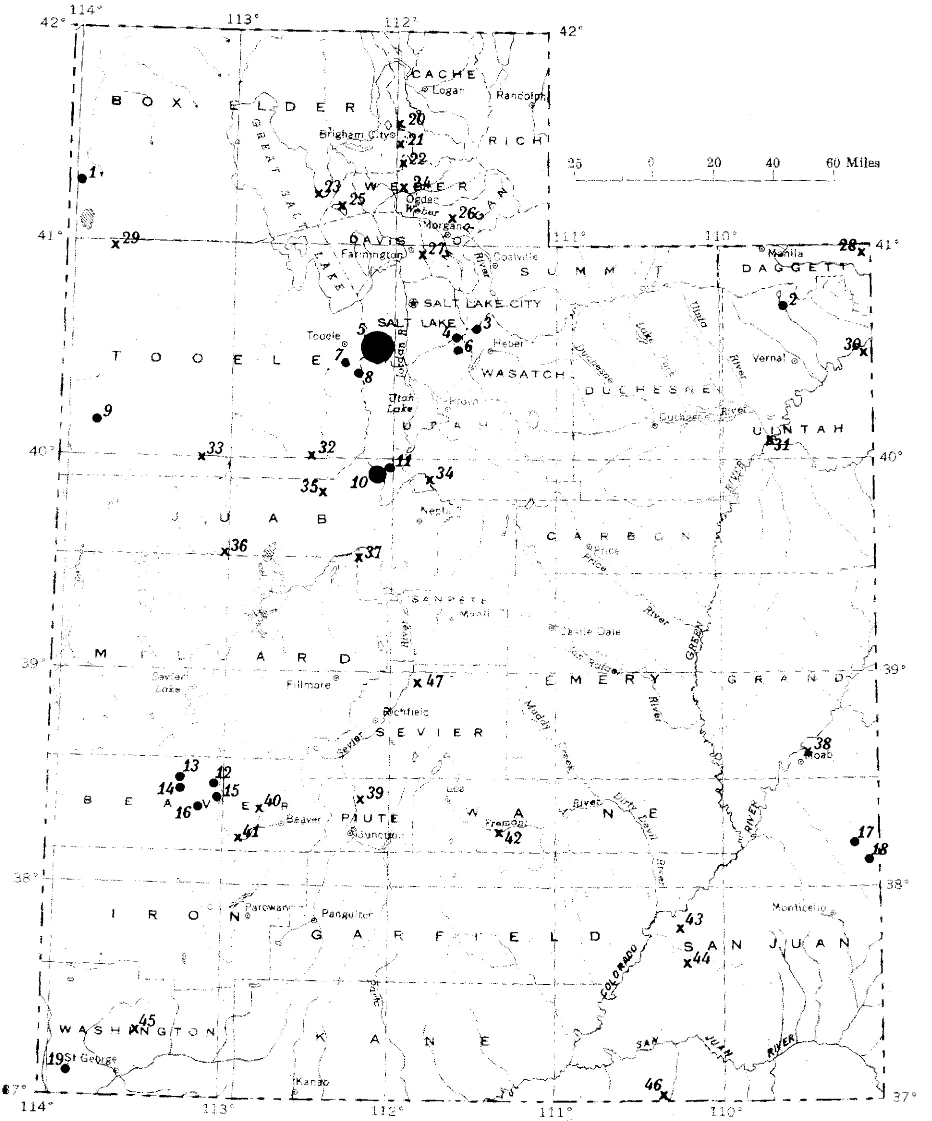
Utah did not ship significant amounts of copper until 1897 when the Highland Boy mine (later part of the Utah Consolidated Mining Co. property) a replacement deposit in limestone, was put into production. A smelter was built in 1899 in Murray, 8 miles south of Salt Lake City, to treat the concentrates.

Meanwhile, Col. Enos A. Wall became interested in low-grade copper ores in the porphyry intrusives; in 1898, he sold an interest to Capt. Joseph R. DeLamar who assigned two of his staff engineers, Daniel C. Jackling and R. C. Gemmell, to sampling and metallurgical testing of the porphyry ores. After overcoming many difficulties, the Utah Copper Co. was organized in 1903 and production from underground ores began in 1904; steam shovels were placed in operation in 1906 for removal of waste capping. In 1907, mining of ore by shovels began, though underground mining continued until 1914. In 1903 Bingham entered its major productive period (see fig. 2), and Utah reached fifth rank in production in the United States. In 1908, Utah ranked fourth and by 1917, second, a place Utah has maintained most of the time since then. The Kennecott Copper Corp., present owner of the Bingham Canyon mine, obtained the property through acquisition of the Utah Copper Co. stock over a period of years and, in 1936, Utah Copper Co. became an operating division of the Kennecott Copper Corp. (Hammond, 1961, p. 128).

In the last 56 years the Bingham district has produced more than 15 billion pounds of copper, the record for any single copper mine in history. The Bingham mine is now the second largest producer of gold and molybdenum in the Nation (Kennecott Copper Corp., 1961). The ore has been mined from an open pit since 1907. Initially a shallow, leached capping about 100 feet thick was stripped from the ore body, and a thin but persistent zone of enrichment was mined before the primary sulfides were reached (James, Smith, and Bray, 1961, p. 86). As the pit has been deepened, the ratio of waste to ore has increased. In 1962, 2 tons of waste were stripped for each ton of ore mined.

Copper deposits in Utah belong to several types: disseminated deposits in porphyry, contact deposits, replacement deposits, fissure veins, and sandstone deposits. The Bingham district contains representatives of the first four types. The Tintic, Park City, San Francisco, and Big Cottonwood districts are principally replacement deposits, but also contain contact deposits and fissure veins. The sandstone deposits are found on the Colorado Plateau in association with uranium and vanadium deposits.

Location of the mining districts that have produced copper are shown on figure 18, and information on them is summarized in table 4.



EXPLANATION

> 1,000,000	50,000-1,000,000	1,000-50,000	< 1,000

Copper-producing district or area, showing relative amount of production in tons

Numbers refer to districts described in text and tables.

FIGURE 18.—Copper in Utah.

TABLE 4.—*Mining districts in Utah with recorded copper output, 1870–1961*

Map locality	District	County	Type of deposit	References
			MORE THAN 1,000 TONS	
1	Lucin	Box Elder	Replacement bodies in limestone along north-south fault zones; mainly oxidized copper minerals in clay matrix.	Butler and others, 1920, pp. 492–495; Blue, D. M., 1960.
2	Carbonate	Duchesne	Replacement bodies in Mississippian(?) limestone; mainly oxidized copper minerals.	Butler and others, 1920, p. 604.
3	Park City (Uinta, Blue Ledge).	Wasatch and Summit.	Byproduct copper in base-metal replacement deposits in limestone and fissures; oxidized copper minerals on upper levels, chalcopyrite and tetrahedrite on lower levels.	Boutwell, 1912, p. 82; Wilson, 1959, pp. 181–188.
4	Big and Little Cottonwood.	Wasatch	Byproduct copper in base-metal replacement deposits in limestone and brecciated zones along thrust faults and veins.	Calkins and Butler, 1943; Crittenden, Sharp, and Calkins, 1952, p. 31.
5	Bingham (West Mountain).	Salt Lake	Mostly disseminated chalcopyrite and chalcocite in porphyry; replacement deposits in limestone, and veins in sediments and porphyry.	Boutwell, 1905, pp. 126–154; James, Smith, and Bray, 1961, pp. 81–100.
6	American Fork	Utah	Byproduct copper from lead-zinc-silver veins and replacement deposits in limestone.	Calkins and Butler, 1943, pp. 133–145.
7	Stockton (Rush Valley)	Tooele	Byproduct copper minerals in lead-zinc replacement bodies	Butler and others, 1920; Gilluly, 1932, pp. 136, 139–151.
8	Ophir	do	do	Butler and others, 1920, p. 376; Gilluly, 1932, pp. 139–151.
9	Gold Hill (Clifton)	do	Copper-bearing veins and replacement bodies in marble	Nolan, 1935, pp. 101, 103.
10	Tintic	Juab and Utah	Byproduct copper minerals in lead-zinc-silver replacement bodies and veins.	Cook, 1957, pp. 57–79.
11	East Tintic	Utah	Byproduct copper minerals in lead-zinc-silver ore bodies	Bush, 1957, pp. 97–102.
12	Beaver Lake	Beaver	OK mine. Replacement pipe in quartz monzonite. Oxidized copper minerals to 200 feet; enriched sulfides (covellite and chalcocite) below grading into primary chalcopyrite.	Butler, 1913; Butler and others, 1920, pp. 505, 517.
13	Preuss	do	Cactus mine. Breccia pipe in quartz monzonite; oxidized copper minerals in upper workings; primary chalcopyrite at depth.	Butler, 1913; Butler and others, 1920, pp. 504, 520, 522.
14	San Francisco	do	Coproduct copper minerals in silver-lead-zinc-copper replacement bodies along fault contact.	Butler and others, 1920, p. 503.
15	Rocky	do	Harrington-Hickory mine. Byproduct copper minerals in lead-silver in replacement ore bodies in limestone adjacent to quartz monzonite.	Butler, 1913, pp. 194–196; Butler and others, 1920; Hewett and others, 1936, p. 74.
16	Star and North Star	do	Moscow mine. Byproduct copper minerals in lead-zinc replacement ore bodies.	Butler and others, 1920, p. 504; Hewett and others, 1926, p. 75.
17	Big Indian	San Juan	Disseminated copper minerals in Triassic sandstone; oxidized minerals (malachite, azurite) near the surface, sulfide minerals (covellite-chalcocite-bornite) at depth	Butler and others, 1920, pp. 614–615; Finch, 1959, pp. 141–142.
18	Lisbon Valley (Pioneer)	do	Disseminated copper minerals in sandstone	Butler and others, 1920, p. 615.
19	Tutsagubet	Washington	Oxidized copper and lead-silver ore bodies in Pennsylvanian limestone.	Kinkel, 1951; Hewett and others, 1936, pp. 76–77.

LESS THAN 1,000 TONS

20	Box Elder	Box Elder	Copper, lead, and zinc deposits in a fault zone striking N. 60° E. and dipping 50° SE. in Cambrian limestone.	Butler and others, 1920, pp. 221–222.
21	Willard	do	Copper and lead minerals in vein in Algonkian Precambrian quartzite; galena, tetrahedrite, pyrite, chalcopyrite are the ore minerals.	Butler and others, 1920, p. 222.
22	Sierra Madre	Weber and Box Elder.	Narrow veins composed of quartz, chlorite, pyrite, and chalcopyrite in Precambrian granite.	Butler and others, 1920, p. 223.
23	Promontory	Box Elder	Copper deposits in quartzite striking NE. and dipping 16° to 20° SE.; disseminated chalcopyrite and bornite(?) are the ore minerals.	Butler and others, 1920, pp. 499–502.
24	Weber	Weber	Vein between quartzite and limestone containing copper ore with gold and silver.	Butler and others, 1920, p. 223.
25	Fremont Island	do	Small veins containing gold, silver, copper, and lead	Butler and others, 1920, pp. 502–503.
26	Morgan	Morgan	Veins striking N. 30° to 45° W. and replacement bodies containing pyrite, chalcopyrite(?), and oxidized copper minerals in quartz-calcite gangue.	Butler and others, 1920, pp. 219–220.
27	Farmington	Davis	Vein striking E. and dipping 60° to 90° N., 4 to 12 feet wide; contains chalcopyrite, pyrite, specularite, and quartz.	Butler and others, 1920, p. 226.
28	Browns Park area	Daggett	Copper carbonates and sulfides in veins and disseminated in Precambrian quartzite, mica schist, and amphibolite.	Butler and others, 1920, p. 605, Hansen, 1957.
29	Silver Islet	Tooele	Lenticular bodies in fissures that strike N. and dip steeply W.; minerals are quartz, and sulfides of lead, copper, and iron.	Butler and others, 1920, pp. 487–488.
30	Little Split Mountain area	Uintah	Copper carbonates and chalcocite in sandstone of late Paleozoic age.	Butler and others, 1920, p. 606.
31	Ouray area	Wasatch	Copper and iron, largely oxidized near the surface. Copper carbonates and chalcocite in sandstone of Tertiary age.	Do.
32	Columbia	Tooele	Quartz-fluorite veins containing pyrite and chalcopyrite that strike N. 25° to 45° W. in granite.	Butler and others, 1920, pp. 427–429.
33	Dugway	do	Replacement veins in limestone containing lead, silver, and copper minerals.	Butler and others, 1920, p. 463; Staatz and Carr, in press.
34	Santaquin	Utah	Narrow veins of chalcopyrite with specularite, quartz, and chlorite in fissures in Cambrian quartzite and shale.	Butler and others, 1920, pp. 329–330.
35	West Tintic	Juab	Silver-lead-zinc-copper ores along fissures that strike N. 65° to 75° E. and N. 15° to 20° E.	Butler and others, 1920, pp. 439–444.
36	Detroit	Juab and Millard	Pyrite, chalcopyrite, and other sulfides in veins in limestone near porphyry dikes.	Butler and others, 1920, pp. 464–465.
37	Leamington	Millard	Quartz veins containing copper carbonates and iron oxides	Butler and others, 1920, p. 423.
38	Moab area	San Juan	Chalcopyrite, chalcocite, covellite, and bornite disseminated in sandstone; oxidized copper minerals near surface.	Finch, 1959, pp. 143, 150.
39	Marysvale (Ohio)	Sevier	Chalcopyrite, tetrahedrite, galena, sphalerite, and pyrite in veins with quartz, fluorite, and barite.	Butler and others, 1920, pp. 555–556.
40	Granite	Beaver	Sulfides of copper, lead, and zinc in replacement bodies and contact deposits.	Butler and others, 1920, pp. 533–536.
41	Lincoln	do	Sparse copper minerals in gold-silver ore from the Creole mine	Butler and others, 1920, p. 530.
42	Capital Reef area	Wayne	Oxidized copper minerals in channels in sandstone	Finch, 1959, p. 152.

TABLE 4.—*Mining districts in Utah with recorded copper output, 1870–1961*—Continued

Map locality	District	County	Type of deposit	References
			LESS THAN 1,000 TONS	
43	White Canyon area	San Juan	Chalcopyrite, bornite, pyrite, and covellite in uranium deposits in sandstone.	Trites and Chew, 1956, p. 244.
44	do	do	Covellite and chalcocite associated with uranium deposits	Finch, 1959, pp. 141, 142.
45	Silver Reef	Washington	Sulfides of copper associated with silver minerals in sandstone	Butler and others, 1920, p. 592.
46	Monument Valley	San Juan	Oxidized copper minerals associated with uranium deposits in sandstone.	Finch, 1959, p. 148.
47	Salina Creek	Sevier	Oxidized copper minerals associated with lead-zinc ores in calcareous sandstone.	Butler and others, 1920, pp. 558–561.

DISSEMINATED ORES IN PORPHYRY

The Bingham district is one of the best examples of metal zoning in the world. A central zone of copper and molybdenum is surrounded by a middle zone of copper-lead-zinc and an outer zone of lead-zinc-silver (James, Smith, and Bray, 1961). The central zone coincides roughly with the Bingham porphyry stock which cuts limestone and quartzite of the Oquirrh Formation. Copper and molybdenum sulfides are the principal ore minerals. The middle zone on the periphery of the porphyry stock contains replacement bodies of copper ores which grade laterally into copper-lead-zinc ores. Chalcopyrite and bornite are the principal copper sulfides; enargite is locally significant. In the outer part of the middle zone galena and sphalerite predominate. In the outer zone galena, sphalerite, and tetrahedrite are the principal ore minerals; many of these ores are high in silver and gold. The copper content is commonly low, except locally in the oxidized zones.

The central zone in the porphyry stock is about two-thirds of a mile in diameter (James, Smith, and Bray, 1961, p. 86). Studies of the distribution of iron, copper, and molybdenum in this zone show that the iron content is highest just outside the borders of the stock; copper is irregularly distributed but is generally higher near the borders; and molybdenum is higher in the central part. The copper sulfides are chalcopyrite (56 percent of the copper), bornite (29 percent), chalcocite (12 percent), and covellite (3 percent). Molybdenite is the only molybdenum mineral. Pyrite and pyrrhotite are the principal iron sulfides; magnetite and specularite occur locally in peripheral contact zones.

Although the distribution of copper sulfides is far from uniform, careful blending of ores from different parts of the pit provides a uniform mill feed. Ore mined in 1962 contained, on the average, 16 pounds of copper to the ton, and about 0.03 ounce of gold. The molybdenum content of the ore probably averages about 0.04 percent, based on statements of the Kennecott Copper Corp. (1961) concerning copper-molybdenum ratios in the concentrates (30:1.5).

Major long-range improvements are being made at the mine, mills, and smelter to increase production to 1950 levels (275,000 short tons of copper annually). This work is scheduled for completion in 1967.

Other examples of disseminated copper deposits in Utah are the OK and Cactus mines (in districts Nos. 12 and 13), in Beaver County (Butler and others, 1920, pp. 504, 517). Copper metallization at the OK mine is in a pipelike body in quartz monzonite; oxidation extends to a depth of about 200 feet, and below a thin enriched zone, primary chalcopyrite and pyrite are found. The Cactus mine deposit is a chimney-shaped body in brecciated quartz monzonite; chalcopyrite, pyrite, iron oxides, tourmaline, and barite fill cavities in the breccia. Recent exploration in nearby contact deposits at the Bwana mine in the Beaver Lake district (No. 12) by J. F. Powers and A. O. Taylor has led to the installation of a 500-ton mill by the Majestic Mining & Oil Co. Exploration of disseminated copper deposits in quartz monzonite northwest of the Bwana mine was being carried on in 1963 by the Bear Creek Mining Co.

The copper deposits in Beaver County are in the Wah Wah-Tushar mineral belt. This belt appears to have excellent potential for additional discoveries in areas covered by alluvium and volcanic rocks. (See section on economic geology, p. 28.)

CONTACT METAMORPHIC AND REPLACEMENT DEPOSITS

Contact metamorphic and replacement bodies in the Bingham, Tintic (No. 10), Park City (No. 3), and San Francisco (No. 14) districts have contributed important amounts of byproduct copper from silver and lead ores. In the last three of these, copper has made up from 3 to 10 percent of the total values in the ore. In general, the copper content has increased downward, and will play a larger role in future production from these areas as the mines are deepened.

On the west side of the Kennecott pit at Bingham, mines of the Anaconda Co. in Carr Fork have yielded about 12 million tons of ore from two limestone units interlayered with quartzite (Hansen, 1961, p. 70). These units dip steeply and are locally overturned; in places the ore was more than 100 feet thick (Boutwell, 1905, p. 267). The oxidized zone was shallow; the sulfide ores contained chalcopyrite, pyrite, galena, and sphalerite in a gangue of lime silicates, iron oxides, and marble.

In the Tintic district, copper is recovered from silver, gold, and lead ores (Cook, 1957, p. 57). The major ore bodies are in folded Paleozoic rocks that have been broken by thrust, strike-slip, and high-angle faults (Morris, 1957, pp. 1–56). The principal ore-bearing faults strike northeast and the ore bodies are localized at the intersections of north-trending and north-northeast-trending fissures. Most of the ore has come from replacement deposits, but considerable production has also come from fissure deposits. The principal primary copper minerals of the replacement deposits are enargite and tetrahedrite and associated galena, sphalerite, argentite; the principal copper minerals in the fissures are enargite, some chalcopyrite, arsenopyrite, tetrahedrite, and associated silver sulfides.

The Tintic district is in the Deep Creek-Tintic mineral belt. Other areas of good potential for future discoveries are on the fringes, especially east and south of the presently productive areas.

In the Park City district (No. 3) copper ores are associated with silver-lead-zinc ores in the Ontario and Mayflower ore zones (Wilson, 1959, p. 188), which strike northeast. The primary ore bodies consist of galena, sphalerite, chalcopyrite, enargite, chalcocite, and bornite; the oxidized copper minerals were largely azurite and malachite. Replacement ore bodies formed adjacent to fissures that strike N. 50°–70° E.; the ore bodies are as much as 10 feet thick and 800 feet long.

The Park City district is in the Oquirrh-Uinta mineral belt. Most of the production thus far has come from Mississippian to Permian limestones; limestones below the Mississippian units offer good potential for deeper exploration.

Contact metamorphic and replacement copper deposits in the San Francisco and nearby districts are peripheral to intrusive bodies that contain disseminated copper deposits. The Horn Silver ore body is a pipelike replacement body formed along a fault contact between limestone and silicified volcanic rock. Galena, sphalerite, and chalcopyrite are the primary ore minerals; chalcocite and covellite are the principal copper minerals in the enriched zone; brochantite, azurite, and malachite are the copper minerals in the oxidized zone (Butler and others, 1920, p. 526). The copper minerals were mined mainly from the sixth to ninth levels.

COPPER DEPOSITS IN SANDSTONE

Copper deposits in sandstone are associated with deposits of uranium and vanadium on the Colorado Plateau, principally in the Lisbon Valley (No. 18) Big Indian (No. 17) and White Canyon (Nos. 43 and 44) districts in southeastern Utah. (See section on uranium, p. 124.)

The deposits are mostly in fluvial Triassic sandstone and conglomerate, especially the Shinarump Member of the Chinle Formation (Fischer and Stewart, 1960; Finch, 1959, pp. 141, 147). The ore minerals are chalcocite, covellite, bornite, and chalcopyrite which are associated with pyrite, marcasite, and uranium and vanadium minerals; copper carbonates occur in oxidized zones. The ore minerals fill pores in the host rock and locally replace fossil wood fragments and detrital grains. The ore bodies are mostly in channels cut into the underlying rock and are lenticular or tabular. In the 1957–61 period the grade of ore mined generally ranged from 0.75 to 2.0 percent copper and averaged about 1.0 percent.

It is estimated that known and undiscovered resources of copper in Utah are roughly equal to the total mined to date. Much of this resource probably is in the Bingham porphyry copper deposit. Although reserve figures for this deposit are not available, the recently announced $100 million expansion program of the company probably is indicative that the mine will continue the present rate of output for the next several decades. Other important reserves are known and additional resources may be found in hidden porphyry deposits in the Oquirrh-Uinta, Deep Creek-Tintic, and Wah Wah-Tushar mineral belts. (See section on economic geology, p. 28, and fig. 8.)

GOLD

(By M. H. Bergendahl, Denver, Colo.)

Gold is prized by man as a universal standard of value, the common medium of exchange in world commerce, and the monetary standard of many nations. It also is widely used in the decorative arts and to a limited extent in industry and science.

Gold most commonly occurs as the native element associated with quartz or metallic sulfides; it also occurs alloyed with silver as electrum, or combined with tellurium, silver, and other elements in several telluride minerals; and in several rare minerals it forms compounds with mercury, bismuth, and chlorine.

Since 1946, Utah has ranked second among the states in annual output of gold and through May 1963, Utah has produced about 16,915,000 ounces of gold. It ranks seventh among the States in total gold output. The most productive area is near Salt Lake City, where the four largest mining districts—Bingham, Tintic, Camp

Floyd, and Park City—are located. A total of 13 districts have produced more than 10,000 ounces of gold each (fig. 19). These are:

[Total output in ounces through 1961 [1]]

1. Bingham (West Mountain)	11,304,442
2. Tintic	2,648,789
3. Camp Floyd	1,115,764
4. Park City	817,886
5. Gold Mountain (Kimberly)	[2] 159,000
6. Ophir-Rush Valley	[2] 104,000
7. Mount Baldy and Ohio (Marysvale)	[2] 77,500
8. American Fork	45,023
9. San Francisco	38,818
10. Cottonwood (Big and Little)	30,510
11. Clifton (Gold Hill)	25,865
12. Stateline and Gold Springs	[2] 12,760
13. Willow Springs	[2] 11,650

[1] Data from U.S. Bureau of Mines.
[2] Through 1959, Koschman, A. H., and Bergendahl, M. H., unpublished data.

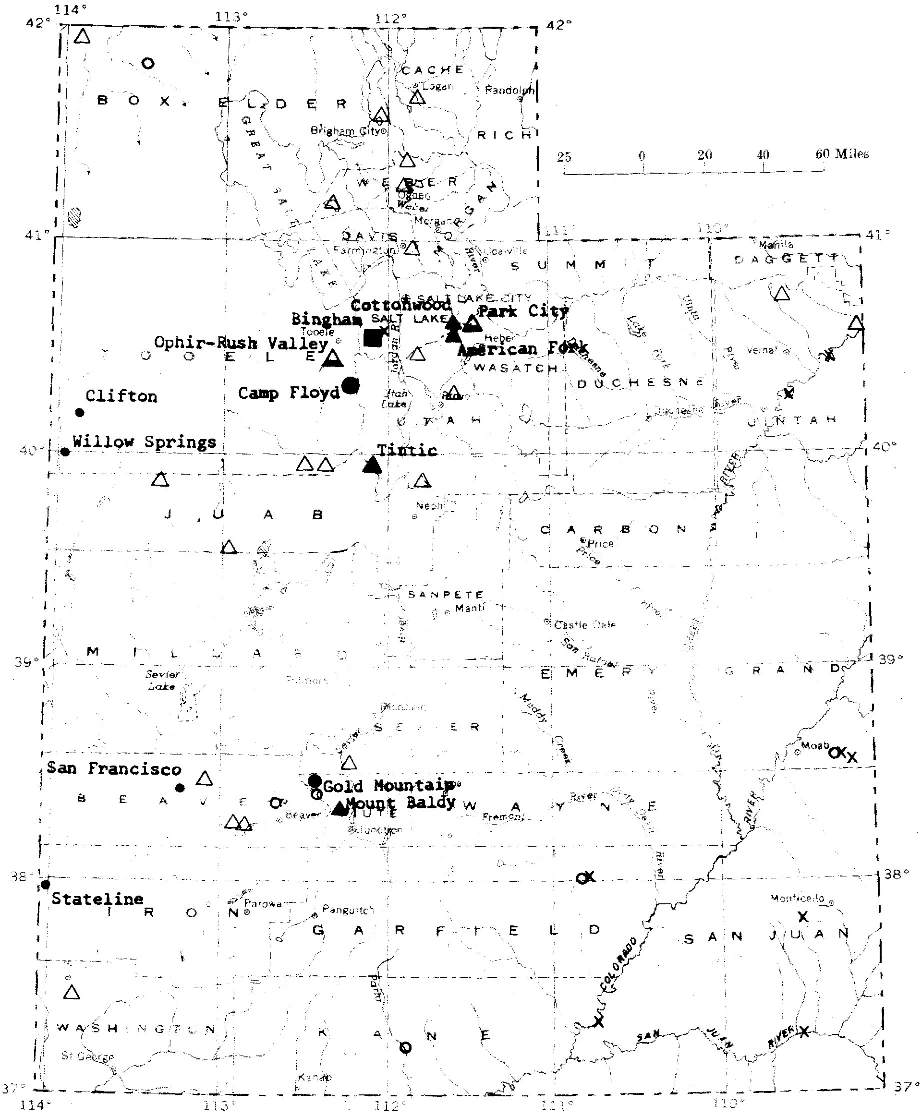
Gold played little part in the early developments in Utah. The settlers were more concerned with establishing a viable community and did not deliberately seek gold. Rather, they looked for and found the more utilitarian resources needed in their pioneer life, such as salt, coal, iron, lead, and sulfur.

Not until 1863, some 16 years after settlements were established, were the first ores containing gold discovered in lower Bingham Canyon. The ores were oxidized lead-silver ores with a little gold. The discoveries are credited to the off-duty activities of Army personnel stationed at Camp Douglas, some of them veterans of the search for gold in California. Gold placers were found in the same canyon the following year, and the ensuing wave of prospecting located most of the metallic mining districts in the State within the next few years, including the Cottonwood-American Fork area in 1866, the Tintic area in 1869–70, and the Park City area in 1870–71.

Although gold was the principal lure, in most of the deposits gold was associated with other metals and was produced only as a byproduct of silver, lead, and copper. There was enough gold in each district to encourage further search.

Gold placers also were discovered in the Camp Floyd district in 1870, but the gold content was too low to more than spark some excitement. Gold mining as such, did not reach the frenzied heights achieved earlier in California or later in Alaska. The rich silver-lead ores, although they contained gold, had to be smelted to recover the values.

Two major developments about 1870 provided the impetus for gold mining in Utah—the installation of smelters and the completion of railroads. Production at Tintic, for example, doubled in 1879 and jumped from $1 million in 1885 to $5 million in 1890 (Lindgren and Loughlin, 1919, p. 106). Bingham also expanded its operations during this period. Prospectors continued to make important finds. The discovery of the Ontario ore body at Park City in 1872 gave this district early prominence (Boutwell, 1912, p. 19). Other mines were active in the San Francisco, Ophir-Rush Valley, and American Fork districts in the 1870's, and in the Stateline and Clifton (Gold Hill) districts in the 1890's.



EXPLANATION

Gold-mining district, showing principal type of deposit and relative output, 1865-1959

Type of deposit	> 1,000,000	100,000-1,000,000	10,000-100,000	< 10,000
	(output in troy ounces)			
Disseminated	■			
Replacement	▲	▲	▲	△
Vein	●	●	•	o
Placer				x

Districts named on map have produced more than 10,000 troy ounces.

FIGURE 19.—Gold in Utah.

At intervals during the 1870's and 1880's the Mercur lode at Camp Floyd had been unprofitably worked and the district became virtually deserted. In 1890 attempts were made to extract gold using the newly developed cyanide process. The results were successful, and Camp Floyd soon became a major gold producer (Gilluly, 1932, pp. 123, 124).

The depression of 1893 and the accompanying drop in the price of silver had a profound effect on mining in Utah. At Bingham interest turned to the copper deposits that had previously been considered too low in grade to be mined. After several years of experimentation, exploration, and consolidation of properties, large scale mining of the disseminated copper deposits was begun in 1907. (Boutwell, 1935, p. 349). Gold has been consistently an important byproduct of these operations. Output of copper ores at Bingham has been increased to the extent that today it is the second largest gold producer in the United States.

In Utah, gold occurs in four major types of deposits: replacement deposits, fissure veins, disseminated copper deposits, and placers. In most districts it is found in more than one of these types of deposits.

Replacement deposits.—The replacement deposits are found principally in folded and faulted limestone beds of Paleozoic and Mesozoic age. These are most commonly tabular bodies that follow bedding, but locally as at Tintic, fault intersections may influence the formation of chimney-shaped deposits (Cook, 1957, pp. 63–70). The primary ores consist of masses of metallic sulfide minerals in which the gold is present as minute disseminations. Rich ore occurs in the oxidized portions of these deposits where gold has been released by the decomposition of the sulfides.

Unique among the gold-bearing replacement deposits of Utah is the Mercur lode in the Camp Floyd district. The principal minerals are pyrite, realgar, orpiment, and cinnabar in a gangue of jasperoid, barite, and calcite. The gold is too fine grained to be seen, and its mode of occurrence is not known; however, analyses have shown a relationship between gold and carbon (Butler and others, 1920, p. 394).

In most other replacement deposits in Utah, gold is a byproduct of ores mined principally for lead, silver, or zinc. Districts in which replacement deposits have yielded significant amounts of gold are Tintic, Cottonwood, Ophir-Rush Valley, Willow Springs, Mount Baldy, San Francisco, and Park City, and some of the Bingham ores.

Fissure veins.—The fissure vein deposits are mineralized fractures or faults that occur in rocks of a wide variety of lithologic types and geologic ages. Tertiary volcanic rocks contain gold-bearing veins in the Stateline district (Butler and others, 1920, p. 565), and the Gold Mountain district (Callaghan, 1938, pp. 98–100; Lindgren, 1906, pp. 88–90). Veins occur in various sedimentary formations of Paleozoic age in the Bingham district (Boutwell, 1905, pp. 126–154), the Tintic district (Cook, 1957, pp. 70–71), the Park City district (Wilson, 1959, pp. 183–188), and the Clifton district (Nolan, 1935, pp. 97–103). In the American Fork district quartzite beds of Precambrian and Cambrian age are cut by veins (Calkins and Butler, 1943, pp. 93, 94). A mass of Tertiary diorite porphyry in the Park City district is host for a few veins (Wilson, 1959, pp. 183–188).

The minerals of the veins include pyrite, arsenopyrite, galena, sphalerite, chalcopyrite, tetrahedrite, enargite, bornite, argentite, and locally small amounts of sulfantimonides and sulfarsenides. Gangue minerals are quartz, carbonate, fluorite, barite. Adularia, which is characteristic of epithermal deposits, is a component of the gangue in the veins of the Stateline district (Butler and others, 1920, p. 565) in the Gold Mountain district (Lindgren, 1906, pp. 88–90), and the Mount Baldy district, where alunite is also abundant (Butler and others, 1920, p. 557). The gold in the veins occurs as fine particles of native gold, as tellurides, or dispersed in the sulfide minerals.

Disseminated copper deposits.—The Bingham district contains the only important deposit of this type in Utah and is by far the most important ore deposit in the State. Copper is the principal commodity, but large quantities of gold are recovered as a byproduct.

The disseminated copper ore body is a mass of fractured and altered monzonite of Tertiary age. Grains of copper sulfides coat the walls of fissures and minute fractures that cut the monzonite and adjacent wallrocks. These veins and veinlets contain quartz, orthoclase, and smaller amounts of chalcopyrite, molybdenite, galena, and sphalerite. The gold is very fine-grained and occurs in the copper minerals. It is recovered from the slimes resulting from the electrolytic refining of the copper anodes.

The placers of Utah are in stream gravels, where the gold derived from weathering was separated mainly from silver and base metal deposits, and concentrated by gravity through the action of moving water. Gold placers in Utah have been of minor economic importance and only those at Bingham had any appreciable output. Other placers were worked along the San Juan, Green, and Colorado Rivers, but were not large producers. In part, the relative lack of placer deposits in comparison to other western mining areas reflects the kind of mineralization found in Utah's mining districts. Free gold is sparsely present in a few ores, but in most is intimately associated with metallic sulfides and would be released in a very finely divided state during weathering. Another factor that worked against placer accumulation is the lack of abundant perennial streams to work and rework the sediments. Most of the gold that might have formed placers in other environments became dispersed in the immense basin fillings.

All four types of gold deposits in Utah are distributed in near proximity to intrusive stocks and small batholiths, and the emplacement of these intrusions was influenced by regional structures.

The Cottonwood, American Fork, and Park City districts are clustered in an irregular area whose center is at the intersection of the northtrending thrusts of the Wasatch Range with the westward projection of the anticlinal axis of the Uinta Mountains. The fairly large intrusive bodies in this area, aside from dikes and sills, are the only intrusive rocks known in the Wasatch Mountains. This area also contains the only important ore deposits (Calkins and Butler, 1943, pp. 3–4). At Bingham, northwest-trending folds in Paleozoic rocks are cut by west to northwest-trending thrusts and high-angle faults and by northeast-trending reverse faults. The intersection of the northeast-trending faults with trends of fold axes and the northwest faults were loci for the intrusions and their associated ore deposits (James and others, 1961, pp. 49–66). In the Camp Floyd district, sedimentary rocks of Paleozoic age were deformed into northwest-trending folds, faulted and intruded by several monzonite and rhyolite stocks and sills of Tertiary age (Gilluly, 1932, pp. 6, 41). At Tintic the ore deposits are spatially related to stocks of quartz monzonite and monzonite porphyry which intrude a thick series of folded and complexly faulted Paleozoic sedimentary rocks overlain by flows of quartz latite and latite lavas (Morris, 1957, pp. 30–51). The largest deposit of the San Francisco district, the Horn Silver ore body, is on a fault between Upper Cambrian carbonate rocks and Tertiary volcanic rocks (D. M. Lemmon, written communication, 1963) ; other deposits include unmineralized breccia pipes and contact zones. In the Gold Mountain district, the deposits are in a sequence of volcanic rocks believed to be of early Tertiary age, which is cut by masses of quartz monzonite (Callaghan, 1938, pp. 98–100). In the Mount Baldy district, faulted and warped Jurassic sedimentary and early Tertiary(?) volcanic rocks are hosts for the ore deposits (Butler and others, 1920, pp. 538–557). The Ophir-Rush Valley district is underlain by sedimentary rocks of Cambrian to Pennsylvanian age that were folded into a northwest-trending anticline and then faulted and intruded by numerous stocks, dikes, sills, and plugs of monzonite, rhyolite, andesite, lamprophyre, and nepheline basalt. The major deposits are at intersections of limestone beds of Pennsylvanian age with faults (Gilluly, 1932, pp. 157–162). Paleozoic sedimentary rocks in the Clifton district were subjected to at least five cycles of faulting and then mineralized (Nolan, 1935, pp. 97–103). Complex faulting of Paleozoic sedimentary rocks is also associated with mineralization in the Willow Springs district (Nolan, 1935, pp. 167–168). The deposits of the Stateline district occur in flat-lying, but extensively fractured Tertiary volcanic rocks. These deposits are shallow and are typical of the epithermal type in that they are not directly related to an intrusive (Butler and others, 1920, p. 565).

The rich, easily mined oxidized ores of the pre-1900 era have long been exhausted, and from the end of World War II to the present, the gold-mining industry has been faced by a selling price that has been held fixed during a period of steadily rising costs, together with production of generally lower grades of ores. As a consequence, gold output in the United States has steadily declined.

Due mainly to the large production of base-metal ores at Bingham, Tintic, and Park City that yield gold as a byproduct, Utah's gold output belies the depressed condition of gold mining elsewhere in the United States. Since 1905, gold production has been more closely related to reserves and economic factors that govern the mining of base metals, and the post-World War II period records a vigorous increasing trend for gold (fig. 2).

What can be predicted for the future in terms of reserves and output? Some expression of the total known and undiscovered gold resources in Utah is possible when based on available mine reserve data, past production records, and geologic inference. Such an estimate indicates that Utah has total resources of known and undiscovered materials that contain about twice as much gold as has been mined to date. Some of these resources are known, and others may be found in deposits in the Oquirrh-Uinta, Deep Creek-Tintic, and

Wah Wah-Tushar mineral belts. (See section on economic geology, p. 28, and fig. 8.) Since the open-pit copper mining at Bingham currently accounts for more than 90 percent of Utah's gold, the activity of this single district probably will dominate the gold output for the next several decades. (See section on copper, p. 75.) The vein gold districts in the State will continue relatively inactive, but the renewed activity at Tintic will almost certainly yield important quantities of gold. It appears likely that gold output will continue at its present levels unless economic factors change radically.

IRON

(By R. G. Reeves, Washington, D.C.)

Iron ore is the prime raw material in the production of iron and steel, which in turn are basic to our present industrial economy. In addition to iron ore, huge quantities of fuel (coal of coking quality), water, and lesser amounts of limestone and other raw materials are required for the production of iron and steel. The iron and steel industries and their related manufacturing industries are most fully developed where iron ore and coal occur or can be brought together easily and cheaply. In 1961, 54 percent of U.S. iron and steel production was in Pennsylvania, Ohio, and Indiana; most of this was used in nearby industries. The Western States,[1] with 15 percent of the population (1960 census), produces only about 7 percent of the Nation's iron and steel. In the Western States, production is concentrated in Utah, California, and Colorado, with minor steel production in Arizona, Oregon, and Washington. At the present time, most of the ore on which the western iron and steel industry is based comes from Utah, Wyoming, and California.

Of the iron ore consumed in the United States, most (93 percent in 1961) is used in blast furnaces to make pig iron. Most of this pig iron and the remainder of the iron ore is used to make steel. Pig iron is mostly iron with some remaining impurities such as phosphorous and sulfur, depending on the composition of the ore and the blast furnace practices. Removal of impurities in the various steel-making processes may be costly and lead to considerable loss of iron or decrease in capacity, so the amount and nature of the impurities in the ore are often of greater importance than the absolute iron content.

The processes, including types of furnaces, used in an integrated iron and steel plant depend largely on the composition of the ore. Also, blast furnaces and attendant steel furnaces should be a certain minimum size (currently about 800 to 1,000 tons per day for blast furnaces) to be efficient and competitive. Installations of this size require large quantities of iron ore (15 to 20 million tons during the life of the smallest practicable installation) of a reasonably uniform composition, both as to iron content and impurities. Exploitation of small deposits of a few hundred thousand to a few million tons are therefore not feasible unless the ore is suitable for, and within economic transportation limits of, an established iron or steel plant.

---

[1] Includes for this discussion the States of Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Utah, Washington, and Wyoming.

Large volume low-cost mining operations by open-pit methods are favored.

Prior to World War II, almost all iron ore was charged directly into blast and steel furnaces without beneficiation. In 1961, more than 80 percent of the crude ore [2] mined in the United States was beneficiated before use; such material comprised 55 percent of the ore used in domestic furnaces. The chief reasons for this were: (1) Threatened or anticipated exhaustion of available high-grade ore during World War II, which stimulated beneficiation techniques and installations, (2) excessive fines (material under a given size, generally one-half inch) produced at some large-scale operations, which could not be used satisfactorily in blast furnaces, and (3) improved furnace operation and efficiency resulting from the use of beneficiated material. This use of such material instead of crude ore is increasing, chiefly owing to this improved furnace operation and efficiency, and is expected to continue to increase.

World production of iron ore in 1961 was 498 million long tons; [3] that of the United States was 137 million long tons of crude ore. Of the ore produced in the United States, 26 million long tons was direct shipping ore, and the remaining 111 million long tons was beneficiated to produce 54 million long tons of usable ore. Utah ranked fifth among the States in domestic production, producing 3,602,000 long tons.

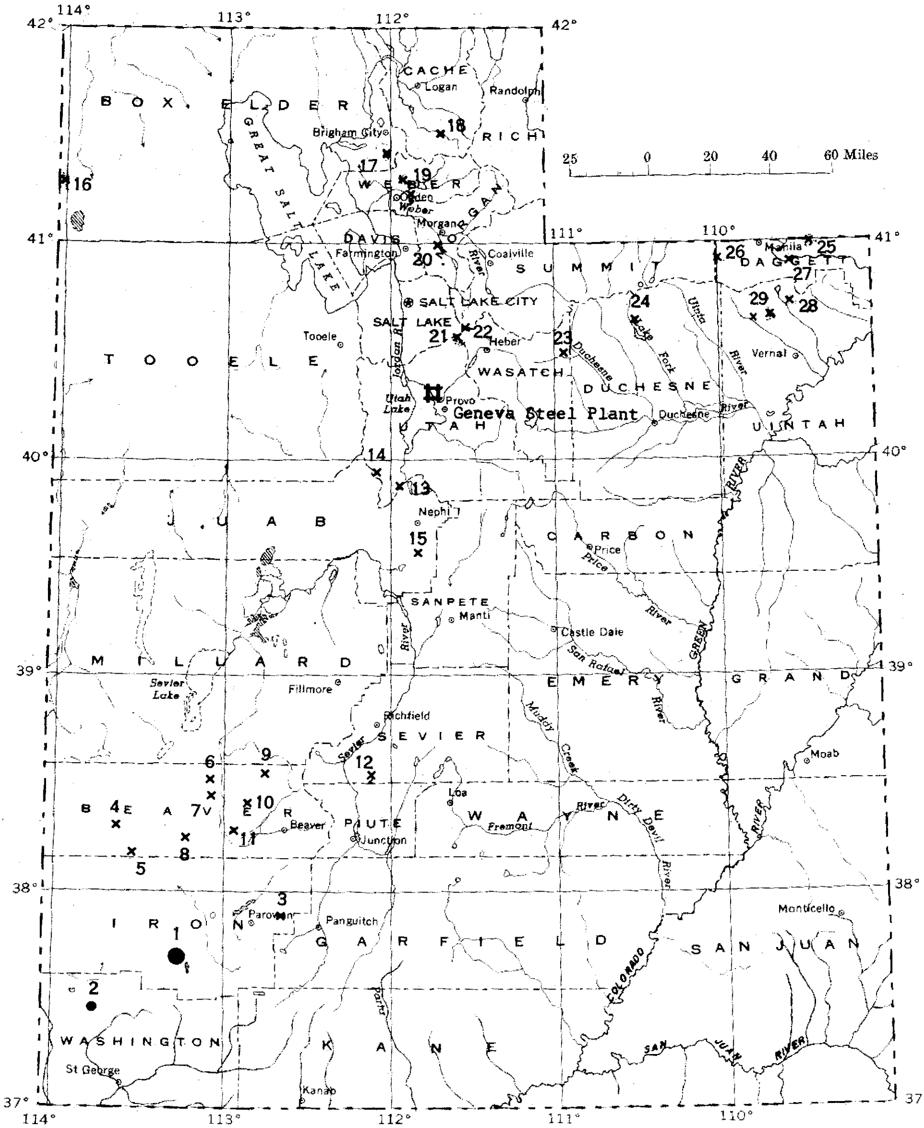
Mining of iron ore in Utah commenced in 1852, but was sporadic and rather unimportant until the early twenties when the availability of Utah coking coal and other raw materials and the promise of suitable markets brought about the establishment of a blast furnace and other facilities near Provo (Larson, 1963, pp. 248–261). As a result, by 1962, 67 million long tons of iron ore had been produced, with a value of $313 million. Except for a few tens of thousands of tons, all of this production was from the Iron Springs district. About three-fourths of Utah iron ore is used in the Geneva steel plants near Provo; the rest is shipped chiefly to Pueblo, Colo.

Iron deposits and iron ores may be classified in many ways; on the basis of origin or form of the deposits, and on the basis of mineralogy, physical characteristics, grade, or by use of the ore. The iron deposits of Utah are mostly massive and irregular, in which the iron ore minerals have replaced principally sedimentary rocks, although locally igneous rocks have been replaced. Veins of iron ore, although numerous, widespread, and containing material of exceptional quality, are generally too small to be mined profitably. Both the irregular massive and vein deposits are related to intrusive bodies. Gossans formed by the leaching and oxidation of pyrite and other metallic sulfides, and "bog ore" deposits of hydrous iron oxides deposited in lakes and swamps also constitute iron deposits in Utah.

Iron ores are classed as hard, soft, or intermediate, depending on the amount of fines produced during mining, crushing, and handling; as Bessemer or non-Bessemer, based largely on the phosphorous content (Bessemer ore has less phosphorous); as direct shipping or crude ore, depending on whether or not beneficiation is needed before use

[2] The term "crude ore" in the iron and steel industry is material that is not beneficiated prior to use in blast or steel furnaces. "Usable ore" is material that may be charged into furnaces, and consists of "direct shipping ore" and beneficiated crude ore.

[3] A long ton is 2,240 pounds avoirdupois.



EXPLANATION

Size of district or deposit: Production plus reserves, in long tons

- ● Large: more than 10,000,000
- ● Intermediate: 2,000,000 to 10,000,000
- × Small: less than 2,000,000

Numbers refer to mines and districts listed in text

FIGURE 20.—Iron in Utah.

in the furnace; as self-fluxing (produces a satisfactory slag during smelting); and in many other ways depending on the purpose for which the classification is intended. Most of the iron ore produced from Utah deposits is hard, high-grade, non-Bessemer, direct-shipping ore.

The principal Utah iron ores consist of one or both of the iron oxide minerals hematite (70 percent iron) and magnetite (72 percent iron). Ores that contain siderite, an iron carbonate mineral (48 percent iron); "limonite," various hydrous forms of iron oxide; or iron silicates are less common and less important. Pyrite and other iron sulfides are minor sources of iron as byproducts of other mining and metallurgical operations.

Iron deposits and occurrences are widespread in Utah, and have been reported in at least 16 of the 29 Utah counties. The only known major deposits, from which almost all of the Utah iron-ore production has been obtained, are those of the Iron Springs district in central Iron County. Smaller deposits occur in the Bull Valley-Cove Mountain district, Washington County; in the Uinta Mountains in Daggett, Duchesne, Summit, and Uintah Counties; in the Wasatch Range, in Box Elder, Morgan, Salt Lake, Wasatch, and Weber Counties; and in the Bear River Mountains in Cache County. Gossans have been exploited for iron ore for flux in the Wah Wah Range and elsewhere in Beaver County; in Utah County near Eureka; near Lucin, Box Elder County; and southeast of Sevier, Sevier County. Utah iron-ore deposits have been described principally by Boutwell (1904), Leith (1904), Leith and Harder (1908), Butler and others (1920), and Crawford and Buranek (1943). Twenty-eight of the more important districts, deposits, and occurrences are shown in figure 20 and listed in table 5. These deposits are shown as large, intermediate, or small (fig. 20). As designated by Dutton and Carr (1947) for western United States iron-ore deposits, large deposits contain more than 10 million long tons, intermediate deposits have from 2 to 10 million long tons, and small deposits have less than 2 million long tons.

Table 5.—*Iron ore districts, deposits, and occurrences in Utah*

Number	Name of district, deposit, or occurrence, and location	Type	Reference
1	Iron Springs district, Iron County: T. 35 S., Rs. 12–13 W., T. 36 S., Rs. 13–14 W., and T. 37 S., R. 14 W.	Hematite-magnetite replacement in limestone, and magnetite veins.	Leith (1904), pp. 229–237; Leith and Harder (1908): Mackin (1947, 1953); Granger (1963, pp. 146–150).
2	Bull Valley-Cove Mountain district, Washington County: T. 38 S., R. 17 W.	do	Leith and Harder (1908), pp. 90–92; Wells (1938), pp. 477–507.
3	Paragonah district, Iron County: Secs. 19, 30, T. 33 S., R. 7 W.	Massive magnetite replacement in intrusive volcanic rock.	Young (1947), p. 1, fig. 1; J. W. Powers, oral communication.
4	Central Wah Wah Range deposit, Beaver County: West-central part, T. 27 S., R. 15 W.	Probably brown "ore," gossan type.	Utah Mining Association, p. 30.
5	Blonde Mountain (Iron Queen) deposits, Wah Wah Range, Beaver County: T. 29–30, S., R. 15 W.	Hematite replacements in limestone.	Crawford and Buranek (1943), pp. 13–14.
6	Iron Mine Pass deposits, Beaver County: Sec. 19, T. 26 S., R. 11 W.	Small, scattered pods of hematite in dolomite bed in Precambrian(?) quartzite.	D. M. Lemmon, oral communication.
7	Rocky district, Beaver County: Sec. 23, T. 27 S., R. 11 W.	Massive magnetite replacement in limestone.	Hobbs (1945b), p. 95, pl. 36.
8	Blue Mountains area, Beaver County: Southwest corner (secs. 30 and 31), T. 29 S., R. 12 W.	Hematite-magnetite replacements in limestone.	Young (1947), p. 1, fig. 1.

TABLE 5.—*Iron ore districts, deposits, and occurrences in Utah*—Continued

Number	Name of district, deposit, or occurrence, and location	Type	Reference
9	Mineral Range deposit, Beaver County: Central part, T. 26 S., R. 8 W.	Not given	Utah Mining Association (1959), p. 30.
10	McGarry district, Beaver County: Northeast part, T. 28 S., R. 9 W.	do	Do.
11	Cave mine, Beaver County: Sec. 12, T. 29 S., R. 10 W.	"Limonite," gossan	Butler and others (1920), pp. 530–531.
12	Krotki Iron (Iron Cap) mine, Antelope Range, Sevier County: Sec. 15, T. 26 S., R. 3 W.	Manganiferous limonite in tuff breccia of the Bullion Canyon volcanics.	Butler and others (1920), p. 546; Crawford and Buranek (1943), p. 17; Callaghan and Parker, 1961.
13	Spalding and Queen of the West deposits, Utah County: Secs. 9 and 16, T. 11 S., R. 1 W.	Manganiferous iron ore	Crittenden (1951), pp. 47–48.
14	Dragon and Black Jack iron mines, Tintic district, Utah County: Secs. 30 and 31, T. 10 S., R. 2 W.	Gossan bodies at contact of monzonite intrusives.	Lindgren and Loughlin (1919), pp. 258–261; Butler and others (1920), p. 415; Crawford and Buranek (1943), p. 15.
15	Levan area, Juab County: Southwest part, T. 14 S., R. 1 E.	Not given	Utah Mining Association (1959), p. 55.
16	Copper Mountain mine, Lucin district; Box Elder County: Southeast part, T. 7 N., R. 19 W.	"Limonite," gossan type	Butler and others (1920), pp. 492–493; Crawford and Buranek (1943), pp. 16–17.
17	Willard district, Box Elder County: Sec. 13, T. 8 N., R. 2 W.	Hematite-magnetite "ferruginous schist" (replacement body, metamorphosed?).	Butler and others (1920), p. 222; fig. 36, p. 221.
18	Mineral Point deposit, Cache County: Secs. 24 and 25, T. 9 N., R. 2 E.	Hematite replacement in limestone.	Crawford and Buranek (1943), pp. 12–13.
19	Weber district, Weber County: About sec. 30, T. 6 N., R. 1 W., and sec. 30, T. 7 N., R. 1 W.	Hematite-magnetite replacement bodies in limestone.	Butler and others (1920), p. 223; Crawford and Buranek (1943), p. 11.
20	Norway Iron Mining & Manufacturing Co. mine, Hardscrabble district, Morgan County: Northeast part, T. 3 N., R. 2 E.	"Brown ore," probably gossan type.	Butler and others (1920), p. 226; Crawford and Buranek (1943), p. 10.
21	Mountain Lake deposit, Salt Lake County: Sec. 2, T. 3 S., R. 3 E.	Contact metamorphic magnetite in Mississippian limestone.	Crawford and Buranek (1943), p. 9; Calkins and Butler (1943), p. 92.
22	Brighton-Park City area, Summit County: Sec. 30, T. 2 S., R. 4 E.	Hematite masses at contact of limestone and diorite.	Boutwell (1912), p. 110.
23	Rhodes Plateau deposits, Wasatch County: Sec. 7, T. 1 N., R. 9 W., Uinta meridian.[1]	Hematite replacement of limestone "in and adjacent to E.-W. fracture and breccia zones."	Boutwell (1904), p. 226, Butler and others (1920), pp. 602–603, Crawford and Buranek (1943), pp. 5–7.
24	Moon Lake deposit, Duchesne County: West-central part, T. 2 S., R. 13 E.	Not given	Utah Mining Association (1959), p. 41.
25	Spring Creek deposit, Daggett County: About secs. 14–15, T. 3 N., R. 22 E.	Limonite with manganese	Boutwell (1904), p. 225.
26	Birch Creek deposit, Daggett County: Sec. 3, T. 2 N., R. 17 E.	"Limonite," gossan type	Crawford and Buranek (1943), p. 8.
27	Red Canyon deposit, Daggett County: Probably northwest of Dutch John in secs. 31–34, T. 3 N., R. 22 E.	Hematite vein. [More probably hematite lens in schist in the Precambrian Red Creek quartzite (W. R. Hansen, oral communication, 1963)].	Utah Mining Association, p. 38.
28	Pope Iron mine, Uintah County: Sec. 21, T. 1 S., R. 21 E.	Hematite replacement in Mississippian limestone or in shale of Uinta Mountain group.	Butler (1920), p. 603, Crawford and Buranek (1943), p. 7; Kinney (1955) p. 162.
29	Woodside deposits, Uintah County: Sec. 8, T. 2 S., R. 20 E.	Hematite replacement in Mississippian limestone, and brown oxide in limestone breccia; brown oxide in shale breccia.	Butler (1920), p. 603; Crawford and Buranek (1943), pp. 7–8; Kinney (1955), pp. 161–162.

[1] All other descriptions refer to Salt Lake meridian.

The Iron Springs district (No. 1, fig. 20, table 5) is in south-central Iron County, 15 miles west of Cedar City. Iron ore was discovered in 1849 (Larson, 1963, p. 248) and has been intermittently exploited since 1852, at first for small furnaces near Cedar City and continuously from 1924 on a large scale for the blast furnaces at Ironton and later, Geneva, near Provo.

The iron-ore deposits of the Iron Springs district are magnetite and hematite replacement bodies in the Jurassic Homestake Limestone Member of the Carmel Formation. The known deposits extend 18 miles, from Three Peaks southwesterly to Iron Mountain, in an area about 3 miles wide. The ore bodies are clustered around three quartz monzonite intrusive bodies; from northeast to southwest these are the Three Peaks, Granite Mountain, and Iron Mountain stocks.

Many of the individual ore bodies were exposed at the surface and have been known since early days. Geologic studies of the district have been made by the U.S. Geological Survey (Leith, 1904; Leith and Harder, 1908; Mackin, 1947 and 1954; and Mackin and Ingerson, 1960) and by company and private geologists. Magnetic surveys by the U.S. Bureau of Mines (Cook, 1950) and the several companies working in the district have disclosed blind ore bodies or extensions of known ore bodies; these have been explored by the Bureau of Mines (Young, 1947, and Allsman, 1948) and by the companies, adding appreciably to the ore reserve in the district.

Reserves of all categories of iron ore were estimated by Dutton and Carr (1947) at 350 million long tons. Although many millions of tons have subsequently been mined, exploration has substantially added to these reserves, which are presently considered sufficient to maintain present or slightly higher levels of production for at least a century.

The Bull Valley-Cove Mountain district (No. 2) is in northwestern Washington County, 40 miles southwest of Cedar City and 20 miles southwest of the Iron Springs district. The iron deposits are in a west-trending area 5 miles long and 2½ miles wide, with most of the deposits in the east end (Bull Valley area) and the west end (Cove Mountain area). The deposits were extensively prospected in the early 1900's and were later explored by magnetic surveys by private companies and by trenching and drilling by the Bureau of Mines during World War II; reserves in the Bull Valley area (Granger, written communication) based on results of the Bureau of Mines exploration were estimated at 1 million long tons and those in the Cove Mountain area at slightly more than 1 million long tons (Selfridge, written communication). There has been no production from the area.

The Bull Valley-Cove Mountain area is underlain by Mesozoic sedimentary rocks, chiefly dark bluish-gray limestone and sandstone, that have been intruded by biotite syenite porphyry (Wells, 1938). The intrusion arched, folded, and fractured the sedimentary rocks. Volcanic rocks, which are in part contemporaneous (latite flows) and in part younger (agglomerate, rhyolite flows) than the porphyry, surround the area of sedimentary rocks and porphyry.

The iron deposits are veins and replacement bodies of magnetite and hematite. Veins from 1 to 40 feet thick and over 200 feet long occur in the limestone, latite, and syenite porphyry (Wells, 1938, p. 482). The replacement deposits are in the limestone along the southern edge of, and in roof pendants within the biotite syenite porphyry intrusive body. The largest known replacement body is triangular, 300 feet by 400 feet along the base, with an exposed height of 300 feet.

Small iron deposits, which occur in the Uinta Mountains (Nos. 23–29), probably were first discovered by the Indians who used the material for paint (Boutwell, 1904). In 1879–80, 500 long tons of iron ore were produced from a deposit at Rhodes Plateau (No. 23) in Wasatch County, near the western end of the range about 25 miles east of Heber. Iron-bearing material was also mined from the Pope iron deposits (No. 28) in Uintah County near the eastern end of the range, about 20 miles north of Vernal, for use as flux at the nearby Dyer copper mine smelter (Crawford and Buranek, 1943). No other production has been recorded. The known deposits appear to be small and remote.

The Uinta Mountains iron deposits are chiefly vein and replacement deposits of hematite and magnetite. Siderite (iron carbonate), as nodules in shale and replacing Paleozoic limestone, has also been reported from the Rhodes Plateau area (Crawford and Buranek, 1943), and some "limonite" occurs in gossans.

Small amounts of ore have been produced from deposits scattered throughout the Wasatch Range (Nos. 17–22) for smelter flux and for use in a small furnace near Ogden. Most of them are relatively inaccessible. They are mostly magnetite-hematite replacement or contact metamorphic bodies in limestone, around the peripheries of intrusive bodies. They include deposits east of Brigham (No. 18), Cache County; near Ogden (No. 19), Weber County; near Morgan (No. 20), Morgan County; and the Mountain Lake deposit (No. 21) at the head of Big Cottonwood Canyon, Salt Lake County.

The Mineral Point iron deposit (No. 18) is in the southern part of the Bear River Range, Cache County, about 20 miles east of Brigham City. Intermittent, small shipments are reported of high-grade ore from a small ore body that contains pure, coarsely crystalline, micaceous hematite that has replaced limestone (Crawford and Buranek, 1943, p. 12).

Iron deposits occur in the central and southern parts of the Wah Wah Range (Nos. 4–5), southwestern Beaver County, from which some ore was shipped to the copper smelter at Frisco for use as flux (Crawford and Buranek, 1943, pp. 13–14). The deposits are small lenticular hematite and limonite replacement bodies in limestone.

The Krotki Iron (Iron Cap) mine (No. 12), Sevier County, the Dragon and Black Jack iron mines (No. 14), southeast of Eureka, Utah County, and the Copper Mountain mine (No. 16) about 6 miles southwest of Lucin, Box Elder County, furnished small to moderate amounts of iron ore to nearby copper smelters for flux. All of these deposits are considered to have formed by the oxidation and leaching of disseminated sulfides of iron and base metals (Crawford and Buranek, 1943, p. 15). Ores of this type are rarely suitable for use in the production of iron and steel owing to incomplete removal of the sulfur and base metals, and because of the generally small and irregular size of the deposits.

Reserves of all classes (measured, indicated, and inferred) of iron ore in Utah are estimated at 500 million long tons, of an average grade of about 55 percent iron. Most of these reserves are in the deposits of the Iron Springs district. Other significant reserves are known only in the Bull Valley-Cove Mountain deposits. The potential for undiscovered deposits of importance in Utah is small.

The Iron Springs, Bull Valley-Cove Mountain, and many of the other Utah iron-ore deposits have been examined and, where warranted, explored. In the Iron Springs and Bull Valley-Cove Mountain districts, exploration has been intensive, and it is unlikely that any significant ore bodies have been missed; this also holds true for most of the more promising deposits in other districts.

The Iron Springs deposits are favorably situated with respect to transportation facilities, and contain ore of sufficiently high iron content to serve as blast furnace feed and hard-lump open hearth ore. Recent competition of beneficiated ore from neighboring States has caused some cutback in production, but the district should continue to be an important source of iron ore for the foreseeable future.

LEAD, ZINC, AND SILVER

(By T. H. Kiilsgaard and A. V. Heyl, Washington, D.C.)

Lead, zinc, and silver are closely associated in ores, hence these metals are discussed together in this report. Most Utah deposits yield ores containing more than one of these metals, and commonly all three of them. All three of the metals are widely used industrially, and the income derived from mining and processing each of them has contributed enormously to the growth and development of the mining industry in Utah.

Lead deposits possibly were known in the Territory of Utah as early as 1848–49 (Arrington, 1963, p. 196) and some attempts were made to mine them as early as 1858 (Romney, 1963, p. 48), but output was desultory until 1870 when the arrival of the railroads stimulated the metal mining industry (Butler and others, 1920, p. 118). Some silver was produced prior to 1870, partly from placer gold, but zinc was not recovered until 1904 (Butler, 1920, p. 142). The yearly output of the recovered lead, silver, and zinc for the 1865–1961 period is shown on figure 2, and the total output and dollar values of these metals are as follows:

	Short tons	Troy ounces	Value
Lead	5,111,423		$688,104,000
Zinc	1,550,703		282,950,000
Silver		813,830,000	609,849,000

The importance of Utah as a producer of silver is demonstrated by the fact that through 1960 Utah was the second-ranking State in the United States in output of silver (McKnight, 1962). The trend of silver output has been closely paralleled by that of lead. (See fig. 2.)

Lead and zinc occur in many different minerals, but in deposits of primary ores the most common occurrences are as the lead sulfide, galena, and the zinc sulfide, sphalerite. Silver occurs as a minor constituent in most deposits, primarily accompanying lead, copper, or gold. In lead sulfide deposits silver commonly occurs as "argentiferous galena," or as minute inclusions of any of several silver-bearing minerals. The values of silver in these deposits range widely, from those in which there are only trace amounts to those in which the chief values are in silver. For example, ores of the porphyry copper deposit at Bingham contain only a few cents per ton in silver yet because of the large tonnage mined the silver output is important. Deposits of lead and silver ores in Utah also normally contain some copper and minor amounts of gold.

Most deposits of primary lead, zinc, and silver ores are oxidized for varying depths below the ground surface usually extending to or near the level of the underlying ground-water table. In this zone galena is oxidized to a number of secondary minerals, the more common of which are anglesite and cerussite. The conversion usually takes place without appreciable migration of the lead. Removal of other more soluble minerals by meteoric water during oxidation commonly produces an enriched concentration of oxidized lead ores. Sphalerite, on the other hand, reacts quite differently during oxidation. It converts to very soluble compounds, which are transported by acidified meteoric water until the solutions are neutralized and the zinc is precipitated as secondary oxidized minerals. Typical of these are smithsonite and hemimorphite, the latter one more commonly known as calamine. These secondary ores form massive irregular replacement bodies or disseminated masses. Because of the differences in behavior during oxidation, bodies of oxidized lead ores and oxidized zinc ores usually are separate.

Silver behaves somewhat like lead during oxidation. Primary ores of silver are dissolved and the silver is precipitated as secondary minerals in an enriched secondary zone. This secondary zone may be at the site of original primary ore deposition, or it may be downward from the original site. Cerargyrite (hornsilver) is a common secondary mineral of silver, as is argentite and native silver. Below the zone of oxidation, the grade of silver in primary ore usually is less than the grade in overlying, secondarily enriched ore. Oxidized deposits of lead and silver ores commonly occur together, and in the early days of western mining these rich, near-surface deposits were particularly attractive and were widely worked. At depth, the unoxidized counterparts to many of these deposits were too low in grade to be profitably worked, and, after the near surface ores were worked out, the deposits were abandoned, or were workable only during periods of high metal prices. At other deposits the amount of silver diminished with depth, but the ore bodies proved workable as primary lead deposits from which the silver could be recovered as a byproduct or coproduct. This type of deposit has, over the years, yielded far more silver than the oxidized ores.

Most of the lead, zinc, and silver deposits of Utah are in the western part of the State, in the Basin and Range province. Of the many different types of deposits in the province the most productive have been replacement deposits in carbonate rocks. These sedimentary host rocks have been folded and faulted in varying degrees, and most have been intruded by igneous rocks of intermediate to acidic composition. The lead, zinc, and silver mineralization appears to be spatially and genetically related to these intrusions. The replacement bodies commonly are localized by fissures along which ore has been deposited to form veins. Some replacement bodies are along or adjacent to these veins but many of the larger bodies have replaced especially favorable beds of the host rock and extend some distance away from the apparently associated veins.

Along the western side of the State there are a few vein deposits in volcanic rocks of Tertiary age. These veins have been worked for gold and silver, and have been mined only to shallow depths. Elsewhere in the State, lead, zinc, and silver have been mined from other types of deposits, including veins in quartzite, veins at the fault contact of different types of rocks, veins in intrusive rocks, and other types.

Lead, zinc, and silver ores have been mined from many deposits that range in size from prospects to major mines. Most of the output of ore, however, has come from the 28 districts shown in table 6. The relative metal output and mineral reserves of these mining districts are compared using the following classification, adapted from McKnight and others (1962):

Districts of first magnitude: those in which production plus estimated reserves total more than 1 million tons of lead, or 1 million tons of zinc, or 50 million ounces of silver.

Districts of second magnitude: those in which production plus estimated reserve totals from 50,000 to 1 million tons of lead, or 50,000 to 1 million tons of zinc, or 5 to 50 million ounces of silver.

Districts of third magnitude: those in which production plus reserves totals from 1,000 to 50,000 tons of lead, or 1,000 to 5,000 tons of zinc, or 100,000 to 5 million ounces of silver.

Districts of these three magnitudes are named in table 6 and shown with corresponding numbers on figure 21. Individual districts are ranked on the table in magnitude for each metal. Thus, Park City, for example, ranks in first magnitude in lead and silver but second magnitude in zinc. Districts where output and reserves of metal are less than third magnitude in rank are not shown on the map.

In combined value, 87 percent of the lead, zinc, and silver produced in Utah has come from the Bingham, Park City, and Tintic districts. The Bingham district (No. 8, fig. 21, table 6), which is widely known as a producer of copper, also is the leading producer of lead, zinc, and silver in Utah, in terms of combined output having yielded a total value for these metals, through 1961, of $607,421,000.

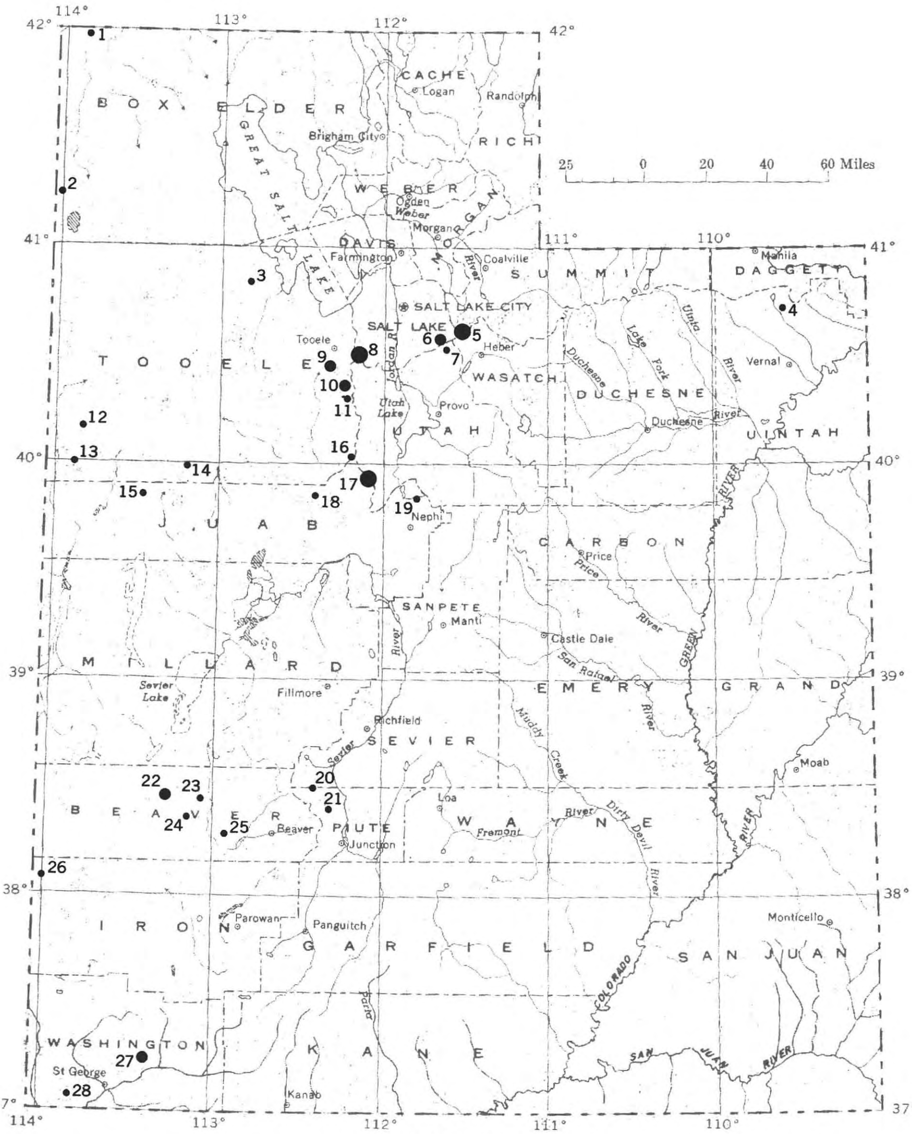
Ores of the district occur in a complex of mineral deposits, grouped about a mineralized porphyry stock. Mineralization in the deposits is zoned. The central porphyry area is enriched in copper, and is surrounded by a zone enriched in lead, zinc, and silver. The lead, zinc, silver ore occurs in veins and as replacement deposits in calcareous strata of the Oquirrh Formation. Over several decades ore from underground workings in the district has averaged about 7 percent lead, 7 percent zinc, less than 1 percent copper, 7 ounces silver per ton and 0.10 ounce gold per ton (James and others, 1961, p. 95). Although there are hundreds of old mines and prospect workings in the lead, zinc, and silver zone, most of the production during recent years has come from the U. S. and the Lark mines, which in 1960, produced about 6,000 tons of ore per week.

The Park City district (No. 5, fig. 21, table 6) ranks second to the Bingham district in the combined output of lead, zinc, and silver, having a total value, through 1961, of $433,172,000. The Park City district is approximately at the intersection of the east-trending Uinta arch and the north-trending Wasatch Range. In this area sedimentary rocks ranging in age from Cambrian to Triassic are folded to form the north-trending Park City anticline, are complexly faulted,

TABLE 6.—*Principal lead, zinc, and silver districts in Utah*

Map No.	District	County	Magnitude of rank[1]			Type of occurrence	References
			Lead	Zinc	Silver		
1	Ashbrook (Vipont mine)	Box Elder	—	—	3	Bedded replacement lenses and stockworks in limestone.	Peterson, 1942.
2	Lucin	do	3	—	3	Replacement bodies adjacent to fissures in limestone	Butler and others, 1920.
3	Lakeside	Tooele	3	—	3		Do.
4	Carbonate	Uintah	—	—	3	Replacement bodies in limestone	Do.
5	Park City	Summit and Wasatch	1	2	1	Bedded replacement bodies and lodes along faults in limestone; veins in quartzite and diorite porphyry.	Boutwell, 1912, 1933.
6	Big and Little Cottonwood	Salt Lake	2	3	2	Bedded replacement bodies, pipes and veins in limestone; veins in quartzite and in shale.	Calkins and Butler, 1943.
7	American Fork	Utah	3	3	3	Bedded replacement bodies in limestone; veins in quartzite.	Do.
8	Bingham	Salt Lake	1	1	1	Bedded replacement bodies along faults in limestone; disseminated bodies in quartz monzonite.	Boutwell, 1905; Hunt and Peacock, 1948; James and others, 1961.
9	Rush Valley (Stockton)	Tooele	2	2	2	Bedded replacement bodies along faults in limestone	Gilluly, 1932.
10	Ophir	do	2	2	2	Bedded replacement bodies, pipes, and veins along fissures in limestone, and hornfels.	Do.
11	Camp Floyd (Mercur)	do	—	—	3	Bedded replacement bodies in limestone and replacement along veins.	Do.
12	Gold Hill (Clifton)	do	3	—	3	Replacement bodies along fractures in limestone; veins in quartz monzonite.	Nolan, 1935.
13	Willow Springs	do	3	—	—	Replacement bodies in limestone	Butler and others, 1920; Nolan, 1935.
14	Dugway	do	3	3	3	Veins in limestone and in quartzite	Butler and others, 1920.
15	Fish Springs	Juab	3	—	3	Replacement bodies along faults in limestone	Do.
16	North Tintic	Tooele	3	3	—	Bedded replacement bodies along faults in limestone	Lindgren and Loughlin, 1919.
17	Tintic	Utah and Juab	1	1	1	Replacement bodies along fractures in limestone; veins in igneous rocks.	Lindgren and Loughlin, 1919; Billingsley and Crane, 1933.
18	West Tintic	Juab	3	—	3	Replacement bodies along fissures in limestone	Butler and others, 1920; Stringham, 1942.
19	Mount Nebo	do	3	—	—	Veins, pipes, and bedded replacement bodies along faults in limestone.	Butler and others, 1920.
20	Gold Mountain	Piute	—	—	3	Veins in dacite	Do.
21	Ohio and Mount Baldy	do	3	—	3	Replacement bodies in limestone; veins in quartzite and in dacite.	Do.
22	San Francisco and Preuss	Beaver	2	3	2	Veins in quartz latite or at its contact with limestone; breccia pipe in quartz monzonite.	Do.
23	Rocky (Old Hickory mine)	do	—	—	3	Contact metamorphic deposits in limestone	Do.
24	Star	do	3	3	3	Replacement bodies and pipes along faults in limestone.	Do.
25	Bradshaw (Cave mine)	do	—	—	3	Replacement bodies along faults in limestone	Do.
26	Stateline	Iron	—	—	3	Veins in volcanic rocks	Do.
27	Silver Reef (Harrisburg)	Washington	—	—	2	Deposits in sandstone	Proctor, 1953.
28	Tutsagubet	do	—	—	3	Replacement bodies adjacent to fissures in limestone	Butler and others, 1920.

[1] Rank is designated in magnitude as: first (1); second (2); and third (3); less than third is (—).



EXPLANATION

Size of district: Production plus reserves

- ● First magnitude (see text explanation)
- ● Second magnitude
- • Third magnitude

Numbers refer to districts described in text

FIGURE 21.—Lead, zinc, and silver in Utah.

and intruded by diorite and diorite porphyry stocks. The lead-zinc-silver ore bodies are principally along steeply dipping east- to northeast-striking fracture zones and in associated bedded replacement deposits. Vein deposits were mined first and, near the surface, they commonly contained bonanzas of high-grade, oxidized silver ore. The more productive vein deposits were in the Weber Quartzite, although in recent years much ore in the southeastern part of the district has come from veins in diorite. Bedded replacement deposits in limestone extend from 100 to 200 feet away from the fracture zones, are as much as 800 feet in stope length, and average about 10 feet in thickness. The more productive replacement deposits are in the Park City Formation, and a lesser number are in the Thaynes Formation. Exploration during the 1950's disclosed replacement deposits in the underlying Humbug and Desert Formations. These findings have extended the productive life of the district and suggest that other ore bodies may occur where unexplored fracture zones cut the lower lying limestones. Replacement deposits along two subparallel fracture zones, the Ontario-Daly West and the Silver King, have produced most of the lead-zinc ore in the district.

The several mines along these zones have been consolidated and are operated by the United Park City Mines Co. Recent production has come from lower levels of the Ontario mine, one of the oldest mines in the district. In the southeastern part of the district the Mayflower and Pearl vein systems are mined by the Hecla Mining Co. Typical ore consists of galena, light-colored sphalerite, pyrite and some tetrahedrite. There is a suggestion of mineral zoning in the district: ruby silver minerals are common in the northeast section, silver-lead-zinc ore in the central part, and lead-zinc-copper-gold ores in the southeast section, the latter locally associated with the intrusive dioritic rocks.

The Tintic district (No. 17, fig. 21, table 6) contains two subdistricts, the Main Tintic and the East Tintic which have yielded through 1961 lead, zinc, and silver having a combined value of $331,735,000. Ore was discovered in the Main Tintic district in 1869 and since then most of the silver-lead-zinc ore has come from irregular replacement deposits in calcareous rocks of Paleozoic age that are folded into a broad, highly faulted, north-plunging syncline. These rocks are intruded by monzonite and quartz monzonite stocks and, in many places, are overlain by barren volcanic rocks. The replacement deposits occur in definite linear zones or ore channels, of which five major ones are recognized. These zones trend northerly, are parallel to subparallel to the bedding, are continuous and extended in strike length, and tend to persist across faults and through different stratigraphic units. At intersections with faults the deposits may enlarge in size and form nearly vertical chimneys or pipes of high grade ore, some of which have ranked as major ore bodies. The water table is about 1,800 feet below the surface in much of the area and most of the ore above the water table is oxidized. Only one ore zone, the Chief, has been mined to any extent below the water table. More detailed descriptions of the geology and ore deposits of the district are given in Lindgren and Loughlin (1919), Cook (1957), and Morris and Lovering (1961).

The Tintic Standard, one of the great silver-lead mines of the world, is in the East Tintic subdistrict. Most of the ore in this area has come from replacement bodies in shattered, jasperoidized limestone at the intersections of low-angle and northeasterly trending faults (Lovering and Morris, 1960, p. 1134).

During recent years production from the Tintic district has steadily declined. The last of the major mines, the Chief No. 1, closed in 1956, because of low metal prices and high operating costs. During the late 1950's, however, the East Tintic subdistrict was intensely explored by the Bear Creek Mining Co., to further test discoveries made by the U.S. Geological Survey. The Burgin shaft was sunk and much crosscutting and diamond drilling from these workings led to a major discovery. Bush and Cook (1960, p. 1536) described one sulfide ore body, penetrated by four drill holes, which has an average thickness of 66 feet and which average 23.1 ounces of silver per ton, 23.1 percent lead, and 8.4 percent zinc. Estimates of ore reserves have not been publicly released but are considered adequate to sustain many years of substantial production. Possibilities of finding more ore in other parts of the East Tintic area are excellent. Elsewhere in the Tintic district the only known reserves are in the lower parts of the Chief No. 1 mine, in the Mammoth mine, and in a possible low-grade ore body of oxidized ore reported by Heyl (1963, p. B76) in the hanging wall of the lead vein of the Lower Mammoth mine, estimated to contain 100,000 tons of ore averaging 12 percent zinc, and 1.5 ounces silver per ton.

Other districts in Utah have yielded important amounts of lead, zinc, and silver, but all of them are relatively small compared to Bingham, Park City, and Tintic. A few miles west of the Park City district are three formerly important silver-lead-zinc districts, the Big and Little Cottonwood district (No. 6) and the American Fork district (No. 7). Each had some productive mines in the 1950's, several of which might be reactivated under more favorable economic conditions.

The western part of the Park City region and the nearby Cottonwood and American Fork districts are reported to contain oxidized zinc reserves. Many of these reserves are in mine dumps, the grade of which would depend, in part, on the amount of dump material handled, although many thousand tons of material averaging about 20 percent zinc are believed to be available.

The Horn Silver mine in the San Francisco district (No. 22) has been one of the richest and most productive silver-lead-zinc mines in Utah. Prior to World War I it was one of the most famous silver mines in the west, but was operated only on a small scale during the early 1950's and now is idle. The mine produced from a replacement ore body, localized along a fault, at the contact between lower Paleozoic limestones and volcanic rocks of Tertiary age. The oxidized minerals cerargyrite and plumbojarosite were important ores at the mine in early days, but sulfides also were produced. Later, the rare zinc sulfide wurtzite was a main mineral mined. A substantial reserve of oxidized zinc ores remain in this mine that could be produced under favorable economic conditions. At the Cactus mine in the same district, relatively low grade copper and silver ore has been mined from a steeply plunging breccia pipe formed along a fault zone in quartz monzonite.

Other mining districts east and southeast of the San Francisco district include the Star (No. 24), Rocky (No. 23), and Bradshaw (No. 25).

In the Rush Valley (Stockton) and Ophir districts (Nos. 9 and 10) most of the lead, zinc, and silver ore has come from bedded replacement deposits in limestone or in hornfels, at the intersection of the host rocks with feeding fissures. Gilluly (1932, pp. 136–137) described some of these ore bodies as being more than 2,000 feet long, and notes that over a period of years ore from the Ophir Hill Consolidated mine averaged 6 percent lead, 4 percent zinc, 1.3 percent copper, and 5.5 ounces of silver per ton. During the 1950's two mines in the Ophir district, the Ophir and Hidden Treasure, produced ore, some of it oxidized; and four small mines in the Rush Valley district were productive, the Gisborn-Muirbrook, Honorine, Silver Eagle, and West Calumet, the latter being the largest producer.

In Washington County, the Silver Reef district (No. 27) formerly was an important producer of silver. The ore was dominantly cerargyrite (horn silver) and was largely restricted to sandstone strata that contained abundant carbonized plant remains.

In the southwestern part of Washington County the Tutsagubet district (No. 28) has produced some oxidized copper, lead, silver, and zinc ores in recent years.

Deposits of oxidized zinc minerals are widely distributed in the western half of Utah (Heyl, 1963, pl. 1), but only a few small ones are known in eastern Utah. The Tintic group of districts (including Nos. 16 and 18), Star and San Francisco districts, Ophir district, Big and Little Cottonwood district, Park City district, Promontory district (magnitude less than third rank), and Lucin district (No. 2) have been the most productive, and contain most of the known reserves. Most of the known high-grade ore (containing 25 to 50 percent zinc) has been mined, but large quantities of low-grade material (10 to 25 percent zinc) could be mined if methods of beneficiation and market conditions were improved.

Although few mine reserve data are available for lead, zinc, and silver, a combined estimate for the known reserves and undiscovered resources is possible when based on available mine reserve data, past production records, and geologic inference. Such an estimate indicates that Utah has total resources of known and undiscovered ores that contain as much silver and lead as has been mined to date and contain about three times as much zinc as has been mined. These resources are most likely in the Oquirrh-Uinta, Deep Creek-Tintic, and Wah Wah-Tushar mineral belts. (See section on economic geology, p. 28, and fig. 8.)

MANGANESE

(By M. D. Crittenden, Jr., Menlo Park, Calif.)

Manganese is essential to an industrial economy. About 17 pounds are required for each ton of steel and small but essential quantities are also used in the manufacture of dry cell batteries and industrial chemicals (DeHuff, 1960, p. 500). Consumption of manganese ore in the United States now averages about 2 million long tons per year, more than 95 percent of which is used by the steel industry in the form of ferromanganese. But because the United States has limited quantities of high-grade ore (more than 40 percent Mn) required for the production of ferromanganese, domestic production has seldom exceeded 10 percent of the annual consumption, and has often dropped to zero. Foreign supplies are abundant, readily available, and comparatively cheap during peacetime, but have been curtailed or seriously threatened during each national emergency. As a result, manganese has been high on the list of strategic materials, and has been the subject of emergency measures and artificially high prices during each World War, and the Korean conflict.

Production of manganese ore in Utah (fig. 22) reflects this trend, showing peaks in 1918, 1944, and 1953. Starting in 1924, a local

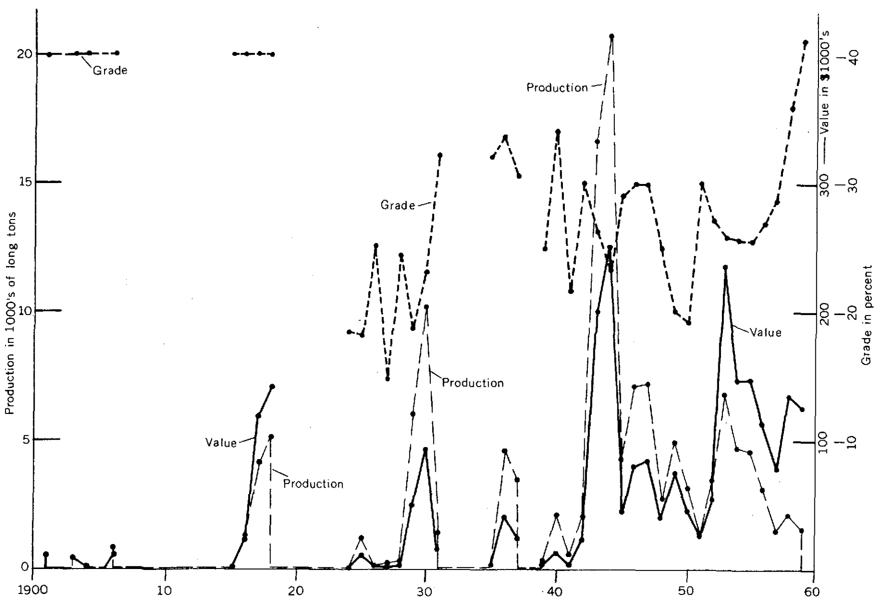
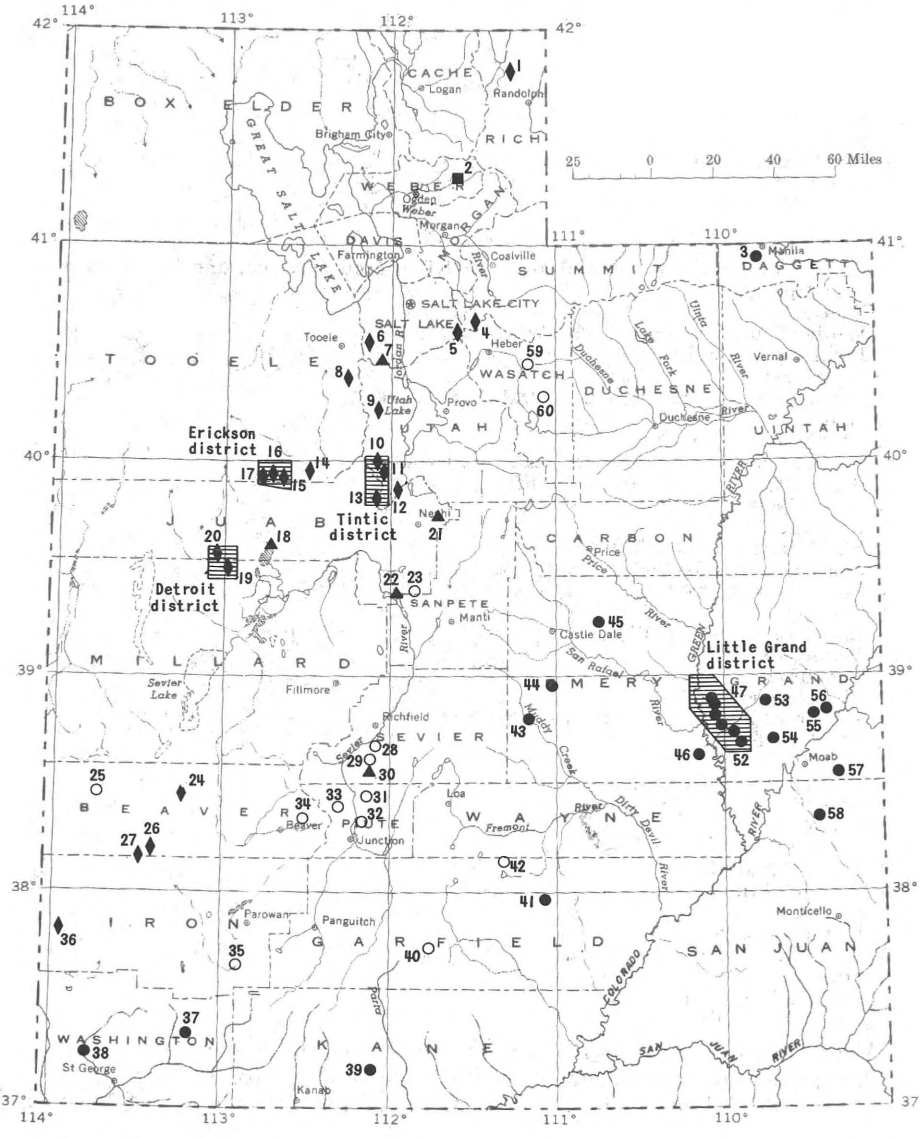


FIGURE 22.—Manganese production in Utah. (Data from U.S. Bureau of Mines, supplemented by data obtained in the field.)

market became available for low-grade ores (20 to 35 percent Mn) at the steel plant in Provo, and two additional peaks between wars resulted.

From 1901 to date, Utah mine shipments total about 150,000 long tons of manganese ore of all grades, with a total value of approximately $2.5 million. Nearly two-thirds of this, or about 90,000 long tons, came from a single group of deposits in the Detroit district in the Drum Mountains (No. 20). (See fig. 23 and table 7.) Second largest production, about 23,000 tons, has come from the Little Grand district (Grand County, Nos. 47–52). The Tintic and Erickson districts have shipped about 6,500 and 2,700 tons, respectively. The remaining production has come from more than 20 small properties, few of which have produced more than a few hundred tons.



MANGANESE DEPOSITS: ♦ Partially oxidized carbonate or silicate ores associated with base or precious metals; ▲ Oxides formed in veins or by hot springs; ■ Oxides formed by descending surface water; ● Oxides from original bedded sources; ○ Unknown origin or uncertain location
Numbers refer to localities listed in text

FIGURE 23.—Manganese in Utah.

TABLE 7. List of manganese deposits in Utah

1. Lakeview.
2. Payday.
3. Daggett Chief.
4. Park City district.
5. Michigan-Utah.
6. Bingham district.
7. Evans Lime quarry.
8. Ophir Hill.
9. Wildcat.
10. North Tintic, Oxen, and Tip Top.
11. Tintic Standard, Apex Standard, Iron King, Iron Blossom, and Black Jack (Empire).
12. Trotter.
13. White Cloud and Black Jack (Winberg).
14. Benmore and Sharp.
15. Deer Trail.
16. Black Jack (Morgan-Cromar), and Black Rock.
17. Indian Boy.
18. Abraham Hot Spring.
19. Black Diamond, Last Chance, and Guy Group.
20. Black Boy group (Staats and Pratt).
21. Black Ledge.
22. Orme.
23. Black Jack (Kendall-Duvall).
24. San Francisco district.
25. Steelville and Spor.
26. Susie Q.
27. Black Jack (Skougard)
28. Yellow Hornet.
29. Noonday.
30. Georgia and Jumbo.
31. Blackbird and Blue Miami Moon No. 1.
32. Dry Canyon.
33. Gilbert.
34. Black Rock (Shotwell).
35. Black Hawk and Joe Louis.
36. Modena.
37. Wallace.
38. Black Beauty No. 1.
39. East of Kanab.
40. Fullmer.
41. Hutch Pasture.
42. East side Boulder Mountain.
43. Muddy River.
44. East of Rochester.
45. Cedar Mountain.

Prices paid for manganese ore in Utah have increased from about $12.50 per ton of 40-percent ore in 1901 to $80.06 per ton of 40-percent ore in 1959. This is equivalent, respectively, to 30 cents and $2 per long ton unit (22.4 pounds of metallic manganese). However, because the average grade of ore shipped from Utah has been 20 to 30 percent Mn, the price on the open market has ranged from 20 to 30 cents per unit. In contrast, Government support prices averaged 70 cents in World War I, 80 cents in World War II, and $2.25 following the Korean conflict. The most recent period of price supports ended in 1959, and no manganese has been produced in Utah (or from other small deposits in the United States) since that time. Renewed production of manganese ore in Utah will probably require another relatively stable period of artificial price supports at a level at least double that which now prevails for ore from foreign sources.

Virtually all of the manganese ore consumed in the United States is in the form of oxides, and this is the only type of ore that is ordinarily marketable. Many mining areas of the west, however, contain significant quantities of manganese carbonate minerals. An example is Butte, Mont., the largest domestic producer. The availability of a mill for carbonate ores at Butte made possible the purchase of such ores from other areas following the Korean conflict. As a result, carbonate ores are estimated to account for somewhere between a fifth and a quarter of the production recorded from the Detroit district in Juab County.

Most Utah ores are low grade, but amenable to concentration. Samples of ore from many deposits have been successfully tested by the U.S. Bureau of Mines (see references), but few of the oxide deposits have been large enough to warrant installation of milling equipment. The deposits in the Detroit district and some of those in southeastern Utah are the principal exceptions.

The manganese deposits of Utah are of several geologic types. The type which has yielded most of the production comprises oxidized hydrothermal deposits associated with precious or base metals. These ores were derived mostly from manganese carbonate which has been converted to the more readily marketable oxide by surface weathering. The largest deposits of this type are in the Detroit district, at the north end of the Drum Mountains near Delta (Nos. 19–20). They consist of bodies of impure manganese carbonate 5 to 20 feet thick formed by replacement of Cambrian limestones near their intersection with mineralized fissures. Exploration of these deposits by diamond drilling was carried out by the U.S. Bureau of Mines in 1941 and 1945 (King, 1947; Crittenden and others, 1961). Ore bodies revealed by this work have been the source of the recorded production from this district. Allowing for differences in grade, and losses in mining, it seems probable that the greater part of the ore outlined by drilling has been recovered. Most material remaining is manganese carbonate averaging less than 20 percent Mn.

A few thousand tons of ore of this same type has been produced at both the Tintic, Nos. 10–13) and Erickson (Nos. 15–17) districts. Smaller quantities have also been shipped from Bingham, Alta, and Ophir and are known at Park City.

A second type of deposit, concentrated mainly in southeastern Utah, is associated with one or more horizons in the Upper Jurassic Morrison and Summerville Formations (Baker and others, 1952). Manganese occurs in these deposits as thin veins, nodules and impregnations of oxides in claystone and sandstone. Although individual nodules assaying 35 to 45 percent Mn can be obtained by hand picking, the average grade of material in the ground is about 10 percent Mn. At the end of an extensive examination in 1940, it was estimated (Baker and others, 1952, p. 76) that the deposits in southeastern Utah contain about 350,000 tons of material containing 4 to 10 percent Mn, about 100,000 tons of material containing 10 to 30 percent Mn, and perhaps 15,000 tons containing more than 30 percent Mn. Recent production of material averaging 40 to 42 percent Mn was obtained by milling. The amount of low-grade material remaining in this area is large, but widely scattered. The costs of milling make it unlikely that production can be obtained except during periods of artificial price supports.

A third type of deposit in Utah consists of veins of oxides deposited directly by rising hot waters or hot springs. Such deposits (fig. 23) are most commonly found in igneous rocks; a group near Richfield (Nos. 28–30) and springs near Delta (No. 18) and Lehi (No. 7) have yielded a small production.

Known reserves of manganese oxide in Utah are capable of yielding a few thousand tons of 40 percent ore per year for several years. Geologic conditions are not favorable for the discovery of very large low-grade or concealed deposits of manganese oxide.

In contrast, the metal mining districts of Utah probably contain manganese carbonate resources amounting to many million tons. Recovery of these resources will depend on the combined value of the manganese and the associated base and precious metals.

MERCURY

(By L. S. Hilpert, Salt Lake City, Utah)

Mercury, which in the mineral industry generally is called quicksilver, is the only metal that is liquid at ordinary temperatures. This property plus its high specific gravity, high electrical conductivity, uniform expansion rate, and other properties has stimulated a worldwide demand that has persisted for many centuries. Uses for the metal in the past were largely for the amalgamation of gold ores, the manufacture of detonators, and use in mercury boilers. Recently the demand has been largely in electrical apparatus, as cathodes in the electrolytic preparation of chlorine and caustic soda, in special paints, industrial control instruments, pharmaceuticals, poison sprays, and bactericides (Pennington, 1960).

The mining and processing of mercury differs from other metals in the relative simplicity and low cost of extracting the metal. The ores are roasted at the mines in retorts or furnaces and the mercury is collected in condensers from the flue gasses. It is bottled for shipment in steel flasks, which in the United States contain 76 pounds of metal.

Utah is not an important producer of mercury although occurrences of the metal were known to occur in the State as early as the 1860's or 1870's (Butler and others, 1920, p. 541; Raymond, 1874, p. 277). The total yield through 1943, the last year of recorded production, is about 3,700 flasks, having a total value of about $160,000 (table 8). This is only about 0.1 percent of the total output of the United States (Bailey, 1960).

Mercury generally occurs in near-surface veins and fractures as the sulfide cinnabar (HgS) and to some extent as the native metal, and is associated with iron sulfides, and minor amounts of the antimony and arsenic sulfides, stibnite (Sb_2S_3), realgar (AsS) and orpiment (As_2S_3). Less commonly it occurs in association with gold and base metal sulfides, but such occurrences are generally not of much importance. The deposits in Utah are exceptions because most of them are associated with gold or base-metal deposits and such deposits have yielded nearly all the mercury.

TABLE 8.—*Mercury produced in Utah, 1886–1961*

Year	Flasks [1]	Sold value
1886	87	} $8,308
1887	[2] 126	
1888–92	0	0
1903	14	
1904	745	
1905	1,133	} 131,292
1906	1,009	
1907	437	
1908–32	0	0
1933	(3)	(3)
1934–35	0	0
1936	25	1,998
1937–39	0	0
1940	53	9,374
1941	19	3,515
1942–43	(3)	(3)
1944–61	(4)	
Total	[5] 3,700	[5] 160,000

[1] A flask contains 76 pounds, except 76½ pounds for period from 1886 to May 31, 1904, and 75 pounds for period from June 1, 1904–07.
[2] Difference between district total and amount listed for 1886.
[3] Data withheld.
[4] No recorded production.
[5] Estimate.

Source: U.S. Geological Survey Mineral Resources of the United States 1886–1921, and U.S. Bureau of Mines Minerals Yearbook 1922–61.

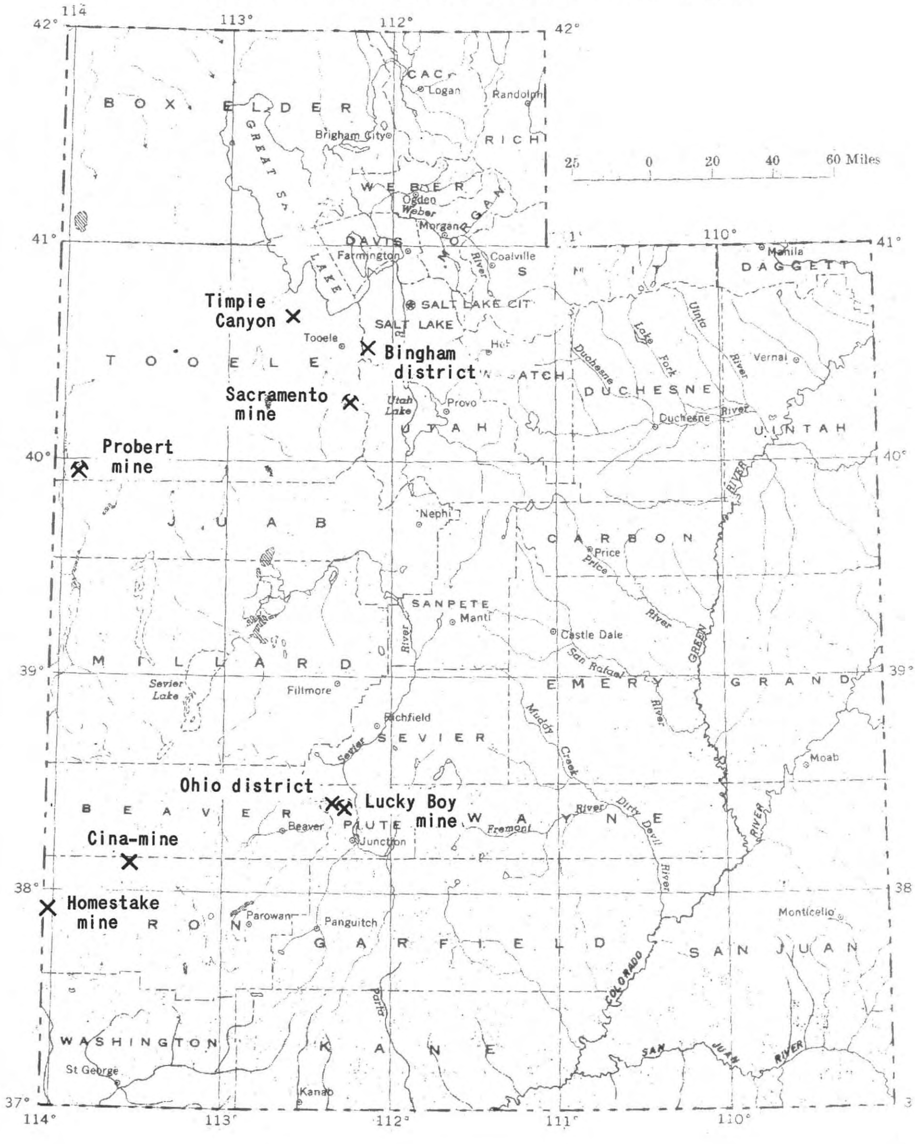
Four or more mines, all in the western part of the State, have yielded mercury in Utah (fig. 24). The most productive property was the Sacramento mine in the Camp Floyd (Mercur) district, Tooele County (Gilluly, 1932). More than 3,000 flasks of mercury were extracted from the ore between 1903 and 1907, when the ore body was exhausted. According to Boutwell (1907), the mercury occurred in cinnabar in a shoot associated with a gold vein near the contact with a porphyry dike. Other occurrences in the district were not rich or extensive enough to warrant exploitation.

The Lucky Boy mine near Marysvale, Piute County, produced the first mercury in Utah in 1886–87. The deposit was found in the early 1880's and yielded more than 200 flasks of mercury before it was exhausted. It was unique because the ore was constituted largely by the rare sulfoselenide and selenide minerals, onofrite [Hg(S, Se)] and tiemannite (HgSe) and a little cinnabar. The ore body was a replacement along the bedding of the Permian Kaibab Limestone on the west side of the Tushar fault. The body probably was related to the same fracture zone as the Deer Trail gold deposit which occurred several hundred feet below the Lucky Boy (McCaskey, 1912, p. 914–915; Callaghan and Parker, 1962). Other occurrences of mercury have been reported near Marysvale in the gold-bearing Ohio and Mount Baldy districts, but no mercury has been recovered from them (Butler and others, 1920, p. 541; Lindgren, 1906, footnote, p. 90).

Since 1907, less than 200 flasks of mercury have been produced; the yield has been sporadic and the records are poor. Most of the metal probably has come from the Probert (Congar Hill) mine, Tooele County. This deposit, which was discovered in the early 1930's (Crawford and O'Farrell, 1932), was localized on a fault, and consisted mostly of cinnabar associated with a barite vein in fractured dolomite.

Some mercury also may have been produced near the head of Timpie Canyon in the Stansbury Range, Tooele County, where a property was being operated in 1958 at an occurrence reportedly consisting of some mercury ore in brecciated dolomite (Rigby, 1958, pp. 124–126).

It is possible that some mercury may also have been produced by the Cina-mine property, Iron County, in the late 1950's or early 1960's.



EXPLANATION

⚒ Mercury mine ✕ Mercury prospect or occurrence

FIGURE 24.—Mercury in Utah.

This property possibly is the Marietta or Stratton prospect (Mineral Resources of the United States, 1914, pt. 1, p. 329). At this property cinnabar is disseminated in opalized seams in tuff along with pods of native sulfur, in the hanging wall of a fault that separates the tuff from underlying dolomite.

Mercury has also been reported in a few other localities in the State, but none are of economic importance. These include occurrences of native mercury in the Gold Springs district, Iron County (Butler and others, 1920, pp. 106, 566); and in the Bingham district, Salt Lake County, where some cinnabar and native mercury were found locally in lead ores.

Utah's mercury resources are quite limited and probably of little commercial importance. Some sporadic production can be expected at times of high mercury prices, but it is unlikely any large deposits will be found.

MOLYBDENUM

(By R. U. King, Denver, Colo.)

Molybdenum is a metal of great importance to our modern ferrous metal industry. It is a silvery white metal, somewhat softer than steel, and has a melting point of about 2,600° Fahrenheit, which is higher than all other metals except tungsten, rhenium, osmium, and tantalum. It is ductile and is resistant to acids and to oxidation at ordinary temperatures. Its chief value, however, derives from the beneficial properties of hardness, toughness, and resistance to corrosion and wear it imparts to alloy steels. In this respect, molybdenum compares favorably with other alloy metals such as vanadium, chromium, tungsten, and nickel.

About 75 percent of the molybdenum consumed in the United States goes into steel, the remainder going into special alloys, metal products, chemicals, pigments, and lubricants. New and in part seemingly exotic uses for molybdenum in the nuclear power field, space technology, and missiles industry give promise of increased demand in the future for this versatile metal.

Molybdenum is widely distributed over the surface of the earth. In the rocks of the earth's crust, its abundance, according to recent estimates, is about 2.5 parts per million (0.00025 percent). It is found in trace amounts in the igneous, metamorphic, and sedimentary rocks, in soils, in ground water, oceans, and hot springs, and in plant and animal tissues. It occurs in nature only in combination with other elements, such as sulfur, oxygen, tungsten, and lead.

The most common molybdenum minerals found in nature are molybdenite (molybdenum disulfide, MoS_2), powellite (calcium molybdate, $CaMoO_4$), wulfenite (lead molybdate, $PbMoO_4$), molybdite (molybdic oxide), ferrimolybdite ($FeMoO_3.nH_2O$), ilsemannite (a water soluble oxysulfate of molybdenum), and jordisite(?) (amorphous molybdenum disulfide). Of these, only molybdenite is currently exploited although some wulfenite was produced and molybdite and jordisite may become economically important in the future.

The first commercial production of molybdenum in the United States was between 1898 and 1906 from wulfenite-bearing vein deposits in Arizona and New Mexico. Production resumed in 1914 and has increased, with few exceptions, to a current annual rate of more than 66 million pounds. From two-thirds to three-fourths of this production comes from the Climax molybdenite deposit in Colorado and the balance is entirely the byproduct of copper mining operations in the western states. Utah's current output is about half the Nation's byproduct molybdenum production and, to date, Utah has yielded a few hundred million pounds of the metal. Moreover, Utah consistently ranks second to Colorado in the production of molybdenum concentrates and the value of molybdenum produced in the State has ranked over the past 10 years between sixth and ninth in dollar value of Utah's mineral commodities.

Significant production of molybdenum in Utah began in 1936, with the byproduct recovery of molybdenum from the copper ore at Bingham. Prior to this date only small quantities of molybdenum had been made from scattered deposits. For example, in 1916 a few hundred pounds of molybdenum were mined at the City Rocks mine in the Alta district, Salt Lake County, and a small production was reported from the Reaper mine in the Clifton (Gold Hill) district, Tooele County.

Molybdenum deposits are of five genetic types: porphyry deposits in which metallic sulfides are dispersed through relatively large volumes of altered rock; contact metamorphic zones and tactite bodies of silicated limestone adjacent to intrusive granitic rocks; quartz veins; pegmatites and aplites; and bedded deposits in sedimentary rocks.

Most molybdenum in the United States has been produced from porphyry deposits. The Kennecott Copper Corp.'s Bingham Canyon mine is in such a deposit and accounts for all of the molybdenum currently produced in Utah. Contact metamorphic deposits commonly contain molybdenum in association with other metals such as tungsten, and bismuth. Four deposits of this type are known in the State, but the molybdenum content has been too small to warrant exploitation.

Several molybdenum-bearing quartz vein deposits occur in the State, but have not been exploited because of limited size or low molybdenum content. The molybdenum mineral in these veins may be molybdenite associated with other metallic sulfides or wulfenite associated with the oxidized portions of lead and zinc ore bodies. In some places pegmatites contain appreciable molybdenite, but those in Utah apparently do not.

Bedded deposits in sandstone contain small quantities of molybdenum, commonly in association with uranium. (See peneconcordant deposits in section on uranium, p. 124.) The molybdenum content generally amounts to no more than a few hundredths of a percent, and to date it has not been recovered. The small quantity of molybdenum in this type of deposit is generally detrimental because it may interfere with the recovery of the uranium, and must be removed from the circuits during milling.

Fifteen deposits or occurrances of modybdenum in Utah are shown on figure 25. Most of the deposits contain scarcely more than trace amounts as accessory minerals. With the single exception of the Bingham Canyon deposit, only small quantities of molybdenum have been produced from these deposits. Molybdenum is reported to occur at a number of additional localities (Bullock, 1960), but the location of some are indefinite and other localities apparently record mineralogic occurrences of academic rather than economic interest.

At the Bingham mine (see fig. 25, locality No. 1), molybdenite occurs in small quantities in seams and grains associated with dissemin-

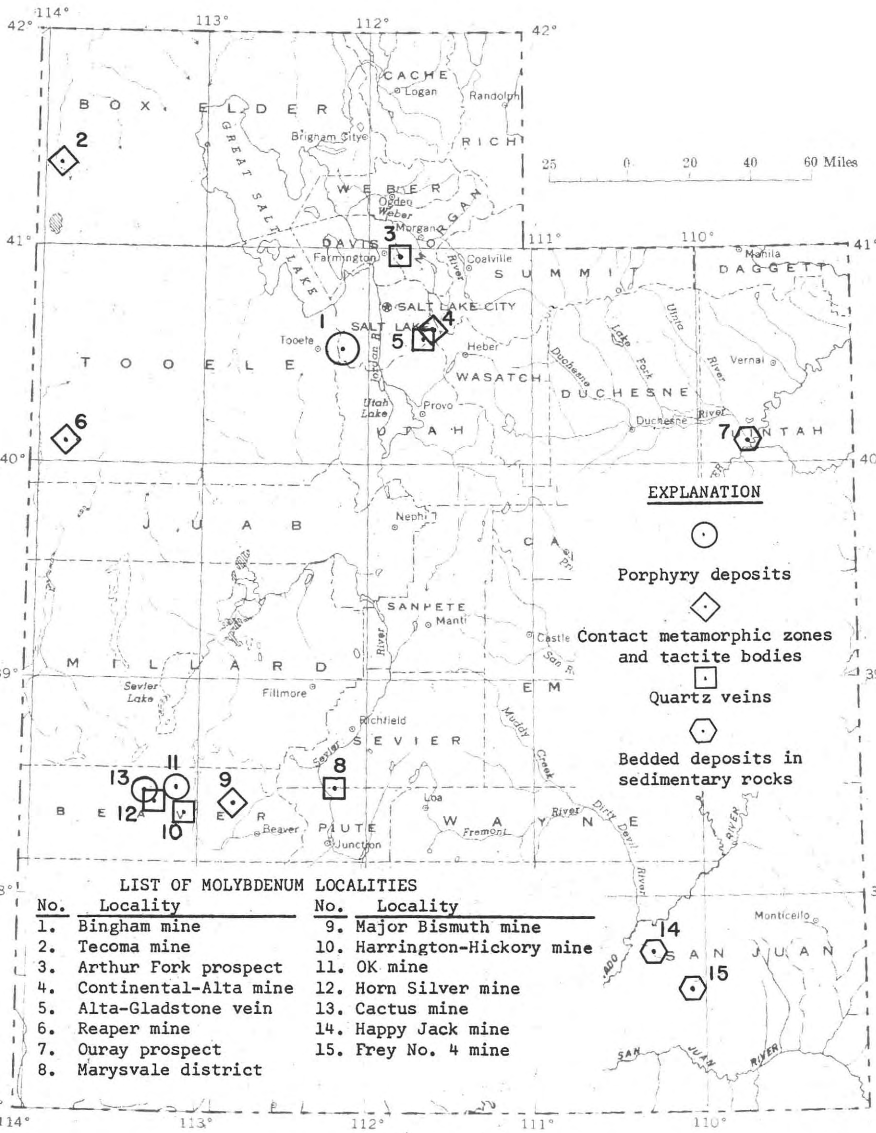


FIGURE 25.—Molybdenum in Utah.

ated copper sulfides in hydrothermally altered quartz monzonite. The molybdenite content of the ore probably averages about 0.04 percent based on statements of the Kennecott Copper Corp. (1961) concerning copper-molybdenum ratios in the concentrates (30:1.5). In spite of this low content of molybdenum, the large tonnages of ore mined makes the Bingham mine the second largest molybdenum producer in the United States, a position it is likely to maintain for some time.

Molybdenite and its oxidation product, powellite, occur in small quantities with copper sulfides, pyrite, and quartz in veinlets and disseminated in a chimney-like breccia zone at the OK mine (No. 11) in the Beaver Lake district, Beaver County (Butler, 1913; Butler and others, 1920). A high grade pocket of molybdenite a few tens of feet in size adjacent to the breccia zone was extracted, but no other output is recorded. The quartz monzonite, which surrounds the breccia zone at the OK mine, is altered over an area of about a half square mile. Some potential for large low-grade disseminated copper-molybdenum deposits exists in the weak sulfide mineralization that penetrates the altered quartz monzonite country rock.

Four other mining districts in Beaver County have molybdenum associated with deposits of other metals, but have had no recorded production. At the Cactus mine (No. 13) in the Preuss district, molybdenite associated with chalcopyrite and pyrite in a quartz-sericite gangue is disseminated in small amounts in a breccia zone in altered quartz monzonite (Butler, 1913). At the Major (bismuth) mine (No. 9) in the Granite district, small quantities of molybdenite and bismuthenite occur with pyrite, fluorite, and contact metamorphic minerals in a tactite zone near quartz monzonite porphyry (Butler and others, 1920). At the Harrington Hickory mine (No. 10) in the Star (Rocky) district, wulfenite occurs in small quantities associated with copper-lead-silver ores in replacement bodies along fissures in limestone (Butler and others, 1920). At the Horn Silver mine (No. 12) in the San Francisco district, wulfenite occurs in the oxidized parts of lead-zinc ore bodies (Butler and others, 1920). The ore bodies are in replacement veins and fissure veins along the Horn Silver fault, and contain galena, sphalerite, and a little copper. The source of the molybdenum in the wulfenite is not known but is thought to be from molybdenum-bearing galena. The Horn Silver mine is credited with significant lead and silver production in past years but there is no recorded production of molybdenum.

The copper and uranium ores at the Happy Jack mine (No. 14), in the White Canyon area, San Juan County, contain small quantities of molybdenum in the form of ilsemannite (Gruner and Gardiner, 1952). The ore occurs as bedded deposits and replacements of fossil plant material in siltstones and sandstones of the Triassic Shinarump member of the Chinle formation. Small amounts of molybdenum also are present in the uranium ores of the Frey No. 4 mine (No. 15), in the Red Canyon area, San Juan County (Gruner and Gardiner, 1952). Both jordisite and ilsemannite have been identified in this bedded uranium deposit in sandstone. The molybdenum content of the ore in these two deposits is probably not more than a few hundredths of a percent.

Molybdenum occurs in veins and in contact metamorphic deposits in the Little Cottonwood (Alta) district, Salt Lake County (Hess, 1908; Butler and others, 1920). In the Alta-Gladstone vein (No. 5), about 2 miles southwest of Alta, molybdenite occurs with pyrite in pegmatitic quartz. The molybdenite content of the vein is a few hundredths of one percent. At the Continental Alta (Michigan-Utah) mine (No. 4) and the adjoining City Rocks mine, 1 mile east of Alta, wulfenite occurs with oxidized ores in a crushed zone of siliceous limestone in contact with granite (Hess, 1908). A few hundred pounds of molybdenum were mined in 1916 from the wulfenite deposits in the Alta district; no further production is recorded.

Ilsemannite occurs in a thin dark-colored sandstone bed at the base of a bluff about 2 miles west of Ouray, Uintah County (No. 7). The mineralized zone is a lenticular body limited to less than 100 feet in depth (Hess, 1925). No data are available as to the grade of the molybdenum content, but presumably it is low.

Molybdenum in the minerals, molybdenite, jordisite, ilsemannite, and umohoite (hydrous uranium-molybdenum oxide) occurs in association with uranium ores in several vein deposits in quartz monzonite in the Marysvale district (No. 8) (Kerr and others, 1952; Kerr, 1957), Piute County. The molybdenum content is not of economic importance, and none has been recovered.

At the Reaper mine (No. 6) in the Clifton (Gold Hill) district, Tooele County, molybdenite and powellite occur in contact metamorphic replacement deposits in marble (Nolan, 1935). The molybdenite is in radiating crystalline aggregates and is surrounded commonly by its oxidation product, powellite. Although selected samples containing several percent molybdenite probably could be obtained, the average grade would be low.

A prospect on Arthurs Fork (No. 3) in sec. 6, T. 2 N., R. 2 E., Morgan County, contains traces of molybdenite associated with uranium and thorium oxides in migmatized biotite gneiss of the Precambrian Farmington Canyon Complex of Eardley (1959). (See section on thorium and rare earths below).

Wulfenite is reported to occur, in the oxidized parts of lead and zinc ore shoots at the Tecoma mine (No. 2) in the Lucin district, Box Elder County (Butler and others, 1920). The ore bodies are in a contact metamorphic zone between limestone and quartz monzonite.

The known reserves of molybdenum in Utah are almost exclusively at Bingham. Although the production data and reserve figures for this mine are not published, the recently announced $100 million expansion program of the company is probably indicative that the mine will continue the present rate of output for the next several decades. The ore reserve necessary to supply such an output would contain several hundred million pounds of molybdenum, assuming the grade will continue to average 0.04 percent molybdenum. No other reserves are known in the State at this time. The best hope for finding additional resources is in porphyry-type deposits particularly in the San Francisco district and adjacent areas, Beaver County. Bedded deposits in sedimentary rocks that contain molybdenum with uranium ores in one or more of the minerals, jordisite, ferrimolybdite, or ilsemannite, are another possible source of byproduct molybdenum.

THORIUM AND THE RARE EARTHS

(By J. W. Adams, Denver, Colo.)

Thorium and the rare earth metals are treated together in this report as they are commonly associated in nature and are closely interrelated economically.

Thorium is a silver gray metal that, like uranium, is the parent of a series of radioactive decay products ending in a stable isotope of lead. Its geochemical behavior, however, is quite different from uranium in that it tends to be dispersed rather than to be concentrated in significant deposits, and it is relatively stable in the weathering process.

The chief uses of thorium are in magnesium alloys and in the manufacture of gas mantles. A major potential use is in atomic reactors where thorium may be converted into a fissionable uranium isotope by neutron capture. The use of thorium for nuclear energy is, however, in the experimental stage and is in competition with relatively cheap, abundant uranium (Kelly, 1962, p. 25).

The rare earth metals comprise the 15 elements having atomic numbers 57 to 71, including lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tu), ytterbium (Yb), and lutetium (Lu). One of these, promethium, is not known to occur in nature. Yttrium (Y), with atomic number 39, is also classed with the rare earths because of its chemical similarities and geochemical affinities.

The first seven elements listed above (La through Eu) are included in the cerium group of rare earths, so-called because cerium is their most abundant member. The remaining eight elements (Gd through Lu) together with yttrium are called the yttrium group. The two groups are also referred to respectively as the "light" and "heavy" rare earths.

The properties of the members of the two groups are sufficiently distinct to cause one group to predominate over the other in most minerals, even though all or nearly all are ordinarily present (Olson and Adams, 1962). The rare earths have many industrial applications such as in the steel industry, nonferrous alloys, glass manufacture and glass polishing, sparking alloys, and carbon electrodes for arc lights and projection lamps. Rare earth requirements are, however, relatively small compared to many other metals, domestic consumption in 1958 being only about 1,600 short tons of rare earth oxides (Baroch, 1960, p. 687). The rare earth industry is developed almost entirely around the cerium group elements, primarily cerium, lanthanum, praseodymium, and neodymium. Although considerable research is being directed to finding uses for yttrium and the heavy rare earth elements the current demand for these is small.

The marketing of ores of thorium and the rare earths is difficult as there is no established market comparable to those of the more widely used metals, and prices of their ores are generally determined by negotiation between buyer and seller. Detailed information on the economic factors of thorium and rare earths is given in a recent publication of the U.S. Bureau of Mines (Kelly, 1962).

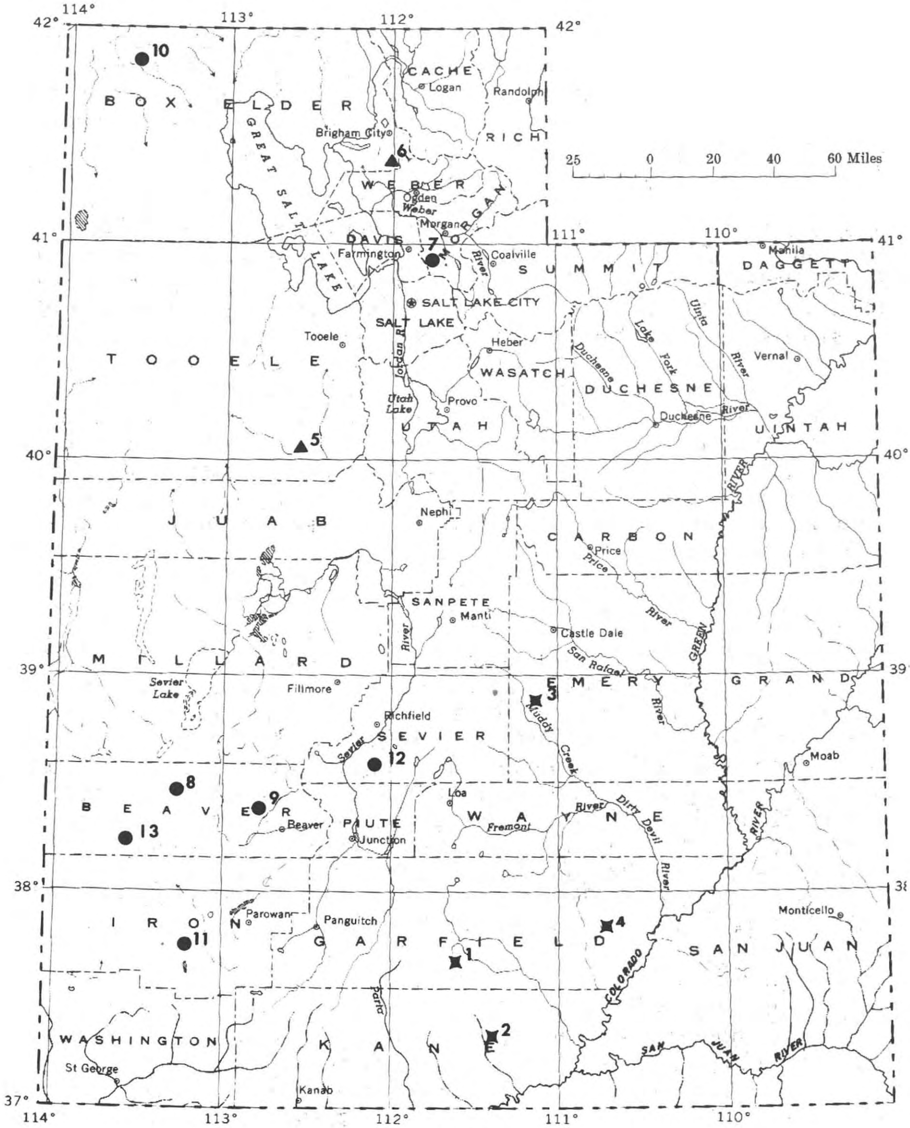
Thorium and the rare earths are found in a large number of minerals, but only a few of these have been found in sufficient concentration to be used as ores. The most important source mineral for thorium is monazite, a phosphate of the cerium group rare earths. The thorium content of this mineral is variable, but commercial monazite commonly contains between 3 to 10 percent thoria (ThO_2) and 55 to 60 percent combined rare earth oxides (Kelly, 1962, p. 5). Other potential sources of thorium are thorianite, thorite, and thorogummite, and multiple oxide minerals such as euxenite.

Monazite is also the principal ore mineral of the rare earths, but important deposits of bastnaesite, a rare earth fluocarbonate, are currently being mined at Mountain Pass, Calif. Both monazite and bastnaesite contain dominantly cerium group elements. Minerals in which the yttrium group predominate include xenotime, and yttrium phosphate, and euxenite.

Minerals containing thorium and the rare earths are found in many geologic environments, but primary concentrations of ore grade are uncommon. Most of the world production of these elements has come from placer deposits in which monazite and other heavy minerals have been concentrated in sands formed from the weathering of igneous and metamorphic rocks. Sea beaches along the coasts of Brazil, India, and Florida, and stream placers in the southeastern United States and Idaho are among the best known deposits of this type. Some sedimentary rocks contain placer deposits that were formed along ancient beaches or river banks. Such consolidated, or "fossil," placers are known in sandstones of Late Cretaceous age at a number of localities in Utah where they have been investigated primarily as a source of titanium (Dow and Batty, 1961). (See section on titanium.) These localities are shown in figure 26 and are (No. 1) south of Escalante in Garfield County, (No. 2) in the southern part of the Kaiparowits Plateau in Kane County, (No. 3) southeast of Emery in Emery County, and (No. 4) on the southwestern flank of the Henry Mountains. Fossil placers in these areas contain large tonnages of rock composed of quartz, feldspar, titanium minerals, magnetite, zircon, and monazite grains cemented by ferric iron and carbonate minerals. The deposits show anomalous radioactivity, much of which is caused by the thorium in the monazite. The highest known average radioactivity is 0.21 percent equivalent ThO_2 and occurs in a deposit in the Henry Mountains. The deposits examined were estimated to contain a total of 1,043,000 tons of rock with an average radioactivity equivalent to 0.09 percent ThO_2 (Dow and Batty, 1961). This level of radioactivity is approximately what would be produced if the rock contained 1.3 percent monazite containing 7 percent ThO_2. However, as some of the measured radioactivity of these rocks may come from other sources, such as uranium in zircon, the actual monazite content may be appreciably lower.

Another potential source of the rare earths in sedimentary rocks is the Meade Peak Phosphatic Shale Member of the Phosphoria Formation of Permian age, which is widespread in northern and north-central Utah (see section on phosphate, p. 195 and fig. 40). Some phosphorite layers in this member may contain abnormal concentrations of certain elements including both yttrium and lanthanum (Gulbrandsen, 1960).

Minerals containing thorium and rare earths have been found in pegmatites in two areas of Utah. One of these is the Sheeprock Mountains in Tooele County (No. 5) where samarskite and an unidentified thorium-bearing mineral have been reported by Cohenour (1959, pp. 118–119). Samarskite is also found as a constituent of granite in the same area (Williams, 1954, p. 1388). The other area is east of Willard (No. 6) in Box Elder County where pegmatites in Precambrian rocks contain cyrtolite, a variety of zircon in which appreciable amounts of uranium, thorium, and the rare earths are present.



EXPLANATION

Concentration in ancient placer in sedimentary rock

Lode, vein, or concentration in igneous or metamorphic rock

Concentration in pegmatite

Numbers refer to localitites mentioned in text

FIGURE 26.—Thorium, rare earths, and pegmatite minerals in Utah.

Both monazite and xenotime, associated with uraninite and molybdenite occur in small, local, biotite-rich pods and layers in migmatized biotite gneiss at a prospect on Arthurs Fork in Morgan County (No. 7). The gneiss is part of the Farmington Canyon Complex of Eardley (1959) of Precambrian age.

Thorium and rare earths have been found in vein deposits in the San Francisco district (No. 8) and at the Sunrise property in Beaver County (No. 9).

What may be a third vein-type occurrence is at the Century mine, Park Valley district, Box Elder County (No. 10) where monazite, arsenopyrite, galena, gold, and pyrite are reported by Bullock and others (1960). Rare-earth-bearing apatite occurs in the magnetite deposits and associated tactite zones at the Smith mine in Iron County (Olson and Adams, 1962) (No. 11).

Thorium is associated with iron and manganese oxides along fracture zones in volcanic rocks in the Monroe area, Sevier County (No. 12). A radioactive zone containing a disseminated thorium-bearing mineral has been found in agglomerate in the Wah Wah Mountains in Beaver County (Olson and Adams, 1962) (No. 13).

Several of these deposits were discovered, through their radioactivity, during the intensive search for uranium, but their thorium and rare earth potential have not been investigated further.

It would appear, however, that the monazite deposits in the consolidated or "fossil" placers described by Dow and Batty (1961) represent the most important thorium and rare earth resources in Utah and that these elements could be valuable byproducts if these deposits were mined for titanium or zirconium.

The rare earth potential of the phosphate rock deposits of Utah also should be considered, for although these elements occur in small amounts in the rock and may be difficult to recover, a very large tonnage of phosphorite is mined and processed annually.

TITANIUM

(By J. W. Adams, Denver, Colo.)

Titanium is a relatively abundant element, but one which only recently has come into commercial importance. It does not occur in nature in its metallic state, but is distributed widely in the earth's crust in the form of oxide and silicate minerals. Two oxide minerals, ilmenite ($FeTiO_3$), and rutile (TiO_2) are the chief sources of titanium and are mined from both primary deposits of these minerals in igneous rocks and secondary deposits in beach or river sands.

Titanium metal is heavier than aluminum, but lighter than steel. Together with its alloys it is used chiefly in aircraft and missile applications where weight-saving is important. Nonmilitary uses are based largely on the resistance of titanium to oxidizing acids and sea water (Ogden, 1961). In addition to metallic utilization, much of the ore consumed annually goes into the manufacture of titanium dioxide paint pigments, welding rod coatings, ceramics, and chemicals. Ilmenite ores are used almost exclusively for pigment manufacture, and rutile ores for the production of metallic titanium and welding rod coatings (Stamper, 1960, p. 889).

Most of the ilmenite and some of the rutile used in the United States are from domestic sources. Major primary deposits of ilmenite, such as that in the Sanford Lake district, New York, are associated with gab broic and anorthositic rocks; both ilmenite and rutile are mined from anorthosite bodies in Virginia (Rogers and Jaster, 1962). Both of these minerals are recovered also from beach sands along the Atlantic seaboard.

Significant deposits of primary titanium ore have not been reported in Utah, but sedimentary deposits of titanium-bearing black sandstone similar to those found in other Rocky Mountain States (Houston and Murphy, 1962) are present in several areas. These deposits, which are weakly radioactive, are fossil beach placers that contain very fine-grained ilmenite, zircon, monazite, and other heavy materials concentrated by erosion, winnowing, and redeposition from older rocks. These minerals, together with grains of quartz and feldspar, are cemented to a highly indurated state with ferric iron and carbonate minerals and form a dark-colored, dense rock which occurs as large lenses in sandstones of Late Cretaceous age. The black sand deposits were concentrated by wave and wind action along the beaches of the eastward-retreating Late Cretaceous sea. With further retreat of the sea, the black sand accumulations were buried under a succession of younger nonmarine sediments which are wholly or partly eroded away where the deposits are now exposed.

In Utah, the known titaniferous black sandstone deposits are in the Straight Cliffs Sandstone and the Ferron Sandstone Member of the Mancos Shale in Emery, Garfield, and Kane Counties (see fig. 26, Nos. 1 4 inclusive). Sixteen of these deposits have been studied by Dow and Batty (1961) who estimate a total of 1,043,000 tons of rock with an average grade of 17.98 percent TiO_2. Preliminary tests by the U.S. Bureau of Mines indicate that the ores from Utah may be beneficiated to yield titanium and zirconium products of marketable grade. Recovery of the TiO_2 contained in the black sandstone ranged from 41.2 to 61 percent (Dow and Batty, 1961), but beneficiation is considered difficult because of the extremely fine grain size and the varying degree of alteration of the constituents.

Utilization of these deposits for titanium is hampered by inadequate tonnage available in any one deposit and the relatively great distances between the various groups of deposits. Interest in their development might increase with the discovery of additional deposits in a single area, or by materially augmenting the resources by exploration of inadequately known deposits. Exploration for additional deposits is greatly simplified because they are confined to specific stratigraphic horizons: all known deposits are in sandstone laid down during regressions of the sea; never during transgressions. They are especially conspicuous because of their dark color and commonly form prominent outcrops because of their resistance to erosion. In addition, their anomalous radioactivity facilitates their detection; many of the known deposits in the Western States were found during airborne reconnaissance for uranium by the Atomic Energy Commission.

TUNGSTEN

(By D. M. Lemmon, Menlo Park, Calif.)

Tungsten metal is light gray, very heavy, and has the highest melting point of the metals (about 3410° C., 6170° F.). It is used in alloy steels for high-temperature applications, in tungsten carbide for cutting tools and armor-piercing shells, as pure metal in lighting and electronics, and in various chemicals for dyes, inks, and fluorescent lamps.

U.S. consumption in 1962 was 13,691,000 pounds of contained tungsten (863,100 units of WO_3), of which domestic ores provided 8,280,000 pounds. Traditionally part of the U.S. supply comes from imports; only from 1953 to 1956, at a premium-guaranteed price, has domestic production exceeded consumption. The alltime maximum annual yield was 15,833,000 pounds of contained tungsten in 1955.

The price of concentrates has ranged widely over the years depending upon demand and availability of imports. Quotations for domestic scheelite in July 1963 were $16 to $18 per short ton unit of WO_3, in contrast to a Government stockpile price of $63 in 1951–56 and a war-induced price of $85 in 1916. Output is quite sensitive to price; at the low rates prevailing since 1956, few tungsten mines have been worked in the United States, and none in Utah.

Since 1914, when tungsten was first produced in Utah, total output is 437 short tons of concentrate containing 60 percent of WO_3 (26,220 units of WO_3), less than 0.2 percent of total U.S. production in that period (U.S. Bureau of Mines Minerals Yearbook, 1956). Some production was reported in 1914–18, 1938, 1940–47, and 1951–56; the maximum annual rate being 84 tons of concentrate in 1954. Tungsten has been of minor importance in Utah mining.

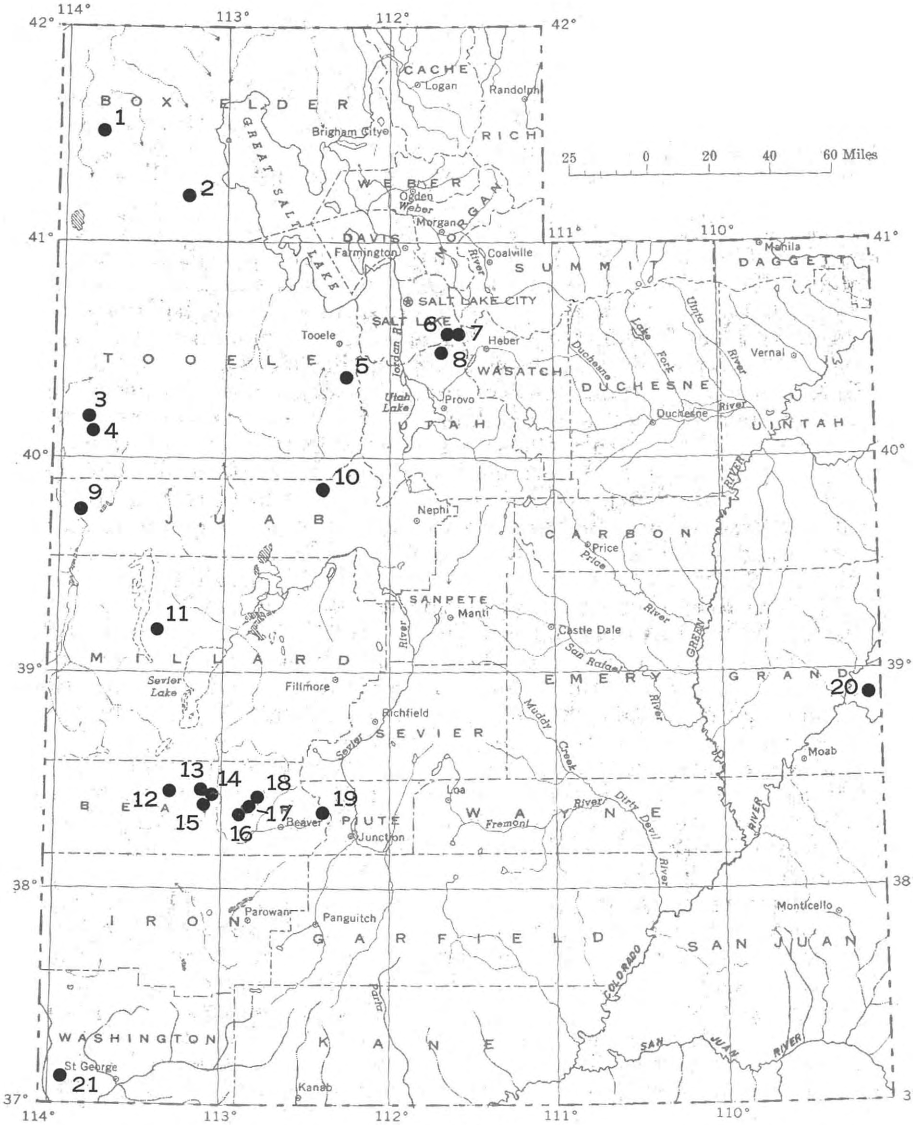
In nature, tungsten does not occur as native metal, but is chemically combined in about a dozen minerals, of which the commercially important ones are ferberite ($FeWO_4$), wolframite ($(Fe, Mn)WO_4$), huebnerite ($MnWO_4$), and scheelite ($CaWO_4$). The tungsten ores contain only small amounts of these minerals.

Tungsten is found in Utah mostly in contact-metamorphic deposits of garnet and other silicates formed at places along contacts of granitic intrusive rocks with invaded limestone. The known deposits are small and are mostly low grade, averaging less than 1 percent of WO_3.

Tungsten minerals have been identified in 21 deposits or districts in Utah. Twelve of these have been productive. The known occurrences are described briefly in the following notes, listed by county; the number in parentheses following names refers to the map (fig. 27), and in some instances represents several closely spaced deposits.

OCCURRENCES BY COUNTY

Beaver County.—Tungsten deposits of Beaver County are clustered about granitic intrusives of the San Francisco, Rocky, and Star districts west of Milford, and in the Mineral Mountains (Hobbs, 1945b). The principal production was from the Old Hickory mine (No. 14) which yielded 6,600 tons of sorted ore containing 0.6 percent of WO_3 in 1941–44. The Copper King mine (No. 15) at the north edge of the Star district was worked during 1942–44 for a yield of 1,100 tons of 0.72 percent WO_3 and 1,200 tons of 0.35 percent WO_3. No output was made from occurrences at the Little May Lilly (No. 15) and Copper Ranch mines (No. 13).



EXPLANATION

Districts, principal mines, or prospects

1. Grouse Creek Mountains
2. Newfoundland Mountains
3. Gold Hill: E.H.B., B. Estelle, Fraction Lode
4. Gold Hill: Reaper
5. Ophir: Ophir Hill
6. Alta: Emma, South Hecla
7. Alta: Mountain Lake
8. Metals Coalition
9. Trout Creek
10. Tintic Western (Desert Tungsten)
11. House Range
12. Cupric
13. Copper Ranch
14. Old Hickory
15. Copper King
16. Creole
17. Pass Canyon
18. Garnet
19. Louise
20. Ryan Creek
21. Beaver Dam Mountains

FIGURE 27.—Tungsten in Utah.

In the San Francisco Mountains the Cupric mine (No. 12), extensively explored in 1941–43 (King and Wilson, 1949), was estimated to have indicated and inferred reserves of 4,000 tons averaging 0.35 percent of WO_3 (Hobbs, 1945b). Other occurrences of scheelite are known in limestones on both sides of the granodiorite intrusive.

On the east side of the Mineral Mountains, the Garnet mine (No. 18) and the Pass Canyon mine (No. 17) yielded respectively in 1943–44,562 tons containing 356 units of WO_3 and 191 tons containing 179 units. On the southwest side of the Mineral Mountains, a little production also was made from the Creole (No. 16) and Two R's mines.

A little huebnerite is present at the Louise claims in quartz veins, 1 to 6 inches thick, in the Tushar Mountains (No. 19) about 10 miles east of Beaver (Butler and others, 192; Everett, 1961, p. 42).

Box Elder County.—Scheelite ore containing several percent of WO_3 has been produced from small bodies of tactite on the west side of the Grouse Creek Mountains (No. 1), north of Lucin. First worked during World War I, the deposits have yielded about 6,000 units of WO_3, principally from the Lone Pine mine, and partly from the Magnitude and Rocky Pass mines.

In the Newfoundland Mountains (No. 2), small lenses of scheelite-bearing tactite were prospected in 1955–56 and about 400 tons of ore containing 1.25 percent of WO_3 were removed (Everett, 1961).

Grand County.—A little scheelite with fluorite is reported in a fault between granite and sandstone at the Ryan Creek prospect (No. 20) in sec. 24, T. 22 S., R. 25 E.

Juab County.—Scheelite is present in late Precambrian rocks at several prospects on the north side of the mouth of Trout Creek (No. 9) in the Deep Creek Range. At the three principal occurrences, scheelite occurs along a fault in limestone at the Trout Creek mine, with beryl in small quartz veins at the Apex mine, and as fracture coatings in schist at the Bacon mine.

In the West Tintic district, at the south end of the Sheeprock Mountains, the Tintic Western mine (also known as Desert Tungsten) (No. 10) was worked through a 400-foot shaft in 1942–44, and 7,198 tons of ore containing 6,734 units of WO_3 were mined. Scheelite was disseminated in six limonite veins 1 to 1½ feet thick, confined to a pendant of limestone in monzonite (Hobbs, 1945a; Wilson, 1950).

Millard County.—In the House Range, south of Marjum Pass, many small bodies of scheelite-bearing tactite border a quartz monzonite stock (No. 11) (Gehman, 1958). They replace individual beds in gently dipping Upper Cambrian limestone. The bodies are mostly low grade, and none are large. More lenses of the same type might be found at depth but profitable exploitation is hindered by the high cost of exploration and production from such bodies.

In 1941–43, shipments to Metals Reserve Co. in Salt Lake City were 1,191 tons containing 1,104 units of WO_3; in 1952–56, shipments from six properties to mills were reported to be 5,506 tons containing 3,611 units of WO_3 (Everett, 1961).

Salt Lake County.—A little scheelite occurs in the Alta district, Wasatch Mountains, in tactite in the Great Western and Big Cottonwood tunnels of the Mountain Lake mine (No. 7) (Crawford and Buranek, 1944), and in the South Hecla mine (No. 6) with sulfides as a small replacement lens in limestone. The rare mineral tungstenite (tungsten sulfide) was found in small amounts at the Emma mine (No. 6), the only known locality (Wells and Butler, 1917; Calkins and Butler, 1943).

Scheelite is disseminated in stockworks of the Little Cottonwood stock (No. 6) which may contain large tonnages of very low-grade material averaging 0.02 percent of WO_3 (Erickson and Sharp, 1954; Sharp, 1958).

Tooele County.—The Gold Hill district has produced about 12,500 units of WO_3, more than any other district in Utah. The principal output, made during World War II, was from tactite deposits north-northwest from Gold Hill: the E. H. B., B. Estelle, and Fraction Lode mines (No. 3). In 1915–17, 1,972 units of WO_3 were produced at the Reaper mine (No. 4) from a pipelike mass of pegmatite (Nolan, 1935).

In the Ophir Hill mine, Ophir district (No. 5), southern Oquirrh Mountains, a little low-grade scheelite ore was found in 1954–55 in limestone of the Cambrian Ophir Shale, and small amounts of ore were shipped.

On Green's Ridge, Sheeprock Mountains, in sec. 23, T. 10 S., R. 6 W., Harris (1958) reports mineralized pods and stringers in altered late Precambrian quartzite near Tertiary granite. They contain limonite, relict pyrite, magnetite, chlorite, and fine-grained scheelite.

Utah County.—A little scheelite in tactite is on the Mayday Extension claim (No. 8) of Metals Coalition Mining Co. on Deer Creek north of American Fork Canyon. In 1943, shipment was made of 77 tons containing 30 units of WO_3.

Washington County.—A little noncommercial scheelite is present in Precambrian gneiss on the southwest side of the Beaver Dam Mountains (No. 21).

RESOURCES

The tungsten deposits now known in Utah are small and with low content of tungsten. Greatly increased ore reserves must be found before tungsten mining can be important in the State. Reserve estimates compiled in 1958 showed stockpiled and indicated ore in Utah to be 11,740 tons averaging 0.6 percent of WO_3 (Everett, 1961, p. 18). The most likely area for finding larger tonnages, but of low grade, appears to be the House Range.

At high prices, it is expected that the past pattern of production from Utah could be repeated.

URANIUM

(By L. S. Hilpert, Salt Lake City, Utah and M. D. Dasch, Washington, D.C.)

Uranium consists of a mixture of the isotopes U^{238}, U^{235}, and U^{234}. The relatively abundant isotope U^{238}, which can be converted to plutonium, and U^{235} are the principal ingredients used in fuel for nuclear reactors for power, testing, research, and propulsion; and for weapons. Minor amounts are also used in the chemical, ceramic, and electrical industries.

Uranium is widely distributed in the United States in rocks of nearly all ages and types. Principal deposits are in sedimentary rocks, particularly continental sandstone and conglomerate, but important ones also are in continental and marine limestone, in lignitic coal and associated carbonaceous shale, and in phosphorite and marine black shale. Some important deposits also occur in veins. Summary discussion of the different occurrences are given by Finch (1955), Schnabel (1955), Stocking and Page (1956), and Butler, Finch and Twenhofel (1962).

Uranium is a commodity of great importance to Utah, but since the initial discovery of minable uranium in Utah the industry has had a varied existence, first stimulated by the demand for radium, then for vanadium, and finally for uranium. These periods are reviewed briefly.

Uranium mining in the State dates from the early years of this century following the discovery by the Curies of radium and its association with uranium. Uranium deposits of the so-called carnotite type were found in southeastern Utah about 1900 and first shipments of ore were made in 1904 (Boutwell, 1905), but production was sporadic until the late forties because of changing market demands. Initially the ores were mined primarily for radium, which occurs in all uranium ores in amounts of about 1 gram for every 200–300 tons of ore containing 2 percent U_3O_8. In 1923, the price for radium collapsed after high-grade ore from the Belgian Congo entered the market; thereafter mining almost ceased until the midthirties, except for a small amount of ore produced for therapeutic purposes. During the radium-mining period Utah produced only a few thousand tons of selectively mined and hand sorted ore that probably averaged between 2 and 3 percent U_3O_8. Through 1926, the total radium extracted from the Nation's ores was estimated to be 250 grams (Hess, 1929, p. 268), of which Utah's yield was about 5 percent (R. P. Fischer, oral communication), or roughly 12 to 15 grams. The dollar value of this ore was based almost entirely on the radium content. During the most productive period from 1909–23, the price on the world market for the elemental radium content in purified salts ranged from $70,000 to $180,000 per gram (Tyler, 1930, p. 41), the most expensive mineral commodity ever mined for commercial purposes (Koschmann, 1962, p. 17).

Relatively little radium was extracted after 1926, and since World War II other radioisotopes have largely replaced it. The dollar value of the ore cannot be estimated because the mining companies extracted the radium and only the refined product entered the market.

In the midthirties, increasing demand for vanadium stimulated production of carnotite ores until early 1944 when the market for vanadium became glutted. During the vanadium-producing period about 108,000 tons of ore was mined, primarily for the vanadium (R. P. Fischer, written communication). The mill tailings from this ore were treated for the recovery of the uranium during the latter part of, and after, World War II until the material was exhausted in 1947.

After 1944 there was a lull in mining until 1948 when the Atomic Energy Commission established a guaranteed price schedule for uranium ore with additional benefits and bonuses.[1] This stimulated exploration and mine development that resulted in establishment of the uranium mining industry. At the end of 1962, this industry had produced about 9 million tons of ore with the contained uranium and

[1] See Atomic Energy Commission Regulations, pt. 60, Domestic Uranium Program Circulars 1 to 6, inclusive, Apr. 9, 1948; June 15, 1948; Feb. 7, 1949; and June 27, 1951.

coproduct radium (excluding vanadium) valued at about $250 million. This ore was removed from literally thousands of deposits, many of which were mined as a single enterprise. The mine production data are summarized in table 9.

TABLE 9.—*Uranium ore production in Utah*

Years	Short tons [1]	Value [1 2]	Years	Short tons [1]	Value [1 2]
1904–36	[3]	[4] $1,000,000			
1937–44	[5] 108,000	[6] 500,000	1957	1,075,759	$29,774,340
1945–47	[7]	[8]	1958	1,239,767	38,582,682
1948–49	[9] 13,504	[9] 248,825	1959	1,210,654	37,310,452
1950	[9] 44,219	[9] 953,430	1960	1,089,757	27,843,154
1951	[9] 61,058	[9] 1,539,199	1961	1,098,783	25,734,215
1952	[9 10] 176,209	[9] 4,224,971	1962	781,955	23,653,000
1953	[9] 194,035	[9] 5,557,993			
1954	[9] 394,000	[9] 10,731,776	Total		
1955	[9] 607,170	[9] 16,984,021	(rounded)	9,000,000	250,000,000
1956	926,273	25,214,342			

[1] Data from U.S. Bureau of Mines Minerals Yearbooks, except as noted.
[2] F.o.b. mine value, base price, grade premiums, and exploration allowance; vanadium excluded.
[3] Few thousand (estimated). Mined principally for radium.
[4] Estimated value of coproduct radium.
[5] Data from R. P. Fischer. Mined principally for vanadium; later processed for uranium.
[6] Estimated value of byproduct uranium.
[7] Few thousand (estimated).
[8] Not significant.
[9] Preliminary figure compiled from file data by courtesy of the U.S. Atomic Energy Commission.
[10] Includes 5,106 tons listed for 1948–52.

Mine output started to decline after 1958 as the result of a saturated uranium market; the decline was brought about by lapsing of some fringe benefits, restrictions on mine allotments, and the lowering price paid for mill concentrates. The bonus paid for initial production of uranium ores from new mines terminated February 28, 1957, and payments made for contained V_2O_5 were discontinued on ores that were too low in vanadium for efficient vanadium recovery. In 1962 a stretch-out program for domestic uranium procurement for the January 1, 1967, to December 31, 1970, period was announced which defers delivery for some ore contracted for delivery before 1967, and specifies a reduction in the price paid for some concentrates to $6.70 per pound for the years 1969–70, inclusive.[2]

Uranium deposits in Utah occur in rocks of many ages and lithologic types. Three general types, namely, peneconcordant, vein, and bedded deposits, are important in Utah and are described below.

The most abundant and most productive type are the peneconcordant deposits. These occur mainly in continental sedimentary rocks, mostly in sandstone and conglomerate, and generally conform with the bedding, but were emplaced after the rocks were deposited. They are generally elongate, tend to occur in clusters, and range in content from less than a ton of ore to more than a million tons. All the ore during the radium and vanadium producing periods came from this type of deposit. They were generally called carnotite deposits before 1950, and some which have yielded copper have been referred to as red bed copper deposits. The grade of the deposits ranges from trace amounts to several percent uranium, but the average grade of the ore is about 0.25 percent U_3O_8.

[2] U.S. Atomic Energy Commission Press Release 356, Washington, D.C., and Grand Junction, Colo., Nov. 17, 1962.

The mineralogy is complex and varies between deposits depending on the relative contents of uranium and vanadium or uranium and copper, and the degree of oxidation. The vanadiferous uranium deposits generally range in U:V ratio from about 1:1 to 1:15 and contain traces of copper and other metals, but in general the copper content is less than in the nonvanadiferous deposits. The so-called nonvanadiferous deposits actually contain small amounts of vanadium and also minor amounts of copper and other metals, but locally contain as much as several percent copper.

Near or at the surface the vanadiferous deposits consist largely of the uranyl vanadates, carnotite and tyuyamunite, and various vanadium minerals; and the nonvanadiferous deposits contain the uranium hydrous oxide, becquerelite. When much copper is present the minerals are commonly the hydrous phosphate and hydrous sulfate of copper and uranium, namely torbernite and johannite respectively, and hydrous carbonates of copper.

Below the surface and generally below the water table the unoxidized analogs of these minerals are principally uraninite, coffinite, montroseite, and micaceous vanadium silicates in the vanadiferous deposits; uraninite in the nonvanadiferous deposits; and uraninite and various amounts of iron and copper sulfides where much copper is present. The mineralogy is discussed more completely in Hess (1933), Weeks and Thompson (1954), Finch (1959), and Garrels and Larson (1959).

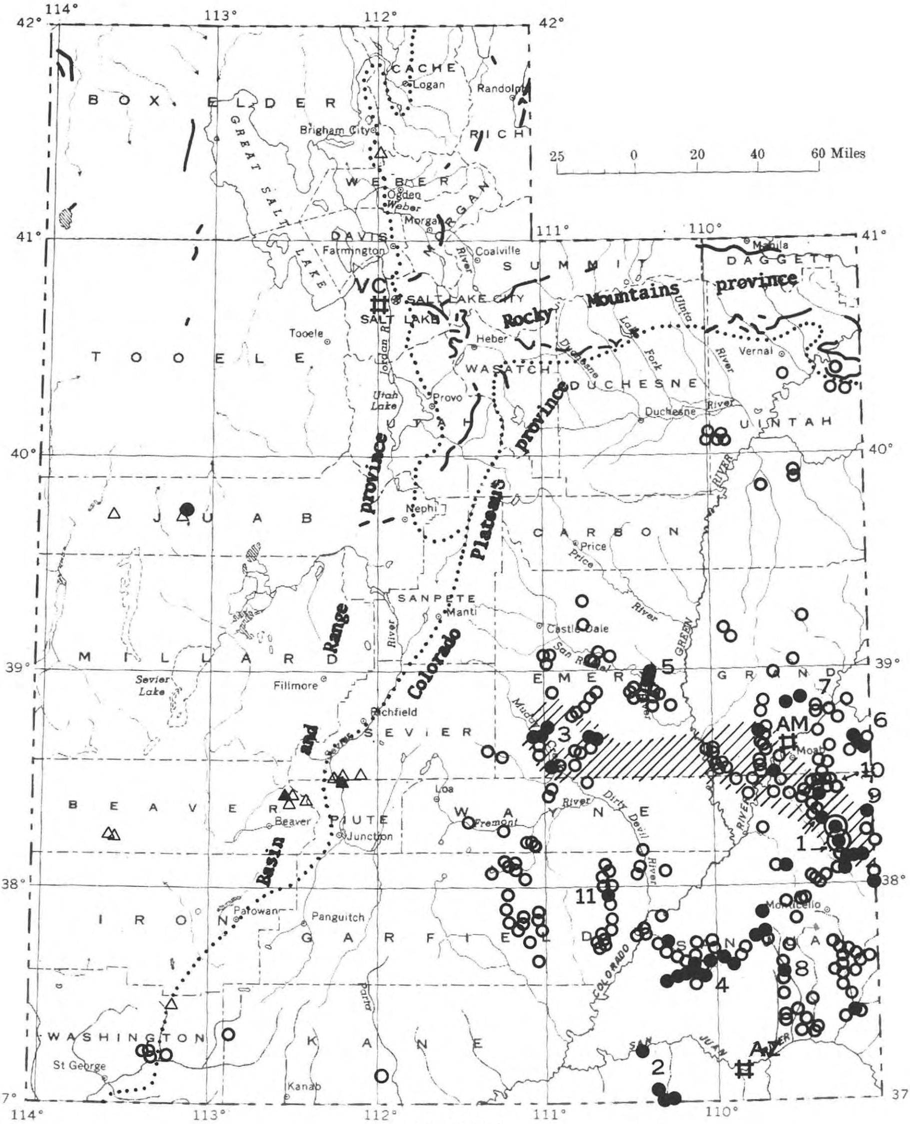
The peneconcordant deposits are nearly all in the Colorado Plateaus province (fig. 28) and principally in rocks of Mesozoic age. About 80 percent of Utah's uranium has come from deposits in the Triassic Chinle Formation, about 15 percent has come from the Jurassic Morrison Formation, and the remaining 5 percent has come from various other units.

Deposits in the Chinle are at or near the base in several somewhat discontinuous sandstone units, chiefly the Moss Back and Shinarump Members and, to a lesser extent, the Temple Mountain Member and a local sandstone unit in the Monitor Butte member (Stewart, 1959).

The larger deposits are clustered in ancient sandstone-filled stream channels concentrated along the northeastern pinchouts or margins of the sandstone units (Johnson, 1959a and 1959b). These clusters constitute relatively elongate areas, or belts, which contain the principal deposits in the Chinle Formation. Most important of these is the Moab uranium belt which, through 1961, yielded about 65 percent of Utah's uranium. The geologic relations of the deposits in this belt and others in the Chinle are defined and discussed by Finch (1959).

The uranium deposits in the Chinle in different places are vanadiferous, nonvanadiferous, or cupriferous. The vanadiferous deposits occur chiefly in the Libson Valley (No. 1, fig. 28) and Monument Valley (No. 2) areas, San Juan County; and in the San Rafael Swell area (No. 3), Emery County. Most of these deposits have a U:V ratio of about 1:3. The Libson Valley area (No. 1), San Juan County, also contains most of the nonvanadiferous deposits, and the cupriferous deposits are mostly in the White Canyon area (No. 4), San Juan County. The U:Cu ratio in these deposits generally ranges from 1:1 to about 1:3.

The uranium deposits in the Morrison formation are nearly all in the Salt Wash member, which crops out throughout many parts of



EXPLANATION

PRODUCTIVE DEPOSITS OR GROUPS OF DEPOSITS
(Numbers refer to areas mentioned in text)

Peneconcordant	Vein	Tons of ore mined through 1961
◉		> 1,000,000
●	▲	10,000-1,000,000
○	△	< 10,000

Outcrop of Phosphoria Formation (uraniferous in part)

Moab uranium belt

Operating mill (VC. Vitro Chemical Co.; AM. Atlas Minerals; AZ. A-Z Minerals Corp.)

FIGURE 28.—Uranium in Utah.

southeastern Utah. This member is an alluvial fan deposited on a broad plain by a system of braided streams that diverged to the north and east (Craig and others, 1955). Near its southwestern source the Salt Wash Member is a conglomeratic sandstone but to the northeast it becomes mudstone; between, it is mostly interbedded sandstone and mudstone. The principal uranium deposits are in relatively thick sandstone lenses with some interbedded mudstone. These lenses represent old complexes of sand-filled stream channels.

The most important deposits occur in such lenses in the Green River area (No. 5), Emery County; in the Polar and Beaver Mesa area (No. 6) and Yellow Cat area (No. 7), Grand County; Lisbon Valley area (No. 1) and Cottonwood Wash area (No. 8), La Sal Creek area (No. 9), and Cane Creek area (No. 10), San Juan County; and on the east side of the Henry Mountains (No. 11), Garfield County.

The Salt Wash ores are nearly all vanadiferous, the U:V ratio generally ranging from 1:2 to 1:15 and averaging about 1:4.

In addition to the deposits in the Chinle and Morrison Formations, scattered peneconcordant deposits occur in other sedimentary formations ranging in age from Permian to Tertiary. Most of these deposits are in sandstone, are small, and have yielded little ore. Mineralogically they are nearly all similar to the Chinle and Morrison deposits. One exception, the Yellow Chief, is a fairly large deposit in western Juab County.

The Yellow Chief is in a valley that separates Spor Mountain from the main part of the Thomas Range. Upper Tertiary lava flows and tuffs in the valley are interbedded with clastic sediments derived from nearby ranges. The host rock for the uranium ore is a massive, tuffaceous, conglomeratic sandstone, locally called the Yellow Chief sandstone. It was deposited in a fluvial environment and is probably late Miocene or early Pliocene in age (Bowyer, 1963, pp. 17–18). The ore mineral is beta-uranophane, which is a secondary uranyl silicate that fills pore spaces and coats the sandstone particles; deposition, for the most part, was stratigraphically controlled. This uranium deposit differs from others in fluvial strata in that carbonaceous matter is inconspicuous or lacking, iron sulfides are sparse, and beta-uranophane is the only uranium mineral present in significant amounts. Bowyer (1963, p. 21) suggests the beta-uranophane may have been formed by concentration in the host rock by vadose and ground water, following erosion of the uranium-bearing fluorspar bodies of Spor Mountain; or it may have been altered from coffinite or uraninite after these primary uranium minerals were precipitated from magmatic fluids.

In addition to peneconcordant deposits, vein-type deposits in Utah have yielded important amounts of ore. This type of deposit includes fracture fillings, stockworks, mineralized breccia, and fracture zones in rocks of all kinds, and pegmatite dikes. Most of these deposits are hydrothermal in origin.

In Utah, uranium-bearing vein deposits are in the Basin and Range province and at the western edge of the Colorado Plateaus province (fig. 28). Fluorite and uranium-bearing minerals are closely associated in several of these deposits, and in some areas the discovery of uranium can be attributed to earlier fluorspar mining.

The Marysvale uranium area in northern Piute County and southern Sevier County contains the most important vein deposits in Utah, and provides the outstanding example of fluorite-bearing uranium ores in the United States. In this area, lower to middle Tertiary Bullion Canyon Volcanics were invaded by middle Tertiary quartz monzonite, granite, and related intrusive rocks, and covered by upper Tertiary Mount Belknap Rhyolite. Following deposition of the Mount Belknap Rhyolite, the uranium deposits were emplaced as veins in the monzonite, as irregular masses at the base of the Mount Belknap Rhyolite, and as fracture fillings and coatings in the Bullion Canyon Volcanics.

Most important are the deposits, or veins, in the monzonite, which consist of the mineralized parts of a set of steeply dipping northeast-trending faults and fractures. The vein material consists of fillings of the open space in fault breccia and of fracture coatings by the principal ore mineral pitchblende and various minor secondary uranium oxides, and associated fluorite, ilsemannite, quartz, and pyrite. The veins range from about 1 inch to 3 feet thick and pinch and swell along the strike and dip. They have been mined along the strike for about 1,000 feet and to a depth below the surface of about 800 feet; they have supplied most of the ore from Utah's vein-type deposits.

The principal producing mines are within a relatively small area on the southwestern margin of a quartz monzonite intrusive.

Deposits in the Mount Belknap Rhyolite are in highly argillized zones above the veins in the monzonite. These deposits are irregular in form and range from a few feet to 100 feet or more in width and length, and from a few feet to several tens of feet thick. Mineralogically they are similar to the veins in monzonite but the ore minerals are more finely disseminated and the ore is rather pockety. The best deposits generally overlie places where the contact between the rhyolite and monzonite is fairly flat. Ore from the deposits in the rhyolite as well as in the monzonite veins averages about 0.20 to 0.25 percent U_3O_8.

Deposits in the Bullion Canyon Volcanics are small, scattered, and unimportant economically.

The geology and mineralogy of the Marysvale uranium deposits are discussed more completely by Walker and Osterwald (1956) and Kerr and others (1957).

In the Indian Creek area of eastern Beaver County erratically distributed uraninite and secondary uranium minerals have been mined along an intensely argillized fault zone. The zone, which contains fluorite, separates Tertiary Mount Belknap Rhyolite from Tertiary Bullion Canyon Volcanics. Some uranium also is present in shear zones in Mount Belknap Rhyolite and tuff, and in fractures in the Bullion Canyon Volcanics.

In the southern part of the Wah Wah Mountains, western Beaver County, uraninite and some autunite are present in rhyolite porphyry in association with fluorite pods adjacent to the faulted contact with Paleozoic carbonate rocks and in fragmental rhyolitic tuff that, in places, directly overlies carbonate rocks.

In the Thomas Range fluorspar district of western Juab County uranium is present in fluorspar pipes that cut Paleozoic dolomites. The uranium apparently is mostly in the crystal lattice of the fluorspar, but in places secondary uranium minerals coat fracture surfaces in dolomite. Samples of rock contain from 0.003 to 0.33 percent uranium, but due to metallurgical problems, the material currently is nonamenable to commercial extraction of uranium (Staatz and Osterwald, 1956, pp. 133–135; 1959, pp. 52–59; Sharp, 1963, p. 14).

West of the Thomas Range in the Honeycomb Hills, uranium minerals are disseminated along bedding planes and fractures in a Tertiary welded rhyolitic tuff.

In northern Washington County, some uranium ore has been mined from breccia zones in the Permian Kaibab Formation near the Hurricane fault. The ore mineral is principally autunite.

A small amount of uranium ore has been mined in eastern Box Elder County, where disseminated uraninite occurs in biotite-rich pegmatitic pods and layers in gneiss of the Precambrian Farmington Canyon Complex.

In addition to peneconcordant and vein deposits, uranium is present in low concentrations in bedded deposits. This type of deposit conforms with the bedding of the host rocks, is generally coextensive with the host unit, and was probably formed contemporaneously with it. Deposits of this type occur principally in phosphorites and in dark marine shales.

Most important, and probably the only ones of this type that are economically important, are the phosphorites, in which uranium occurs as a substitute for calcium in the phosphate mineral, carbonate-fluorapatite (Gulbrandsen, 1960a). Although deposits of this type have not been mined for uranium content in the United States, some uranium is recovered as a byproduct from such deposits mined for phosphate in Florida.

In Utah, the most important deposits of this type occur in several zones in the Meade Peak Phosphatic Shale Member of the Phosphoria Formation. The Meade Peak is almost coextensive with the Phosphoria in northern Utah (fig. 28) and the general distribution, stratigraphy, and relations of the phosphatic units are described by Cheney (1957) and McKelvey and others (1959), and are discussed in the section on phosphate (p. 195). Few data are available on the uranium content of the phosphatic zones of the Meade Peak in Utah, but studies indicate that the uranium content generally can be correlated with the phosphate content (Gulbrandsen, 1960a). According to Gulbrandsen (written communication, 1963), the content in the phosphate units in the Meade Peak Member in Utah, containing at least 18, 24, and 31 percent P_2O_5, respectively, averages 0.005, 0.007, and 0.01 percent uranium, respectively. This is a somewhat lower grade than is found in the Phosphoria farther north (Swanson, 1960, p. 1366).

In dark marine shales local concentrations as high as 0.005 percent uranium have been found in the basal shales of the Gardner dolomite and Brazer Limestone (Duncan, 1953). These occurrences, however, are spotty and the grade generally ranges from about 0.001 to 0.004 percent uranium in these shales and others. Although these shales are rather widespread it is doubtful if the uranium will be of economic significance within the foreseeable future.

As of January 1, 1963, the U.S. Atomic Energy Commission estimated the uranium mine reserves in Utah were 3 million tons of ore that averaged 0.29 percent U_3O_8.[3] This reserve, which is mostly in the Chinle and Morrison Formations deposits in southeastern Utah, is

---

[3] John A. Patterson, address before the National Western Mining Conference, Denver, Colo., Feb. 8, 1963.

only adequate to sustain a mine yield for 3 years at the 1956–62 rate of extraction. During this period the reserves have progressively dropped from a high of 7.5 million tons in 1956. The drop is partly the result of mine depletion, but is mostly the result of lack of exploration and development, caused by the saturated uranium market. As a result, the mining companies have severely curtailed exploration and have only attempted to develop reserves near the mining faces. Although the reserves have gradually become depleted, the picture can be reversed when the market becomes more favorable. The resource potential is actually great enough to sustain mining for many years.

The greatest and most readily tapped potential of additional uranium deposits is in the Chinle and Morrison Formations, which may contain resources at least several times as great as have been mined. These deposits, however, will be more costly to find, develop, and mine than in the past because they will largely occur at depths 1,000 feet and more below the surface.

Most of the future uranium resources probably will be found in the Moab uranium belt, the most favorable parts in it being relatively narrow, northwest-trending bands that are parallel to the northeastern margins of the Moss Back, Shinarump, and Monitor Butte Members of the Chinle Formation (Finch, 1959, pl. 10; Johnson, 1959a, pl. 6). Areas within these bands which have the greatest potential are the Lisbon Valley and San Rafael areas (Nos. 1 and 3). Important resources also likely will be found in the Shinarump Member of the Chinle in a westerly trending belt in the White Canyon area (No. 4) and in a northwesterly trending belt in the Monument Valley area (No. 2) (Finch, 1959, pl. 10). Important resources also will be found in the Salt Wash Member of the Morrison Formation. Most favorable are northerly trending zones or channel systems on the eastern flanks of the San Rafael Swell and Henry Mountains (Nos. 5 and 11) (Johnson, 1959a, pl. 7). Other areas containing resources in the Salt Wash are principally Polar and Beaver Mesa (No. 6), Yellow Cat (No. 7), Cottonwood Wash (No. 8), La Sal Creek (No. 9), and Cane Creek (No. 10). Some important resources also may be found in vein deposits in the Marysvale and Indian Creek areas in Piute, Sevier, and Beaver Counties, and in the Tertiary sediments in the western part of the State.

Very large tonnages of uranium occur in the Meade Peak Phosphatic Shale Member of the Phosphoria Formation in northern Utah (table 10). If the need is great, much uranium could be recovered from this source most readily as a byproduct of phosphate mining operations.

TABLE 10.—*Uranium reserves in the Meade Peak Phosphatic Shale Member of the Phosphoria Formation in Utah*

Cutoff content of P_2O_5 in beds 3 feet or more thick	Reserve of rock (rounded long tons) [1]	Uranium grade (percent) [2]	Uranium content (rounded long tons)
More than 31 percent and above entry level	39,000,000	0.01	3,900
More than 31 percent and from entry level to 1,000 feet below	40,000,000	0.01	4,000
More than 24 percent and above entry level	790,000,000	0.007	55,000
More than 24 percent and from entry level to 1,000 feet below	400,000,000	0.007	28,000
More than 18 percent and above entry level	2,800,000,000	0.005	140,000
More than 18 percent and from entry level to 1,000 feet below	1,135,000,000	0.005	57,000

[1] Modified from data compiled by W. C. Gere.
[2] Estimates by R. A. Gulbrandsen.

VANADIUM

(By R. P. Fischer and J. D. Vine, Denver, Colo.)

About 2,000 short tons of vanadium have been consumed annually in the United States in recent years. Three quarters of this has been used in special engineering, structural, and tool steels as an alloy to control grain size, impart toughness, and inhibit fatigue. The other principal domestic uses have been in nonferrous alloys and chemicals (U.S. Bureau of Mines, 1960; Busch, 1961).

Utah is second to Colorado in the production of domestic vanadium ore. The ore mined in Utah has yielded vanadium pentoxide concentrates containing about 6,000 short tons of vanadium, representing about 10 percent of the total domestic production and 6 percent of the total world production. The value of vanadium pentoxide in these ores is estimated at about $7 million, and the vanadium concentrates from Utah ores had an estimated value of $22 million.

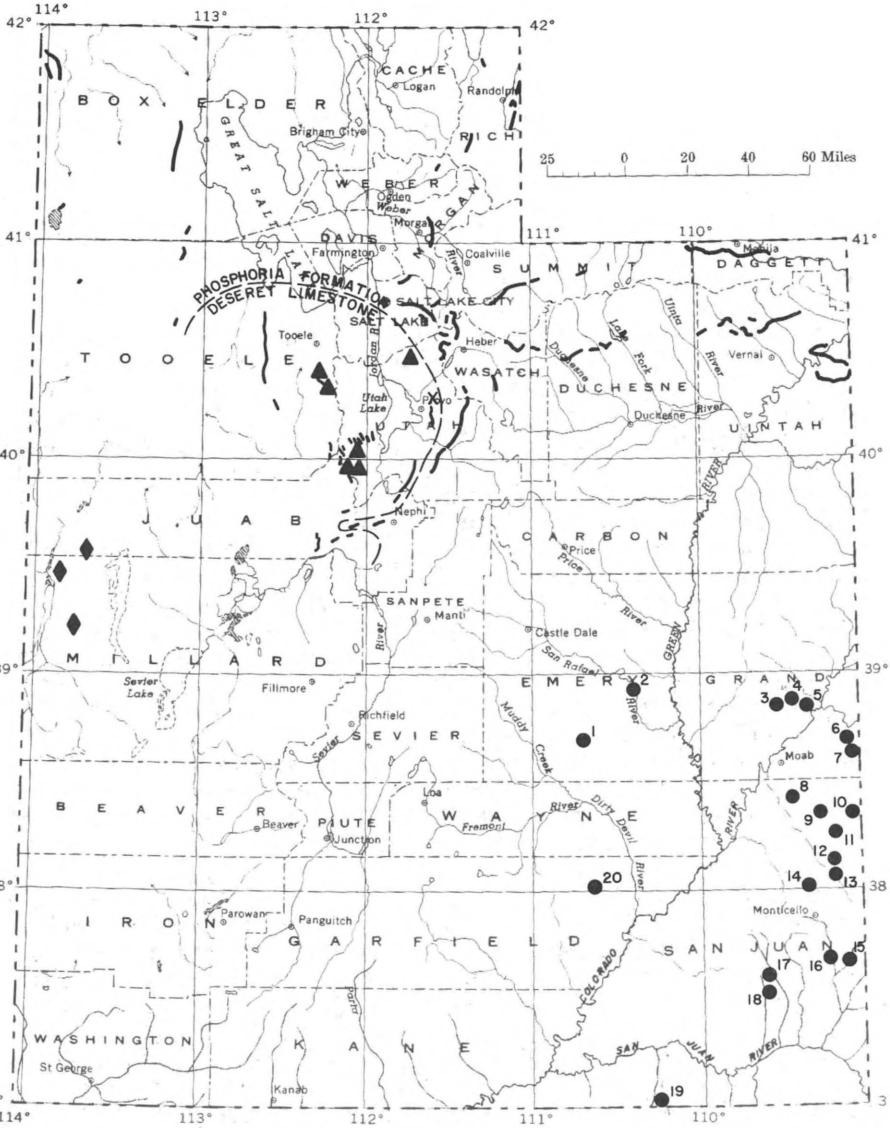
Only about half of the vanadium ore mined in Utah has been milled in Utah; the rest has gone to mills in Colorado. Since 1961, however, vanadium-bearing ferrophosphorus slags from phosphate rock mined in Idaho have been milled in Utah to obtain vanadium concentrates, and this practice may yield a substantial production of vanadium concentrates in Utah in the future.

Deposits of vanadium and uranium in sandstone are the only productive vanadium deposits in Utah. Two other types of deposits—vanadiferous phosphate and vanadiferous shale—are potential sources of vanadium in Utah. These three types of deposits are described briefly below and their distribution is shown on figure 29. (See also sections on uranium, p. 124, and phosphate, p. 195.)

Mining of the vanadium-uranium deposits in sandstone in Utah began in the early 1900's, but until the mid-1930's these mining operations were sporadic and ore production was small. The ore was mined mainly for its radium content, but a little byproduct vanadium and uranium were obtained. During the late 1930's and early 1940's these deposits were mined more intensively and mainly for vanadium. Since the late 1940's these deposits, as well as many similar ones that contain uranium but little or no vanadium, have been mined intensively for uranium. Vanadium has been recovered as a coproduct or byproduct from most of the ore that contains about 1 percent or more V_2O_5.

All of the productive vanadium deposits in Utah are in the southeastern part of the State. Most of them are in the Morrison Formation of Jurassic age; a few are in the Chinle Formation of Triassic age. The host rocks are lenticular beds of continental sandstone that contain rather abundant carbonized plant fossils. The ore minerals impregnate the sandstone and replace the plant fossils. The primary ore minerals consist of oxides and silicates of vanadium and uranium; all of these except the vanadium silicates oxidize to a variety of secondary minerals.

The ore bodies are tabular layers that lie nearly parallel to the bedding of the sandstone. They range from small masses only a few feet across, containing only a few tons of ore, to bodies several hundred feet across, containing thousands of tons of ore; the ore layers average a few feet thick. Ore bodies tend to be clustered in small areas as shown on figure 29.



EXPLANATION

● Principal mining areas of vanadium-uranium deposits in sandstone

1. Temple Mtn.	6. Polar Mesa	11. Lisbon Valley	16. Montezuma Canyon
2. Tidwell Draw	7. Beaver Mesa	12. Dry Valley	17. Cottonwood Canyon
3. Yellow Cat	8. Cane Spring	13. East Canyon	18. Butler Wash
4. Cactus Rat	9. Rattlesnake	14. Peters Hill	19. Monument Valley
5. Squaw Park	10. La Sal Creek	15. Monument Canyon	20. Trachyte Creek

Outcrop of Phosphoria Formation or Deseret Limestone

Sampled exposure: ▲ Deseret Limestone, ♦ Chainman Shale, X Manning Canyon Shale

FIGURE 29.—Vanadium in Utah.

Developed reserves of vanadium-bearing ore in the Morrison and Chinle Formations in southeastern Utah contain a little less than 1,000 short tons of recoverable vanadium, representing nearly a 2-year supply at the rate of mining in recent years. Potential resources in undiscovered deposits, however, probably contain several thousand tons of vanadium, but these deposits will be increasingly costly to find and mine. Likely the production of this type of ore will decline gradually during the next few years. The outlook for their discovery and mining will be influenced chiefly by economic conditions in the uranium-mining industry in the future.

The known deposits of vanadiferous phosphate and shale occur in the northern and western parts of Utah (fig. 29). The total amount of contained vanadium in these deposits is large—perhaps tens of thousands of tons of vanadium—but sampling of these deposits for vanadium has not been adequate to obtain a quantitative appraisal or even a good estimate of the grade of the contained vanadium.

Some of the phosphate rock mined from the Phosphoria Formation of Permian age in Idaho, Wyoming, and Montana contains 0.2 to 0.3 percent vanadium pentoxide (V_2O_5 the conventional reporting unit in the vanadium industry). Vanadium has been recovered from some of this rock, both from operations manufacturing fertilizer and also from slags obtained in making elemental phosphorus. Minable phosphate rock also occurs in the Phosphoria Formation in northern Utah (p. 195), but this material probably is a little lower in vanadium content than that in the states to the north. Phosphate rock of potential value also occurs in the lower part of the Deseret Limestone of Mississippian age in west-central Utah; this material might average about 0.2 percent V_2O_5 (Duncan, 1953, pp. 61–67; Morris and Lovering, 1961, pp. 99–104).

Some thin beds of shale associated with the phosphate rock in the Phosphoria and Deseret Formations contain 1 percent or more V_2O_5, but layers of shale thick enough to mine probably average less than 1 percent V_2O_5. Vanadiferous shale beds also occur in the Chainman Shale of Mississippian age and the Manning Canyon Shale of Mississippian and Pennsylvanian ages in western Utah (Davidson and Lakin, 1961, 1962.) Because of the relatively low vanadium content and metallurgical difficulties, it is unlikely that any of these shales will be exploited for vanadium alone in the foreseeable future. In places, however, these shales also contain unusual concentrations of other elements—chromium, fluorine, molybdenum, nickel, selenium, uranium, and zinc (Gulbrandsen, 1960; Davidson and Lakin, 1961, 1962); ultimately two or more of these metals might be profitably recoverable as coproducts from these rocks.

ANTIMONY AND OTHER MINOR METALS

(By M. D. Dasch, Washington, D.C.)

Antimony, arsenic, bismuth, cadmium, selenium, and tellurium are recovered primarily as byproducts during the smelting and refining of metallic ores. Production figures of smelter byproducts in Utah are, for the most part, unavailable. Indeed, if annual statistics were released, they would be misleading, for, although much of the ore processed by Utah smelters comes from local mines, some of the ore originates in neighboring states—in parts of Arizona, California, Colorado, Idaho, Nevada, and Montana.

The characteristics, uses, and production of antimony, arsenic, and bismuth are discussed by element in the following paragraphs. The occurrences of these elements in Utah are then summarized by mining district, rather than by individual commodity. The uses, production, and occurrences of cadmium, selenium, and tellurium are discussed separately by commodity. A resource statement for all six elements concludes the discussion.

Antimony is an element that can occur in several different forms, a property referred to as allotropy. In the common form, it is a brittle, tin-white material with a metallic luster. It occurs rarely in the native state, more commonly as the mineral stibnite, a steel-gray crystalline antimony trisulfide.

Antimony is alloyed with certain metals in order to harden them and to inhibit corrosion. In 1961, the most recent year for which complete production statistics are available, the greatest consumption outlet for antimony was as antimonial lead for use in batteries. Significant quantities of the element were also used in ceramics and glass, in flameproofing chemicals and compounds, and to an increasing extent in plastics. Although antimony possesses no indispensable properties, it is technologically superior to other elements in many of its uses. Furthermore, it is relatively cheap and can be substituted for more expensive metals.

Antimony is found in two types of deposits: one type is simple both mineralogically and structurally, the other is complex. The simple type consists predominantly of native antimony, stibnite, and in places their oxidized equivalents. The minerals occur in siliceous gangue and may be accompanied by small quantities of pyrite and other metal sulfides. Examples in Utah of this simple type of deposit are: the Antimony Canyon (Coyote Creek) deposits, Garfield County; the Dry Lake antimony mine, Box Elder County; and the antimony deposits west of Gunlock, Washington County. In the complex type of deposit, antimony commonly is present in sulfo-salts of copper, lead, and silver, or in sulfides of copper, lead, zinc, and silver. The antimony is locked within the complex crystal lattice of certain ore minerals such as tetrahedrite (copper-antimony sulfide). Stibnite less commonly is the principal antimony mineral in these complex ore bodies. Antimony mined in the United States has come almost entirely from the complex type of deposit (White, 1962, p. 1). Examples of these complex ores are some that are mined in the Park City, Tintic, and Bingham districts of Utah. Antimony generally is a byproduct, at times a coproduct, recovered from metallic ores, especially those of lead. Commercial antimony ores range from low grades of 1 to 2 percent antimony to high grades of 71.5 percent, or nearly pure stibnite.

Antimony was mined in Utah about 1880, when stibnite was first shipped from the Antimony Canyon (Coyote Creek) deposits in Garfield County. Production from this locality was sporadic and was limited to periods when antimony prices were high, as in 1906 and 1907. A little antimony was mined in Utah between 1915 and 1917, in response to needs of World War I, some of it from the Dry Lake antimony mine, Box Elder County. Ore was also shipped from this mine during World War II. Although byproduct antimony has been recovered at several Utah smelters (Utah Mining Association, 1959, p. 22), production information is unavailable.

Arsenic is a brittle, poisonous, allotropic element that is widespread in small quantities. In the common form, it has a near metallic luster and is tin white or silver gray; exposure to air turns it black. Arsenic seldom occurs in the native state. More commonly it is found in one of three minerals: orpiment (arsenic trisulfide), realgar (arsenic monosulfide), and arsenopyrite (sulfarsenide of iron). Arsenic also is mineralogically associated with copper, lead, cobalt, nickel, iron, and silver, with or without sulfur.

Arsenic is recovered as a byproduct during treatment of copper, lead, and less commonly, gold and silver ores. No domestic deposits are mined only for arsenic content at the present time. Elemental arsenic has not been recovered as a byproduct in this country in recent years. Instead, the element has been produced and consumed as arsenic trioxide or arsenious oxide, commercially called white arsenic. It is used primarily in the manufacture of calcium and lead arsenate insecticides. Since 1944 there has been a marked decrease in its consumption, owing to public preference for less toxic organic insecticides, such as DDT. The only extensive application of white arsenic, other than as a poison, is in glassmaking.

From 1923 through 1947, Utah was second and at times first in domestic white arsenic production; rank was not given for the State during the years preceding and following this span. Several Utah smelters produced arsenic, from the early part of the century through 1959. The Garfield smelter of the American Smelting & Refining Co. and the Midvale smelter of the U.S. Smelting Refining & Mining Co. recovered white arsenic from lead ores shipped from the Tintic district and from other parts of the State. In Tooele, the International plant of the Anaconda Co. recovered white arsenic over a period of years. From 1953 through 1958, only the Midvale plant was reported as recovering white arsenic. In 1959, it was dismantled and sold, and since that year there has been no report of arsenic production in the State.

Bismuth is a brittle, reddish-silver element that has a metallic luster and is chemically similar to antimony and arsenic. Small quantities of it are widely distributed throughout the world. Native bismuth, bismuthinite (bismuth trisulfide), and a number of other bismuth-bearing minerals generally are found in stringers and pockets in hydrothermal veins. In some places, bismuth enters into the crystal lattice of certain ore minerals, such as galena (lead sulfide). Few deposits are concentrated enough to be mined solely for bismuth. Most of it is produced as a byproduct of lead ores, and to a lesser extent of copper, tungsten, and gold ores.

In 1961, 35 percent of the bismuth metal consumed in the United States was used in pharmaceuticals, and in other industrial and laboratory chemicals. Sixty-one percent was used in fusible and other types of alloys (Spencer and den Hartog, 1962, p. 344). In the future, bismuth may become increasingly important in nuclear and electronic applications, and in thermoelectric elements and liquid metal reactors. Although other metals can be substituted for the element in some of its uses, bismuth has a relatively stable position in the present economy.

Bismuth production in Utah was reported as early as 1871. Lead ores from the Tintic district were smelted at the Bingham Junction plant of the U.S. Metals Refining Co. earlier in the century, and for many years the lead bullion was sent to Indiana where bismuth was recovered as a byproduct. In 1914, one lot of bismuth ore was shipped from the Clifton (Gold Hill) district, Tooele County. Bismuth recovery has been reported at various times by other Utah plants: the Garfield smelter of the American Smelting & Refining Co. (prior to 1959); the International plant at Tooele, of the Anaconda Co.; and the Midvale smelter of the U.S. Smelting Refining & Mining Co. Utah production is not mentioned specifically after 1948 in the U.S. Bureau of Mines Minerals Yearbook.

Antimony, arsenic, and bismuth often occur within the same mines or mining districts. The significant deposits have been adequately summarized in two U.S. Geological Survey mineral investigations resource maps and accompanying texts: Antimony (White, 1962, pp. 4–5) and bismuth (Cooper, 1962, p. 12). Many of the localities were originally reported by Butler and others (1920). Occurrences of these three elements are discussed below, alphabetically by county and by district or deposit, and their locations are shown on figure 30.

Beaver County: Granite district (No. 17): In the Major (Bismuth) mine, bismuth (bismuthinite) and molybdenum are present in tactite near a Tertiary quartz monzonite porphyry intrusive. A little ore containing 7 percent bismuth was shipped from the Granite district in 1871 (Blake, 1885, p. 654).

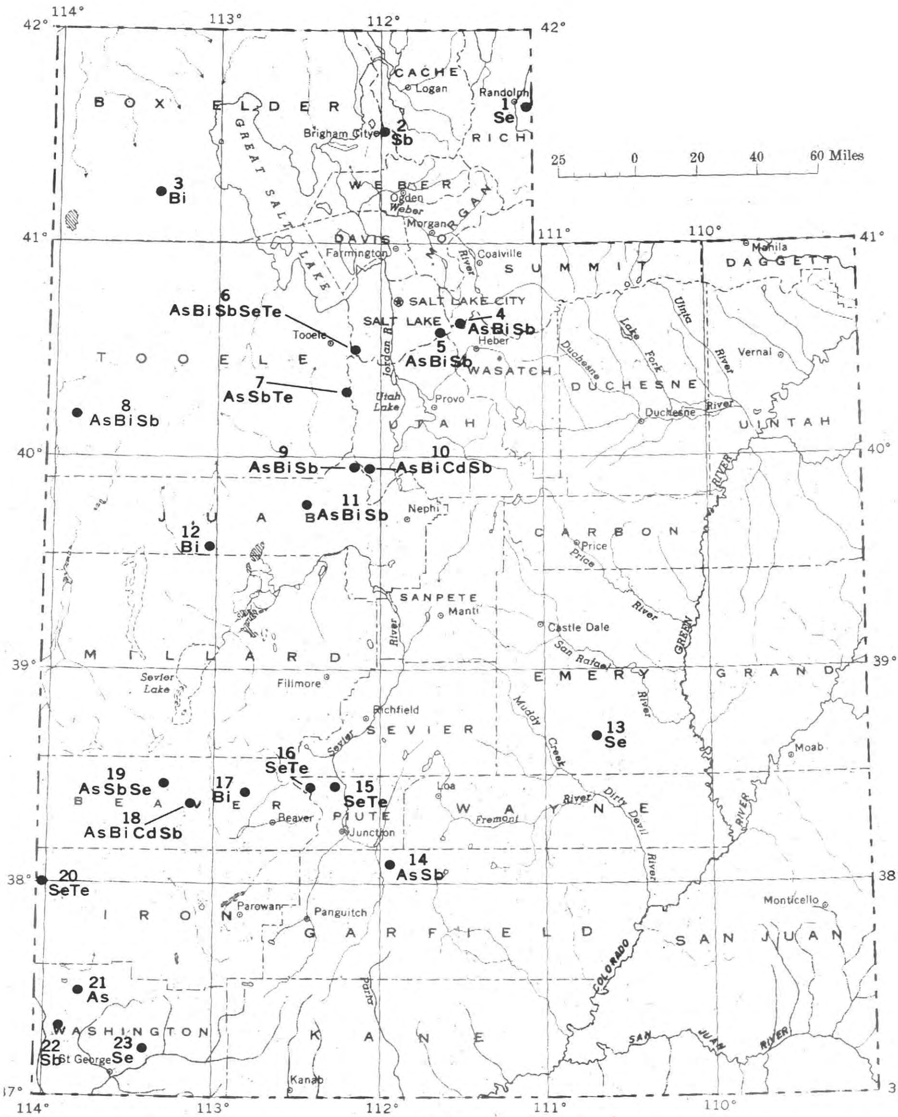
San Francisco district (No. 19): Antimony (sulfantimonides) and arsenic (sulfarsenides) are associated with lead and zinc ore minerals in the Horn Silver mine. The ore bodies occur as replacement deposits in volcanic rocks.

Star district (No. 18): Bismuth (bismuthinite) is present in the St. Mary's mine, and is associated with lead, silver, and copper ores. The ore bodies replace limestone, near a Tertiary quartz monzonite stock. Arsenic and antimony have also been reported from the district.

Box Elder County: Dry Lake antimony mine (White, 1951, pp. 21–22) (No. 2): Concentrations of stibnite and antimony oxides occur irregularly in a quartz vein and in brecciated limestone near the vein. The ore averaged 10 percent antimony. About 100 tons of antimony have been produced since the mine was first opened in 1897.

Near Newfoundland (No. 3): High-grade bismuth ore is associated with copper (Hovey, 1905, p. 375).

Garfield County: Antimony district (Richardson, 1908; Traver, 1949; White, 1951) (No. 14): The Antimony Canyon (Coyote Creek) deposits have been mined for stibnite and for antimony oxides. Antimony minerals occur as veinlets, irregular masses, and disseminations, in and near faults and fractures. The ore is limited primarily to a sandstone unit that overlies a boulder conglomerate. Realgar and other arsenic-bearing minerals are also present. Before 1917, 1,200 tons of hand sorted ore containing 600 tons of stibnite was mined (White, 1951, p. 22). Production from this locality has been sporadic. A concentrating mill was built in 1906 at the nearby town of Antimony to process the local ore. Soon after its completion antimony prices dropped and it was never reported in operation. Several



EXPLANATION

● District or deposit

As	Arsenic	Sb	Antimony
Bi	Bismuth	Se	Selenium
Cd	Cadmium	Te	Tellurium

Numbers refer to localities mentioned in text

FIGURE 30.—Antimony, arsenic, bismuth, cadmium, selenium, and tellurium in Utah.

smaller antimony deposits are located about 5 miles north of Antimony Canyon.

Juab County: *Detroit district* (No. 12): Bismuth has been reported from the E.P.H. claim. It occurs with copper, gold, and silver in replacement veins in limestone that is cut by monzonite porphyry dikes.

Tintic district (No. 9): Antimony, arsenic, and bismuth have been reported from ores of many mines in this district. Complex sulfide deposits, containing lead, copper, silver, gold, and zinc, are in Paleozoic carbonate rocks.

West Tintic district (No. 11): Antimony and arsenic occur in quartz-complex sulfide veins carrying lead, copper, and zinc. The ore bodies are in Paleozoic limestone and granitic rocks. Bismuth is reported from two mines where the principal metals are tungsten and gold.

Salt Lake County: Bingham district (No. 6): Antimony (tetrahedrite) and bismuth occur in copper ores and associated lead, zinc, silver, and gold ores.

Little Cottonwood (Alta) district (Kasteler and Hild, 1948) (No. 5): Sedimentary rocks, ranging from Cambrian quartzite to Carboniferous limestone, are cut by igneous dikes and stocks in the Little Cottonwood district. Ore bodies, associated with fissure systems, replace the carbonate rocks. The district primarily has produced copper, lead, gold, silver, and zinc. The South Hecla mine, entered by the Dwyer Tunnel, was, at one time, one of the major sources of bismuth in the United States. The element generally occurs in the mineral bismuthinite. Eighteen thousand pounds of bismuth was produced from the mine between 1912 and 1925, and 11,861 pounds was produced between 1944 and 1945 (Kasteler and Hild, 1948, pp. 3, 4). In 1947, 3,494 pounds of bismuth was recovered in the Little Cottonwood district probably from the same workings (Matthews, 1947, p. 761). Antimony also has been recovered from the South Hecla mine; 3,866 pounds were produced during 1944 and 1945 (Kasteler and Hild, 1948, p. 4). In 1920 the Sells Tunnel produced 8,517 pounds of bismuth from copper-silver ore; arsenic and antimony were also reported (Heikes, 1922, p. 67).

Summit County: Park City district (No. 4): Antimony (tetrahedrite), arsenic, and bismuth minerals are associated with lead, zinc, copper, silver, and gold in veins and replacement deposits in limestone, quartzite, and intrusive porphyry.

Tooele County: Camp Floyd (Mercur) district (No. 7): Antimony (stibnite) and arsenic (realgar and orpiment) are associated with silver, gold, mercury, and copper in silicified Paleozoic limestone.

Clifton (Gold Hill) district (Nolan, 1935) (No. 8): The Clifton district, organized in 1869, has been a source of gold, silver, copper, lead, and zinc ores. Two mines, the Gold Hill mine of the Western Utah Copper Co., and the U.S. mine of the United States Smelting, Refining & Mining Co., produced large quantities of arsenic in the past; they are inactive at the present time. Arsenic replacement deposits are present in the Mississippian Ochre Mountain Limestone. The ore bodies occur in roof pendants enclosed by quartz monzonite, and are primarily composed of arsenopyrite; they are associated with ore shoots valuable for lead and silver content. Scorodite (hydrated iron arsenate) is extensively developed in some places as an oxidation product of arsenopyrite. Until about 1920, arsenic in ores of the Clifton district was valueless to the producer and was not recovered. Between 1920 and 1925, about 9,000 tons of metallic arsenic was recovered from processed ores. In 1923, the Salt Lake Insecticide Co., Salt Lake City, began manufacturing calcium arsenate from Gold Hill ores (Heikes and Loughlin, 1925, p. 76); it shut down in 1924. In 1943 and 1944, the Gold Hill arsenic deposits were again mined. Several thousand tons of arsenopyrite, averaging about 23 percent arsenic, was shipped monthly to Midvale for arsenic recovery (Matthews, 1945, p. 754).

Bismuth is present in several mines in the Clifton district. In the Wilson Consolidated mine, native bismuth, bismuthinite, and the oxidation product, bismutite, occur with gold ore in a limestone. Shipments of bismuth ore were made from this deposit in 1914 and 1917.

South of Gold Hill, at the southern end of the Deep Creek Mountains, antimony (stibnite) is associated with cinnabar (White, 1951, p. 22).

Utah County: East Tintic district (No. 10): Antimony and arsenic are present in Paleozoic carbonate rocks with complex sulfide ores that contain lead, zinc, copper, and silver. In the North Lily mine, bismuth occurs with lead and silver in limestone replacement deposits.

Washington County: Bull Valley district (No. 21): The arsenic minerals, realgar and orpiment, are present in a breccia zone that crops out in the streambed of Arsenic Canyon (Butler and others, 1920, p. 598).

West of Gunlock (White, 1951, p. 22) (No. 22): Stibnite and antimony oxides are sparsely distributed in stringers and pockets in a silicified limestone. The ore averages about 1 percent antimony; a few tons were shipped from the deposit in 1918.

Cadmium is a soft, ductile, bluish-white metal that is produced commercially from two sources. One is a rather rare, yellow to orange cadmium sulfide mineral, greenockite. The mineral commonly occurs as a powdery coating on zinc minerals, especially sphalerite. The other source consists of zinc sulfides such as sphalerite, where cadmium is in solid solution with the mineral.

Zinc sulfides may contain up to 1.4 percent cadmium. Ores mined in the western United States, however, generally carry no more than 0.25 percent of the metal (Lansche, 1960, p. 157). No cadmium-bearing ores have been mined specifically for the metal. It is recovered solely as a smelter byproduct, mainly from zinc ores, but also from ores of other metals, such as lead and copper, that contain some zinc.

The uses of cadmium have remained relatively unchanged since 1907 when the metal was first produced in the United States. It is used primarily in electroplating, especially in transportation and communications equipment, and in fasteners. Significant quantities of the metal are consumed in the production of pigments, chemicals, and alloys.

The United States Smelting, Refining & Mining Co. first recovered cadmium at the Midvale lead smelter about 1918. Recovery of primary metallic cadmium and some secondary metal was reported from the Midvale plant through 1955. The International Smelting &

Refining Co. also produced cadmium at its smelter in Tooele, Utah, during the 1950's.

Cadmium deposits in Utah are seldom mentioned in the literature. In the Star district (No. 18), Beaver County, greenockite replaces and coats sphalerite in the Moscow mine (Butler 1913, p. 93). Zinc ore has been reported to contain appreciable cadmium in the North Lily mine of the East Tintic district (No. 10), Utah County.

Selenium, an allotropic element that is related to sulfur and tellurium, is widely distributed in small quantities in the earth's crust. It occurs as a brick-red amorphous powder, a brownish-black glassy mass, a gray metallic crystalline mass, or as red crystals. Selenium can act either as metal or nonmetal, electrical conductor or insulator, hydrogenator or dehydrogenator, colorant or decolorant. It is highly toxic and is the only element that may be present in healthy plants in quantities lethal to browsing animals.

Selenium rarely occurs in the native state. Most commonly it is in a combined form in native sulfides and selenides, and is associated with copper, iron, uranium, and other metals. No known selenium-bearing ores have been profitably mined solely for the element. Copper sulfide minerals are the most common source of selenium, although lesser quantities are recovered from lead-smelter flue dusts.

Of the selenium produced in 1961, 30 percent was used in high-purity form, chiefly in electronic applications, and 60 percent was used as a commercial grade in the chemical, rubber, metallurgical, ceramic, and glass industries (Wessel and others, 1962, p. 1378).

In 1950, the Kennecott Copper Corp. installed facilities at the Garfield copper refinery to recover selenium from copper ores mined primarily in the Bingham district. Before that date, selenium-bearing anode slimes had been shipped outside the State for further processing.

Selenium is present in a number of Utah mining districts. It occurs with gold and silver ores in the Gold Springs-State Line region (No. 20), Iron County, and in the Bully Boy and Webster mine in the Ohio district (No. 15), Piute County (Butler and others, 1920, pp. 145, 556). Selenium is present in the gold-producing Golden Reef mine of the San Francisco district (No. 19), Beaver County (Butler, 1913, p. 95). It also occurs in mines of the Silver Reef district (No. 23), Washington County; analyses made of the silver ores about 1881 averaged 0.23 percent selenium (Butler and others, 1920, p. 592). Selenium is present in porphyry copper ores of the Bingham district (No. 6), Salt Lake County. One hundred tons of blister copper treated at the Garfield smelter yielded about 56 pounds of selenium (Butler and others, 1920, p. 347). Information has not been published recently on the selenium content of ores treated at the Garfield plant, which are almost exclusively derived from the Bingham mine. Tiemannite (mercury selenide) and onofrite (sulpho-selenide of mercury) constituted the bulk of the mercury ore produced at the Lucky Boy mine, Mount Baldy district (No. 16), Piute County (Butler and others, 1920, pp. 107, 552). (See section on mercury, p. 108.)

Tellurium is a toxic, tin-white element that resembles antimony in appearance and is related to sulfur and selenium. It is neither widespread nor concentrated in large quantities. It rarely occurs in the native state, but is present in more than 40 minerals, none of which is processed solely for the element. Tellurium is recovered as a byproduct of copper and lead ores, and is commonly associated with gold and, in places, with silver.

Only small quantities of tellurium are required in its many applications. It is used in the ceramic, chemical, metallurgical, and rubber industries. Tellurium was satisfactorily substituted for selenium when that element was in short supply during the early 1950's. The future of tellurium is uncertain. It is potentially useful in thermoelements, which convert heat from solar energy or radioactivity to electricity, and which may become increasingly important in space travel. The Kennecott Copper Corp. has conducted research on the recovery of tellurium at the Garfield copper refinery, but there is no recent production record.

Tellurium is associated with gold ores in several Utah mining districts (Butler and others, 1920, pp. 145, 386, 552, 556): the Gold Springs-State Line region (No. 20) in Iron County; the Bully Boy and Webster mine in the Ohio district (No. 15) and the Lucky Boy mine in the Mount Baldy district (No. 16), Piute County; and the Golden Gate mine in the Camp Floyd (Mercur) district (No. 7), Tooele County. Tellurium is present in copper ores of the Bingham district (No. 6). One hundred tons of blister copper processed at the Garfield smelter yielded about 5.54 ounces of tellurium (Butler and others, 1920, p. 347).

The production of antimony, arsenic, bismuth, cadmium, selenium, and tellurium, is, for the most part, dependent upon the mining, smelting, and refining of major metallic ores. Antimony and bismuth are recovered from lead ores; arsenic and tellurium are produced from copper and lead ores; selenium is recovered from copper, and to a lesser extent, lead ores; and cadmium is obtained from zinc ores. These six elements will be produced as long as Tintic, Park City, Bingham, and the many other mining districts in Utah continue to supply major metals. The production of byproducts is relatively inflexible, and problems arise when the demand is great.

The few mines exploited principally for one or more of these minor elements have limited resources. Antimony resources in the simple type of deposit are of low grade. The Antimony Canyon (Coyote Creek) deposits, Garfield County, average 1 to 2 percent antimony. The remaining ore contains at least 1,500 tons and perhaps 10,000 tons of the element.

In the deposits west of Gunlock, Washington County, material averaging about 1 percent antimony may contain several thousand tons of the element. The Dry Lake antimony mine has estimated resources of 250 tons of antimony in high-grade ore and an additional 300 tons in low-grade ore and dumps (White, 1951, pp. 21–22). The two largest arsenic producers in the Clifton district, the Gold Hill mine and the U.S. mine, have substantial resources.

Two potential sources of selenium are present in Utah, Phosphoria shales and seleniferous uranium ores. Large resources of low-grade selenium and other metals are present in carbonaceous shale beds within the Meade Peak Phosphatic Shale Member of the Permian Phosphoria Formation. (See section on phosphate, p. 195, fig. 40.) Carbonaceous shales from two phosphate mines in the Crawford Mountain area (No. 1), Rich County, ranged from 0.01 to 0.037 percent selenium (Rosenbaum and others, 1958, table B).

For many years, seleniferous uranium ores have been recognized as a potential source of industrial quantities of selenium. Carbonaceous uranium ores from the Temple Mountain district (No. 13), Emery County, were analyzed for selenium content. Forty samples from mines within the district assayed from 0.01 to 0.113 percent selenium (Rosenbaum and others, 1958, table B). At present the selenium is not recovered from these and other uranium-bearing materials.

Selected References

Allsman, P. T., 1948, Investigation of iron-ore reserves of Iron County, Utah (supplement to R. I. 4076) : U.S. Bur. Mines Rept. Inv. 4388, 3 p.

Arrington, L. J., 1963, Abundance from the Earth: The beginning of commercial mining in Utah: Utah State Hist. Quart., v. 31, no. 3, p. 192–219.

Baker, A. A., Duncan, D. C., and Hunt, C. B., 1952, Manganese deposits of southeastern Utah: U.S. Geol. Survey Bull. 979–B, p. 63–157.

Bailey, E. H., 1962, Mercury in the United States: U.S. Geol. Survey Mineral Invest. Map MR–30.

Baroch, C. T., 1960, Rare earth metals, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 585, p. 679–690.

Billingsly, Paul, and Crane, G. W., 1933, Tintic mining district, *in* The Salt Lake region: Internat. Geol. Cong., 16th, Washington, D.C., 1933.

Blake, W. P., 1885, Bismuth: U.S. Geol. Survey Mineral Resources U.S., 1883 and 1884, p. 654–655.

Blue, D. M., 1960, Geology and ore deposits of the Lucin mining district: Utah Univ., M.A. thesis.

Boutwell, J. M., 1904, Iron ores in the Uinta Mountains, Utah: U.S. Geol. Survey Bull. 225, p. 221–228.

———, 1905, Economic geology of the Bingham mining district, Utah: U.S. Geol. Survey Prof. Paper 38.

———, 1907, Quicksilver, *in* Mineral Resources of the United States for 1906: U.S. Geol. Survey, p. 491–499.

———, 1912, Geology and ore deposits of the Park City district, Utah: U.S. Geol. Survey Prof. Paper 77.

———, 1933, Park City mining district: Internat. Geol. Cong., 16th, Washington, D.C., 1933, in Guidebook 17.

———, 1935, Copper deposits at Bingham, Utah, *in* Copper Resources of the World: 16th Internat. Geol. Cong., v. 1, Washington.

Bowyer, Ben, 1963, Yellow Chief uranium mine, Juab County, Utah, [*in* Beryllium and uranium mineralization in western Juab County, Utah:] Utah Geol. Soc. Guidebook No. 17, p. 15–22.

Bullock, K. C., Smouse, DeForrest, Robinson, G. B., Jr., 1960, Minerals and mineral localities of Utah, Provo, 170 p.

Busch, P. M., 1961, Vanadium, a materials survey: U.S. Bur. Mines Inf. Circ. 8060.

Bush, J. B., 1957, Introduction to the geology of the East Tintic mining district: Utah Geol. Soc. Guidebook no. 12, p. 97–102.

Bush, J. B., Cook, D. R., Lovering, T. S., and Morris, H. T., 1960, The Chief Oxide-Burgin area discoveries, East Tintic district, Utah; a case history: Econ. Geology, v. 55, 2 parts, pp. 1116–1147 and 1507–1540.

Butler, A. P., Jr., Finch, W. I., and Twenhofel, W. S., 1962, Epigenetic uranium in the United States: U.S. Geol. Survey Mineral Invest. Resource Map MR–21.

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., Loughlin, G. F., Heikes, V. C., and others, 1920, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111.

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.

Callaghan, Eugene, 1938, Preliminary report on the alunite deposits of the Marysvale region, Utah: U.S. Geol. Survey Bull. 886–D.

Callaghan, Eugene, and Parker, R. L., 1961, Geologic map of the Monroe quadrangle, Utah: U.S. Geol. Survey Geol. Quad. Map GQ–155.

———, 1962, Geology of the Delano Peak quadrangle, Utah: U.S. Geol. Survey Quad. Map, GQ–153.

Callaway, H. M., 1960a, Antimony, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 585, p. 61–69.

———, 1960b, Bismuth, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 585, p. 103–109.

Cheney, T. M., 1957, Phosphate in Utah: Utah Geol. and Mineralogical Survey Bull. 59.

Coats, R. R., Barnett, P. R., and Conklin, N. M., 1962, Distribution of beryllium in unaltered silicic volcanic rocks of the western conterminous United States: Econ. Geology, v. 57, p. 963–968.

Cohenour, R. E., 1959, Sheeprock Mountains, Tooele and Juab Counties: Utah Geol. and Mineralog. Survey Bull. 63.

———, 1963a, The beryllium belt of western Utah: Utah Geol. Soc. Guidebook 17, p. 4–7.

———, 1963b, Beryllium and associated mineralization in the Sheeprock Mountains: Utah Geol. Soc. Guidebook 17, p. 8–13.

Cook, D. R., 1957, Geology of the East Tintic Mountains and ore deposits of the Tintic mining districts Utah Geol. Soc. Guidebook no. 12.

Cook, D. R., 1961, Geology of the Bingham district and northern Oquirrh Mountains: Utah Geol. Soc. Guidebook no. 16.

Cook, E. F., 1960, Geologic Atlas of Utah, Washington County: Utah Geol. and Mineralog. Survey Bull. 70, 119p.

Cook, K. L., 1950, Magnetic surveys in the Iron Springs district, Iron County, Utah: U.S. Bur. Mines Rept. Inv. 4586.

Cooper, J. R., 1962, Bismuth in the United States: U.S. Geol. Survey Mineral Inv. Resources Map MR–22.

Craig, L. C., and others, 1955, Stratigraphy of the Morrison and related formations, Colorado Plateau region, a preliminary report: U.S. Geol. Survey Bull. 1009–E.

Crawford, A. L., and O'Farrell, Chas., 1932, Unusual features of a newly discovered mercury ore from the Deep Creek Mountains of western Utah: Utah Acad. Sci. Proc., v. 9, p. 41–44.

Crawford, A. L., and Buranek, A. M., 1943, Utah iron deposits other than those of Iron and Washington Counties, Utah: Utah Geol. and Mineralog. Survey Circ. 24.

Crawford, A. L., and Buranek, A. M., 1944, Tungsten reserves discovered in the Cottonwood-American Fork mining districts, Utah: Utah Univ. Eng. Expt Sta. Bull. 24, 56 p.

Crawford, A. L., and Buranek, A. M., 1945, Tungsten deposits of the Mineral Range, Beaver County, Utah: Utah Univ. Eng. Expt. Sta. Bull. 25, v. 35, no. 15, 48 p.

Crittenden, M. D., Jr., 1951, Manganese deposits of western Utah: U.S. Geol. Survey Bull. 979–A.

Crittenden, M. D., Jr., Sharp, B. J., and Calkins, F. C., 1953 Geology of the Wasatch Mountains east of Salt Lake City, Parleys Canyon to the Traverse Range: Utah Geol. Soc. Guidebook no. 8, p. 1–37.

Crittenden, M. D., Jr., Straczek, J. A., and Roberts, R. J., 1961, Manganese deposits in the Drum Mountains, Juab and Millard Counties, Utah: U.S. Geol. Survey Bull. 1082–H, p. 493–544.

Davidson, D. F., and Lakin, H. W., 1961, Metal content of some black shales of the western United States, Art. 267, U.S. Geol. Survey Prof. Paper 424–C, p. C329–C331.

———, 1962, Metal content of some black shales of the western conterminous United States, Pt. 2, Art. 85: U.S. Geol. Survey Prof. Paper 450–C, p. C74.

DeHuff, G. L., 1960, Manganese, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 585, p. 493–510.

Dow, V. T., and Batty, J. V., 1961, Reconnaissance of titaniferous sandstone deposits of Utah, Wyoming, New Mexico, and Colorado: U.S. Bur. Mines Rept. Inv. 5860.

Duncan, D. C., 1953, Reconnaissance investigations for uranium in black shale deposits of the Western States during 1951 and 1952: U.S. Geol. Survey TEI–381, U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Dutton, C. E., and Carr, M. S., 1947, Iron-ore deposits of the Western United States: U.S. Geol. Survey Strategic Minerals Investigations Prelim. Map 3–212.

Erickson, M. P., and Sharp, B. J., 1954, Disseminated scheelite in the Little Cottonwood stock, Utah: Econ. Geology, v. 49, no. 2, p. 221–223.

Everett, F. D., 1961, Tungsten deposits in Utah: U.S. Bur. Mines Inf. Circ. 8014.

Finch, W. I., 1955, Preliminary geologic map showing the distribution of uranium deposits and principal ore-bearing formations of the Colorado Plateau region: U.S. Geol. Survey Mineral Invest. Field Studies Map MF-16.

———, 1959, Geology of uranium deposits in Triassic rocks of the Colorado Plateau region: U.S. Geol. Survey Bull. 1074-D.

Fischer, R. P., and Stewart, J. H., 1960, Distribution and lithologic characteristics of sandstone beds that contain deposits of copper, vanadium, and uranium: Art. 22 *in* U.S. Geol. Survey Prof. Paper 400-B, p. B-42-B-44.

Fisher, F. L., 1960a, Selenium, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 585, p. 721-726.

———, 1960b, Tellurium, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 585, p. 851-856.

Frey, Eugene, and Wilson, S. R., 1949, Investigation of the Huber-Rydalch manganese deposits, Tooele County, Utah: U.S. Bur. Mines Rept. Inv. 4601.

Garrels, R. M., and Larsen, E. S., ed., 1959, Geochemistry and mineralogy of the Colorado Plateau uranium ores: U.S. Geol. Survey Prof. Paper 320.

Gehman, H. M., Jr., 1958, Notch Peak intrusive, Millard County, Utah: Utah Geol. Mineralog. Survey Bull. 62.

Gilluly, James, 1932, Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U.S. Geol. Survey Prof. Paper 173.

Granger, A. E., 1963, The iron province of southwestern Utah, *in* Guidebook to the Geology of Southwestern Utah: Intermountain Assoc. Petroleum Geologists, pp. 146-150.

Gruner, J. W., and Gardiner, Lynn, 1952, Mineral associations in the uranium deposits of the Colorado Plateau: U.S. Atomic Energy Commission, RMO-566, Tech. Inf. Service, Oak Ridge, Tenn.

Gulbrandsen, R. A., 1960a, Minor elements in phosphorites of the Phosphoria Formation [abs.]: Geol. Soc. America Bull., v. 71, no. 12, pt. 2, p. 1876.

———, 1906b, Petrology of the Meade Park Peak Phosphatic Shale Member of the Phosphoria Formation at Coal Canyon, Wyoming: U.S. Geol. Survey Bull. 1111-C, pp. 71-146.

Hammond, E. D., 1961, History and mining in the Bingham district, Utah, Guidebook, Utah Geol. Soc. no. 16, pp. 120-130.

Hanley, J. B., Heinrich, E. W., and Page, L. R., 1950, Pegmatite investigations in Colorado, Wyoming, and Utah: U.S. Geol. Survey Prof. Paper 227.

Hansen, L. A., 1961, The stratigraphy of the Carr Fork mines, Bingham mining district, Bingham, Utah: Utah Geol. Soc. Guidebook no. 16, pp. 70-80.

Hansen, G. B., 1963, Industry of destiny: Copper in Utah: Utah State Hist. Quart., v. 31, no. 3, pp. 262-279.

Hansen, W. R., 1957, Geology of the Clay Basin quadrangle, Utah: U.S. Geol. Survey, Geol. Quad. Map GQ-101. 1961, Geologic map of the Dutch John Mountain and Goslin Mountain quadrangles, Utah-Wyoming: U.S. Geol. Survey Misc. Geol. Inv. Map I-324.

Harris, DeVerle, 1958, The geology of Dutch Peak area, Sheeprock Range, Tooele County, Utah: Brigham Young Univ. Research Studies Geology Serv., v. 5, no. 1.

Heikes, V. C., 1920 *in* The ore deposits of Utah: U.S. Geol. Survey Prof. Paper 111, pp. 116-150.

———, 1922, Bismuth: U.S. Geol. Survey Mineral Resources of U.S., 1920, pt. 1, pp. 67-69.

Heikes, V. C., and Loughlin, G. F., 1925, Arsenic: U.S. Geol. Survey Mineral Resources of U.S., 1922 pt. 1 pp. 53-76.

Heim, G. W., and Allsman, P. T., 1950, Investigation of Daggett Chief manganese deposits, Manila, Daggett County, Utah: U.S. Bur. Mines Rept. Inv. 4731.

Hess, F. L., 1908, Some molybdenum deposits of Maine, Utah, and California. U.S. Geol. Survey Bull. 340, pp. 231-240.

———, 1925, Ilsemannite at Ouray, Utah: U.S. Geol. Survey Bull. 750.

———, 1933, *in* Ore deposits of the Western States (Lindgren volume), pp. 455-480, Am. Inst. Mining Met. Eng.

Heyl, A. V., 1963, Oxidized zinc deposits of the United States, part 2, Utah: U.S. Geol. Survey Bull. 1135-B.

Hewett, D. F., Callaghan, Eugene, Moore, B. N., Nolan, T. B., Rubey, W. W., and Schaller, W. T., 1936, Mineral resources of the region around Boulder Dam: U.S. Geol. Survey Bull. 871.

Hobbs S. W., 1945a, Tungsten deposits in the West Tintic mining district, Juab County, Utah: U.S. Geol. Survey open-file report, 7 p.

———, 1945b, Tungsten deposits in Beaver County, Utah: U.S. Geol. Survey Bull. 945–D.

Houston, R. S., and Murphy, J. F., 1962, Titaniferous black sandstone deposits of Wyoming: Wyoming Geol. Survey Bull. 49.

Hovey, E. O., 1905, Bismuth: U.S. Geol. Survey Mineral Resources of U.S., 1904, p. 375–376.

Hunt, R. N., and Peacock, H. G., 1948, Lead and lead-zinc of the Bingham district, Utah, [*in* Dunham, K. C. ed.], Symposium on the geology, paragenesis, and reserves of the ores of lead and zinc: Internat. Geol. Cong., 18th, London, 1948.

Hunt, C. B., 1956, Cenozoic geology of the Colorado Plateau: U.S. Geol. Survey Prof. Paper 279.

Johnson, H. S., Jr., 1959a, Uranium resources of the Green River and Henry Mountains districts, Utah—a regional synthesis: U.S. Geol. Survey Bull. 1087–C.

———, 1959b, Uranium resources of the Cedar Mountains area, Emery County, Utah—a regional synthesis: U. S. Geol. Survey Bull. 1087–B.

James, Allan, Smith, Wilbur, and Bray, Eldon, 1961, Bingham district, a zoned porphyry ore deposit: Utah Geol. Soc. Guidebook no. 16, p. 82–100.

Kasteler, J. I., and Hild, J. H., 1948, Lead, zinc, silver, copper, bismuth deposits, South Hecla mine, Alta, Salt Lake County, Utah: U.S. Bur. Mines Rept. Inv. 4170.

Kelly, F. J., 1962, Technological and economic problems of rare-earth-metal and thorium resources in Colorado, New Mexico, and Wyoming: U.S. Bur. Mines Inf. Circ. 8124.

Kennecott Copper Corporation, 1961, The Utah copper story: Kennecott Copper Corp., Utah Copper Division.

Kerr, P. F., and others, 1952, Annual Rept. for July 1, 1951 to June 30, 1952, Part 1, A geologic guide to the Marysvale area: U.S. Atomic Energy Commission RMO–924, Tech. Inf. Service, Oak Ridge, Tenn.

———, 1957, Marysvale, Utah, uranium area: Geol. Soc. Amer. Spec. Paper 64.

King, W. H., 1947, Drum Mountain manganese project, Juab County, Utah: U.S. Bur. Mines Rept. Inv. 3993.

King, W. H., and Wilson, S. R., 1949, Investigation of tungsten deposits at Cupric Mine property, Beaver County, Utah: U.S. Bur. Mines Rept. Inv. 4590.

Kinkel, A. R., Jr., 1951, Preliminary report on the Apex and Paymaster mines, Washington County, Utah: U.S. Geol. Survey open-file report, June 30, 1951, 9 p.

Kinney, D. M., 1955, Geology of the Uinta River-Brush Creek area, Duchesne and Uintah Counties, Utah: U.S. Geol. Survey Bull. 1007.

Koschman, A. H., 1962, Historical pattern of minerals exploitation in Colorado, *in* Minerals and energy pt. 1, Western Resources Conference, 1962: Colo. Sch. Mines Quart., v. 57, no. 4, p. 7–25, Golden, Colo.

Lansche, A. M., 1960, Cadmium, *in* Mineral facts and problems, 1960 edition: U.S. Bur. Mines Bull. 585, p. 155–161.

Leith, C. K., 1904, Iron ores in southern Utah: U.S. Geol. Survey Bull. 225, p. 229–237.

Leith, C. K., and Harder, E. C., 1908, The iron ores of the Iron Springs district, southern Utah: U.S. Geol. Survey Bull. 338.

Lemmon, D. M., and Tweto, O. L., 1962, Tungsten in the United States: U.S. Geol. Survey Mineral Inv. Resource Map MR–25.

Lewis, R. Q., Sr., and Trimble, D. E., 1959, Geology and uranium deposits of Monument Valley, San Juan County, Utah: U.S. Geol. Survey Bull. 1087–D.

Lindgren, W., 1906, The Annie Laurie Mine, Piute County, Utah: U.S. Geol. Survey Bull. 285, p. 87–90.

Lindgren, Waldemar, and Loughlin, G. F., 1919, Geology and ore deposits of the Tintic mining district, Utah: U.S. Geol. Survey Prof. Paper 107.

Lovering, T. S., and Morris, H. T., 1960, in The Chief Oxide-Burgin area discoveries, East Tintic district, Utah; a case history: Econ. Geology, v. 55, no. 6, pp. 1116–1148.

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

———, 1954, Geology and iron ore deposits of the Granite Mountain area, Iron County, Utah: U.S. Geol. Survey Mineral Inv. Map MF–14.

Mackin, J. H., and Ingerson, Earl, 1960, An hypothesis for the origin of ore-forming fluid: U.S. Geol. Survey Prof. Paper 400–B, p. B1–B2.
Matthews, A. F., 1945, Arsenic: U.S. Bur. Mines Minerals Yearbook, 1943, p. 754–759.
———, 1947, Bismuth: U.S. Bur. Mines Minerals Yearbook, 1945, p. 761–766.
McCaskey, H. D., 1912, Quicksilver, *in* Mineral Resources of the United States in 1911—pt. I: U.S. Geol. Survey, House of Repr. Doc. 949, 62d Congress, 3d sess., p. 889–921.
McKelvey, V. E., and others, 1959, The Phosphoria, Park City and Shedhorn Formations in the western phosphate field: U.S. Geol. Survey Prof. Paper 313A.
McKnight, E. T., 1962, How about silver? Mining World, August 1962, pp. 18–22.
McKnight, E. T., Newman, W. L., and Heyl, A. V., 1962, Zinc in the United States, exclusive of Alaska and Hawaii: U.S. Geol. Survey Mineral Inv. Resource Map MR–19.
McKnight, E. T., Newman, W. L., Klemic, H., and Heyl, A. V., 1962, Silver in the United States, exclusive of Alaska and Hawaii: U.S. Geol. Survey Mineral Inv. Resource Map MR–34.
McMahon, A. D., 1960, Arsenic, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 585, p. 71–76.
Morris, H. T., 1957, General geology of the East Tintic Mountains, Utah, Utah Geol. Soc., Guidebook no. 12: p. 1–56.
Morris, H. T., and Lovering, T. S., 1961, Stratigraphy of the East Tintic Mountains, Utah: U.S. Geol. Survey Prof. Paper 361.
Nolan, T. B., 1935, The Gold Hill mining district, Utah: U.S. Geol. Survey Prof. Paper 177.
Ogden, H. R., 1961, Titanium, *in* Hampel, C. A., Rare metals handbook, 2d ed.: New York, Reinhold Publishing Corp., p. 559–579.
Olson, J. C., and Adams, J. W., 1962, Thorium and rare earths in the United States: U.S. Geol. Survey, Mineral Inv. Resource Map MR–28.
Pennington, J. W., 1960, Mercury, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 585, p. 511–519.
Peterson, V. E., 1942, A Study of the geology and ore deposits of the Ashbrook silver mining district, Utah: Econ. Geology, v. 37, no. 6.
Proctor, P. D., 1953, Geology of the Silver Reef (Harrisburg) mining district, Washington County, Utah: Utah Geol. and Mineralog. Survey Bull. 44.
Raymond, R. W., 1874, Statistics of mines and mining in the states and territories west of the Rocky Mountains; Sixth Annual Report: U.S. Treasury Dept., Washington.
Richardson, G. B., 1908, Antimony in southern Utah: U.S. Geol. Survey Bull. 340–D, pp. 253–256.
Rigby, J. K., 1958, Geology of the Stansbury Mountains, eastern Tooele County, Utah, Utah Geol. Soc. Guidebook no. 13.
Rogers, C. L., and Jaster, M. C., 1962, Titanium in the United States: U.S. Geol. Survey, Mineral Inv. Resource Map MR–29.
Romney, M. P., 1963, Historical review of mining in Utah: Mining Congress Jour., v. 49, no. 5, p. 47–52.
Rosenbaum, J. B., and others, 1958, Final report on reconnaissance, exploration, and extraction of selenium: U.S. Bur. Mines unpublished Research Report No. 36.17.
Sainsbury, C. L., 1962, Helvite near Beaver, Utah: Amer. Mineralogist, v. 47, pp. 395–398.
Schnabel, R. W., 1955, The uranium deposits of the United States: U.S. Geol. Survey Mineral Invest. Map MR–2.
Sharp, B. J., 1958, Mineralization in the intrusive rocks in Little Cottonwood Canyon, Utah: Geol. Soc. America Bull., v. 69, no. 11, pp. 1415–1430.
Sharp, B. J., 1963, Uranium in fluorite, Spor Mountain, Utah, *in* Beryllium and uranium mineralization in western Juab County, Utah: Utah Geol. Soc. Guidebook no. 17, p. 14.
Spencer, R. N., and den Hartog, E. E., 1962, Bismuth: U.S. Bur. Mines Minerals Yearbook, 1961, pp. 343–347.
Staatz, M. H., and Osterwald, F. W., 1956, Uranium in the fluorspar deposits of the Thomas Range, Utah, U.S. Geol. Survey Prof. Paper 300, p. 131–136.
———, 1959, Geology of the Thomas Range fluorspar district, Juab County, Utah: U.S. Geol. Survey Bull. 1069.
Staats, M. H., and Griffitts, W. R., 1961, Beryllium-bearing tuff in the Thomas Range, Juab County, Utah: Econ. Geology, v. 56, no. 5, p. 941–958.

Staatz, M. H., 1963, Geology of the beryllium deposits in the Thomas Range, Juab County, Utah: U.S. Geol. Survey Bull. 1142–M.

Staatz, M. H., and Carr, W. J., (in press), Geology and mineral deposits of the Thomas and Dugway Ranges, Juab and Tooele Counties, Utah: U.S. Geol. Survey Prof. Paper 415.

Stamper, J. W., 1960, Titanium, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 585, 883–901.

Stewart, J. H., and others, 1959, Stratigraphy of Triassic and associated formations in part of the Colorado Plateau region: U.S. Geol. Survey Bull. 1046–Q.

Stocking, H. E., and Page, L. R. 1956, Natural occurrence of uranium in the United States—a summary, U.S. Geol. Survey Prof. Paper 300.

Stringham, B. F., 1942, Mineralization in the West Tintic mining district, Utah: Geol. Soc. America Bull. 53, no. 2.

Swanson, R. W., 1960, Phosphate and associated resources in Permian rocks of southwestern Montana, U.S. Geol. Survey Prof. Paper 400–B, p. B–65–66.

Thompson, M. E., 1954, Further studies of the distribution of uranium in rich phosphate beds of the Phosphoria Formation: U.S. Geol. Survey Bull. 1009–D.

Thurston, W. R., Staatz, M. H., Cox, D. C., and others, 1954, Fluorspar deposits of Utah: U.S. Geol. Survey Bull. 1005.

Traver, W. M., 1949, Investigation of Coyote Creek antimony deposits, Garfield County, Utah: U.S. Bur. Mines Rept. Investigations 4470.

Trites, A. F., and Chew, R. T., 1956, Geology of the Happy Jack mine, White Canyon area, San Juan County, Utah: U.S. Geol. Survey Bull. 1009–H, p. 235–248.

Tyler, P. M., 1930, Radium: U.S. Bur. Mines Inf. Circ. 6312.

U.S. Bureau of Mines, 1942–1952, [Ore dressing tests of Utah Manganese ores]: U.S. Bur. Mines Rept. Inv. Nos. 3606, 3628, 4077, 4117, 4130, 4141, 4142, 4389, 4466, 4524, 4545, 4551, 4785, and 5818. (Various authors and titles.)

———, 1960 Mineral facts and problems: U.S. Bur. Mines Bull. 585.

Utah Mining Association 1959, Utah's mining industry: Salt Lake City, Utah Mining Association.

Walker, G. W., and Osterwald, F.W., 1956, Relation of secondary uranium minerals to pitchblende-bearing veins at Marysvale, Piute County, Utah, U.S. Geol. Survey Prof. Paper 300, p. 123–129.

Weeks, A. D., and Thompson, M. E., 1954, Indentification and occurrence of uranium and vanadium minerals from the Colorado plateaus: U.S. Geol. Survey Bull. 1009–B.

Wells, F. G., 1938, The origin of the iron ore deposits in the Bull Valley and Iron Springs districts, Utah: Econ. Geology, v. 33, no. 5, p. 477–507.

Wells, R. C., and Butler, B. S., 1917, Tungstenite, a new mineral: Wash. Acad. Sci, Jour., v. 7, p. 596–599.

Wessel, F. W., and others, 1962, Minor metals: U.S. Bur. Mines Minerals Yearbook, 1961, p. 1367–1385.

White, D. E., 1951, Resources, chap. 3 *of* Materials survey, antimony, 1950: U.S. Bur. Mines, 57 p.

———, 1962, Antimony in the United States: U.S. Geol. Survey Mineral Inv. Resources Map MR–20.

Williams, N. C., 1954, Nonpegmatite beryl occurrence, Sheeprock Mountains, Utah [abs.]: Geol. Soc. America Bull., v. 65, no. 12, pt. 2, p. 1388.

Wilson, C. L., 1959, Park City mining district [Utah]: Intermountain Assoc. Petroleum Geologists, Guidebook 10th Ann. Field Conf., p. 182–188.

Wilson, S. R., 1950, Investigation of the West Tintic tungsten deposit: U.S. Bur. Mines Rept. Inv. 4640,

Young, W. E., 1947, Iron deposits, Iron County, Utah: U.S. Bur. Mines Rept. Inv. 4076.

Zoldak, S. W., and Wilson, S. R., 1953, Bull Valley iron-ore deposits Washington County, Utah: U.S. Bur. Mines Rept. Inv. 4948.

NONMETALLIC AND INDUSTRIAL MINERALS AND MATERIALS RESOURCES

INTRODUCTION

(By L. S. Hilpert, Salt Lake City, Utah)

The nonmetallic and industrial minerals and materials resources are widely distributed throughout the State but, until recent years, have contributed only a small part of Utah's mineral production. Since the mid-1950's the output has increased markedly, which promises these minerals will become increasingly important in the minerals industry. From the standpoint of past production, the most important nonmetallics have been sand and gravel, stone, common salt, clay and potash, in decreasing order. The output of these minerals and materials and others will likely continue to increase to satisfy the demands of an increasing population and industrial expansion. Potash output will probably increase sharply. Underground mine developments in the Paradox basin in southeastern Utah are nearing the production stage, and recent interest has been growing in the establishment of facilities for extracting potash and other byproducts from the brines of Great Salt Lake. Byproducts recovery will probably play an important part in the development of some nonmetallics, such as phosphate. New uses found for various nonmetallic materials will probably play a part in the development of some commodities, as has happened in other states with bloating materials for lightweight aggregate, for example. As will become apparent in the following sections, Utah has tremendous resources in several nonmetallic commodities. New uses found for them or the discovery of special qualities in any of them might be factors that will lead to their use and the establishment of new industry.

ALUNITE

(By R. L. Parker, Denver, Colo.)

Alunite is a hydrous sulfate of potassium and aluminum [$KAl_3(SO_4)_2OH_6$]. Commonly it contains variable amounts of sodium in substitution for potassium, and varieties that contain more sodium than potassium are termed natroalunite. It is white or pale shades of gray, red, brown, or yellow and occurs both as coarsely crystalline aggregates and dense compact earthy masses resembling clay.

Alunite has long been used abroad as a source of potash alum. The mineral, however, has been particularly intriguing to industrial chemists and metallurgists for its components, potassium, aluminum, and sulfur, all marketable commodities. A patented process for the recovery of potassium sulfate and alumina from alunite was developed by Kalunite, Inc. (Fleischer, 1944), and a plant utilizing this process was constructed at Salt Lake City during World War II for the processing of alunite from Marysvale. Although alunite is not now domestically competitive with other sources of potassium salts and alumina, the material represents a future resource.

Alunite in Utah was first discovered in 1910 in the Tushar Mountains a few miles west of Marysvale, Piute County (Butler and Gale, 1912), but little was mined until 1915. Prices increased sharply when German exports of potash were shut off, and during the period 1915–20 several alunite deposits in the Marysvale region produced at least 262,000 tons of ore amounting to 4 to 7 percent of the U.S. production of potash (Callaghan, 1938). The sales value of the potash was close to $4 million. Resumption of imports in 1920 lowered prices and resulted in closure of the alunite mines in Utah.

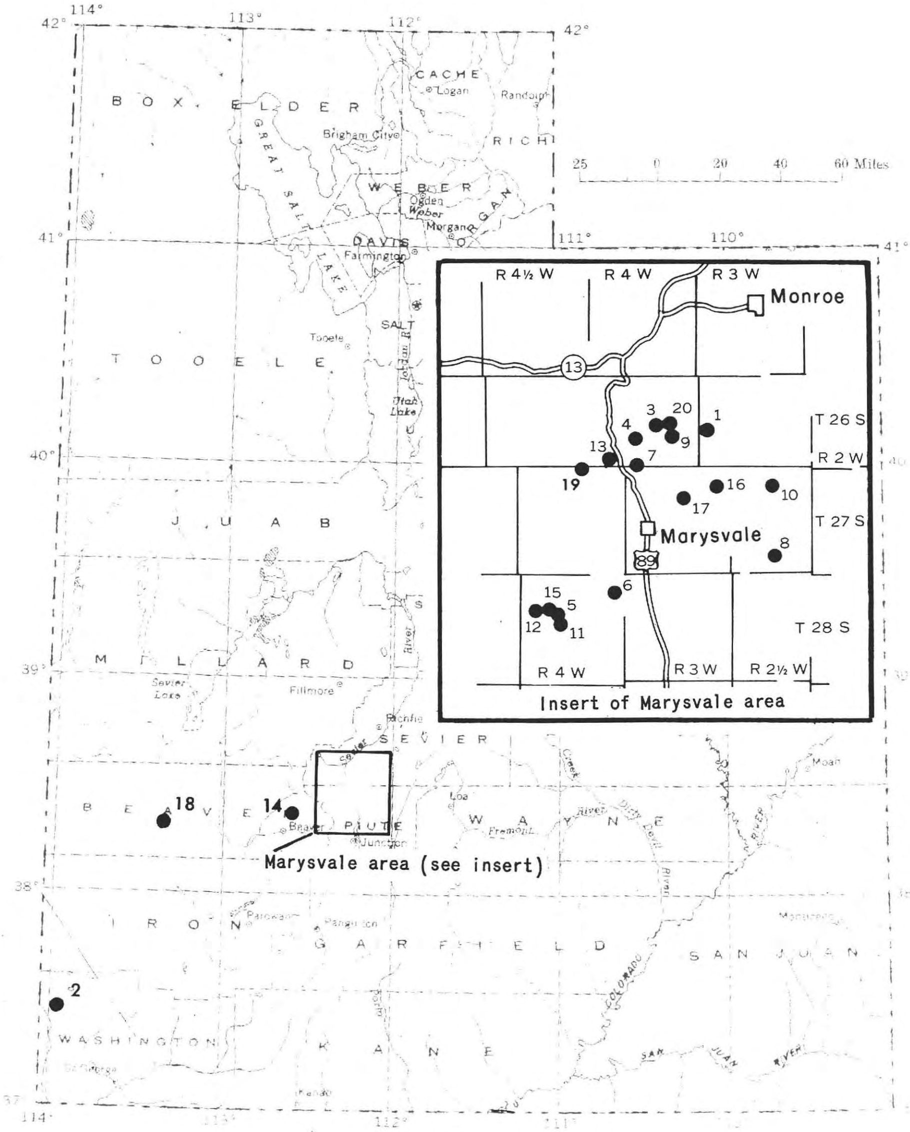
With the onset of World War II alunite was considered as a potential source of alumina, and a joint program of exploration of the deposits at Marysvale was conducted by the U.S. Geological Survey and U.S. Bureau of Mines (Hild, 1946). A plant for the recovery of alumina and potassium sulfate was constructed at Salt Lake City by the Defense Plant Corp., and about 37,000 tons of ore was mined for testing purposes (estimated value about $700,000). With the easing of the war crisis, interest in alunite again subsided, and between 5,000 and 10,000 tons have been mined since, presumably for use in fertilizer (estimated value about $200,000).

The largest resources of alunite in the United States are in Utah. Most of the alunite deposits are in Piute County within an 8-mile radius of Marysvale. Other deposits are in Beaver County about 10 miles northeast of Beaver and in Washington County in the Bull Valley district northwest of St. George. Extensive alunitic alteration is reported from the White Mountain area about 10 miles south of Frisco in Beaver County.

Two types of alunite deposits, vein and replacement, are found in the Marysvale area. The vein deposits consist of fine- to course-crystalline alunite in one or more filled fissures in the Bullion Canyon Volcanics of Miocene(?) age. These deposits are found in the Tushar Mountains in the upper reaches of Cottonwood Creek about 7 miles southwest of Marysvale (fig. 31). Principal veins are nearly vertical, trend N. 35° W., and in many places are 15 to 25 feet wide (Callaghan and Parker, 1962a).

The replacement deposits are mostly in the Antelope Range north of Marysvale. They are irregularly shaped bodies in which the host rocks of the Bullion Canyon Volcanics have been altered to an aggregate of alunite, quartz, and clay minerals. Most of these deposits are apparently distributed circumferentially about an intrusive quartz monzonite stock. The deposits are irregular in grade, size and shape, and replace either tuff beds or flows in the formation. Most deposits contain potassium alunite, but a few contain the sodic variety, natroalunite (Callaghan and Parker, 1961b, 1962; Willard and Callaghan, 1962).

Resources of alunite in the Marysvale region are estimated at 3,740,000 tons of material with an average alunite content of about 54 percent (about 20 percent Al_2O_3), (U.S. Bureau of Mines and U.S. Geological Survey, 1948). Additional lower grade resources in the region,



EXPLANATION

● Alunite deposit or deposits

1. Al Kee Mee
2. Beauty Knoll
3. Big Chief
4. Big Star
5. Bradburn
6. Close In
7. J and L
8. Manning Creek
9. Marys Lamb
10. Marysvale Peak
11. Mineral Products
12. L and N
13. Pittsburg
14. Sheep Rock
15. Sunshine
16. White Hills
17. White Horse
18. White Mountain
19. Winkelman
20. Yellow Jacket

FIGURE 31.—Alunite in Utah.

as compiled from Thoenen (1941), total more than 26 million tons of material containing at least 20 percent alunite.

The Sheep Rock alunite deposit in Beaver County is at the west base of the Tushar Mountains about 10 miles northeast of Beaver (Loughlin, 1915; Callaghan and Parker, 1961a). It is a replacement body in the Pliocene(?) Mount Belknap Rhyolite, which has been replaced by an aggregate of alunite, quartz, and kaolinite over an outcrop area 1,200 feet long and 900 feet wide. No production has been recorded from the deposit, but resources were estimated at 2 million tons of alunitized rock with an average grade of 34 percent alunite (Thoenen, 1941).

A prominent alunite vein occurs at Beauty Knoll in the Bull Valley mining district about 40 miles northwest of St. George, Washington County (Crawford and Buranek, 1948). The vein, reported to be approximately 25 feet wide and 1,500 feet long, strikes northwesterly, is nearly vertical, and is exposed over a vertical distance of about 300 feet. The deposit, which contains both pink and white crystalline alunite in a matrix of gray to white dense aphanitic alunite, was estimated by Frank H. Gunnell of the U.S. Bureau of Mines (in Crawford and Buranek, 1948) to contain nearly 500,000 tons of 80 percent alunite. No production has been reported.

A widespread occurrence of alunite has recently been reported by Stringham (1963) in an east-west trending zone 5½ miles long and ½ to 1½ miles wide on the east and west sides of White Mountain about 10 miles south of Frisco and 15 miles west of Milford in Beaver County. The alunite mineralization is similar to the replacement deposits at Marysvale. Fine-grained alunite, kaolinite, and quartz replace the primary minerals of ash-flow tuff in the White Mountain area. Little is known, however, about the grade of the alunite or potential resources of alunite in this area.

Most of the major alunite deposits in the Marysvale region probably have been discovered by the extensive prospecting and exploration during both World War periods. Hope for extending alunite resources lies in the discovery of deposits in other areas of alunitic alteration such as the areas near Frisco (Stringham, 1963).

BARITE

(By D. A. Brobst, Denver, Colo.)

Barite ($BaSO_4$) is a relatively soft, generally white to gray, heavy crystalline mineral that has a specific gravity of 4.5. It occurs in vein, replacement, and residual deposits either alone or more commonly in association with quartz, chert, jasper, fluorite, celestite, and various carbonate and metallic sulfide minerals (Brobst, 1958, p. 82).

The United States annually consumes between 1 and 2 million tons of barite, about 90 percent of which is ground to minus 325 mesh for use as mud in drilling deep oil wells. The heavy weight of the mud assists in the drilling process and in controlling high oil and gas pressures at depth. The other 10 percent is used both as barite and in the preparation of barium compounds in a great variety of products and industrial processes. Among these are pigments (lithopone), filler in paper, textiles, rubber goods, asbestos products and linoleum, heavy aggregate for concrete, paving material, electronic equipment, ceramics, and glass manufacture. The quality standards of the crude barite vary for different uses (Brobst, 1960, pp. 62–63).

Only a few thousand tons of barite have been produced in Utah and all of it during the 1959–61 period. Most of it came from the Garrick mine, about 10 miles east of Trout Creek, Juab County; most of the remainder came from the Horn Silver mine, Beaver County, and the Barium, Inc., mine, Emery County (fig. 32). The geology of these occurrences is not known. A partly exposed deposit in the Strawberry area, Wasatch County, consists of barite masses in fractured Mesozoic rocks where they are exposed under the upper plate of the Charleston thrust (Arthur Crawford, oral communication). Other deposits consist of a barite vein, as much as 10 feet thick, at the Probert mercury mine, western Tooele County (see section on mercury, p. 232), and a barite vein about 1 foot thick in the Silver Island Range, western Tooele County (Anderson, 1960, p. 161).

Barite also is a common accessory mineral in many metal mines where it could be recovered chiefly as a byproduct in the mining of vein and replacement deposits of copper, lead, zinc, and precious metals. It is especially abundant in the Tintic district, Juab County and the San Francisco district, Beaver County, principally at the Horn Silver mine. The locations of these and other districts, mines, and occurrences in which barite has been reported are shown on figure 32 and listed in table 11 by counties.

TABLE 11.—*Barite localities in Utah*

Beaver County:
- 1. Antelope district.
- 2. Beaver Lake district, Cactus mine.
- 3. Granite district.
- 4. McGarry district.
- 5. Newhouse district, southern Utah mines.
- 6. San Francisco district, Horn Silver mine.

Box Elder County:
- 7. Rosebud district.

Emery County:
- 7a. Barium, Inc., mine.

Iron County:
- 8. Iron Springs district.

Juab County:
- 9. Mount Nebo district.
- 10. Tintic district, Boss Tweed, Carissa, Centennial Eureka, Gold Chain, Grand Central, Iron Blossom, Mammoth, Opohonga mines.
- 10a. Garrick mine.

Morgan County:
- 11. Argenta district, Carbonate Hill mine.

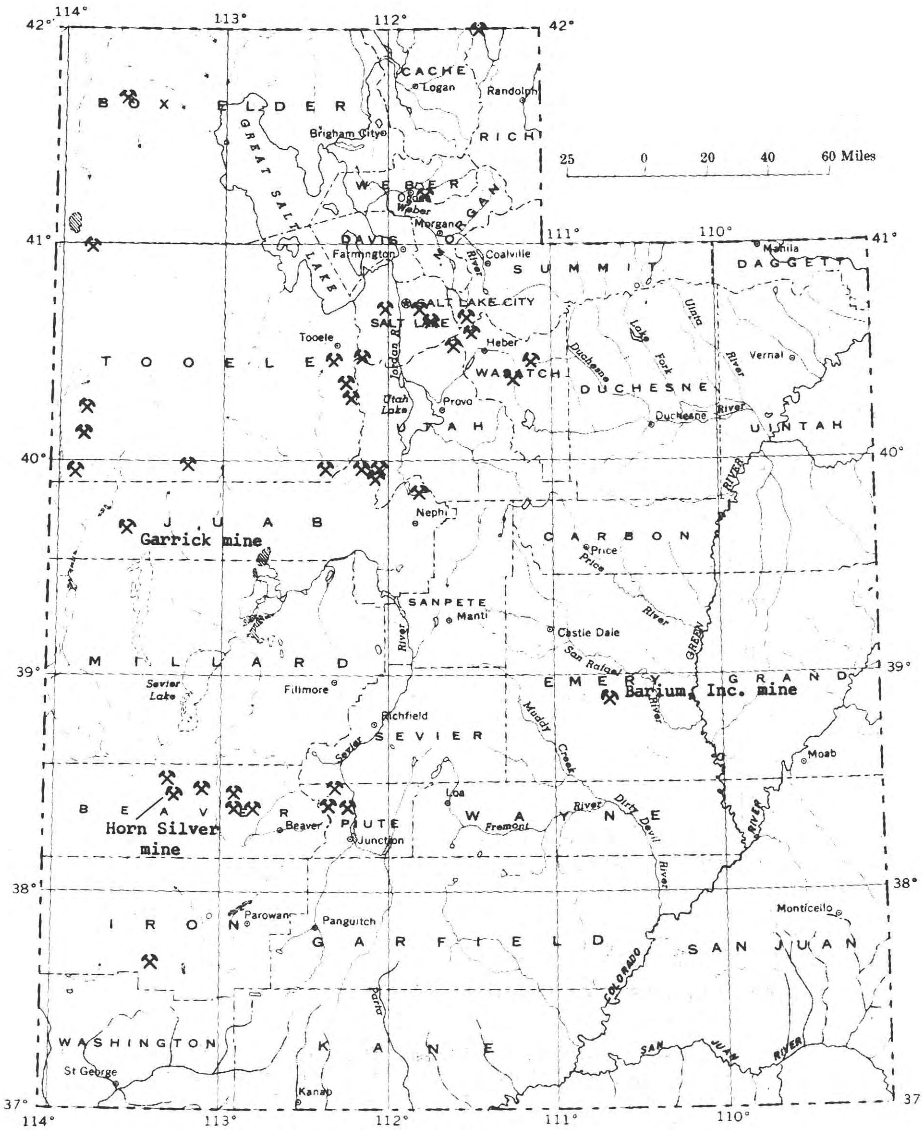
Piute County:
- 12. Deer Creek district.
- 13. Mount Baldy district, Lucky Boy mine.
- 14. Ohio district, Bully Boy and Webster mines.

Rich County:
- 15. Swan Creek district.

Salt Lake County:
- 16. Big Cottonwood district.
- 17. Bingham district.
- 18. Little Cottonwood district, Albion mine, Flagstaff Mountain.

Summit County:
- 19. Park City district.

Tooele County:
- 20. Blue Bell district, Morgan mine.



EXPLANATION

Barite Mines and Deposits: ⚒ Named mines have shipped barite; other occurrences, chiefly in base- and precious-metal mining districts, are shown above and referred to in text.

FIGURE 32.—Barite in Utah.

TABLE 11.—*Barite localities in Utah*—Continued

Tooele County—Continued
- 21. Clifton (Gold Hill) district, Christmas Mining Co., Garrison Monster and Reaper mines.
- 21a. Probert mine.
- 22. Dugway district.
- 23. Mercur district.
- 24. Ophir district, Ophir Canyon, Buffalo, Chloride Point mines.
- 24a. Silver Island.

Utah County:
- 25. American Fork Canyon district, Bog, Dutchman, and Pacific mines.
- 26. East Tintic district, North Lily, Tintic Standard mines.

Wasatch County:
- 27. Strawberry area.

Weber County:
- 28. Argenta district.

Most of these localities are listed by Bullock and others (1960, p. 67) and are described in the references pertaining to the base-metal and precious-metal districts.

The barite resources of Utah cannot be developed adequately under the economic conditions prevailing in 1963. Most of the known barite in Utah is associated with base- and precious-metal deposits and can be produced only as a byproduct. Such byproduct sources are not generally attractive to steady users of barite because available supplies are tied to the fluctuating demand for the principal products. This is even more true in Utah than elsewhere, because the deposits are far from the Nation's major barite markets and the high cost of shipping further reduces its value. Larger deposits in which barite is the major product are available in neighboring and other states that are closer to the markets. A geographic shift in industrial demand for barite, or the discovery of new deposits consisting predominantly of barite could alter significantly the economic position of this commodity.

CLAYS

(By S. H. Patterson, Beltsville, Md.)

Clays mined in Utah include halloysite, a form of kaolin used in making petroleum catalysts and light-colored brick; fire clay for low-heat duty refractory products; bentonite used for drilling mud, foundry sand bonding material, roofing material, laundry compounds, mineral wool, lining of stock tanks, reservoirs, and irrigation ditches, and other purposes; fuller's earth for decolorizing oils and greases, absorbents, and other purposes; and common clay and shale for making brick, tile, other structural clay products, and lightweight aggregate. Total production of clay in Utah in 1961 was 143,000 short tons valued at $1,080,000. In that year, Utah ranked as the 36th state in tonnage and 26th in value of clay produced. Available tonnage and value figures for clay produced in past years are not comparable, because of inconsistencies in reporting certain types of clay; however, the value of clay produced in 1961 is above the yearly average since World War II.

The suitability of clays in Utah for various uses depends on physical properties which are controlled by the mineral and chemical composition of the clay. Clays are natural earthy materials composed of very fine particles (clay minerals) that are principally hydrous aluminum silicates, but may contain small amounts of iron, magnesium, potassium, sodium, calcium, and other ions. The clay minerals that occur in Utah include kaolinite, halloysite, dickite, montmorillonite, illite, and pyrophyllite. Nonclay minerals and other impurities are present in all clays in varying quantities. Quartz or other forms of silica and feldspar are the most common impurities in clay deposits; alunite is abundant in some deposits formed by hydrothermal processes; some sedimentary clays contain appreciable amounts of organic material; and most deposits contain one or more types of iron or titanium-bearing minerals. For most uses, the value of the clay varies with the purity of the clay mineral present; however, for some products, as, for example, bloating clays, nonclay minerals having certain properties are important. Physical properties of clays, one or more of which makes them suitable for different uses, include: plasticity; bonding strength; color; vitrification range; deformation with drying and firing; gelation, wall-building properties, and viscosity of slurries; swelling capacity; etc. The composition, mineral structure, methods of identification, and testing of various clays for different uses has been summarized by Murray (1960), and books by Grim (1953; 1962) contain detailed information on these subjects.

UTAH OCCURRENCES

Halloysite.—Nearly all the catalytic-grade halloysite produced in the United States is from the Dragon mine, which is about 2 miles south of Eureka, Juab County, Utah (fig. 33). The mine is controlled by the Anaconda Co. and is operated by the subsidiary Dragon Consolidated Mining Co. The clay is processed in the Filtrol Corp. plant in Salt Lake City. Mining of the halloysite started about 1931, but was sporadic and unimportant until 1949 when research by the Filtrol Corp. proved that after treatment the clay is useful as a catalyst in the refining of crude oils (Kildale and Thomas, 1957, p. 94). Since then, through 1962, the mine shipments have averaged nearly 60,000 tons per year and total about 765,000 tons. The mine output for the 1931–62 period is listed in the following table:

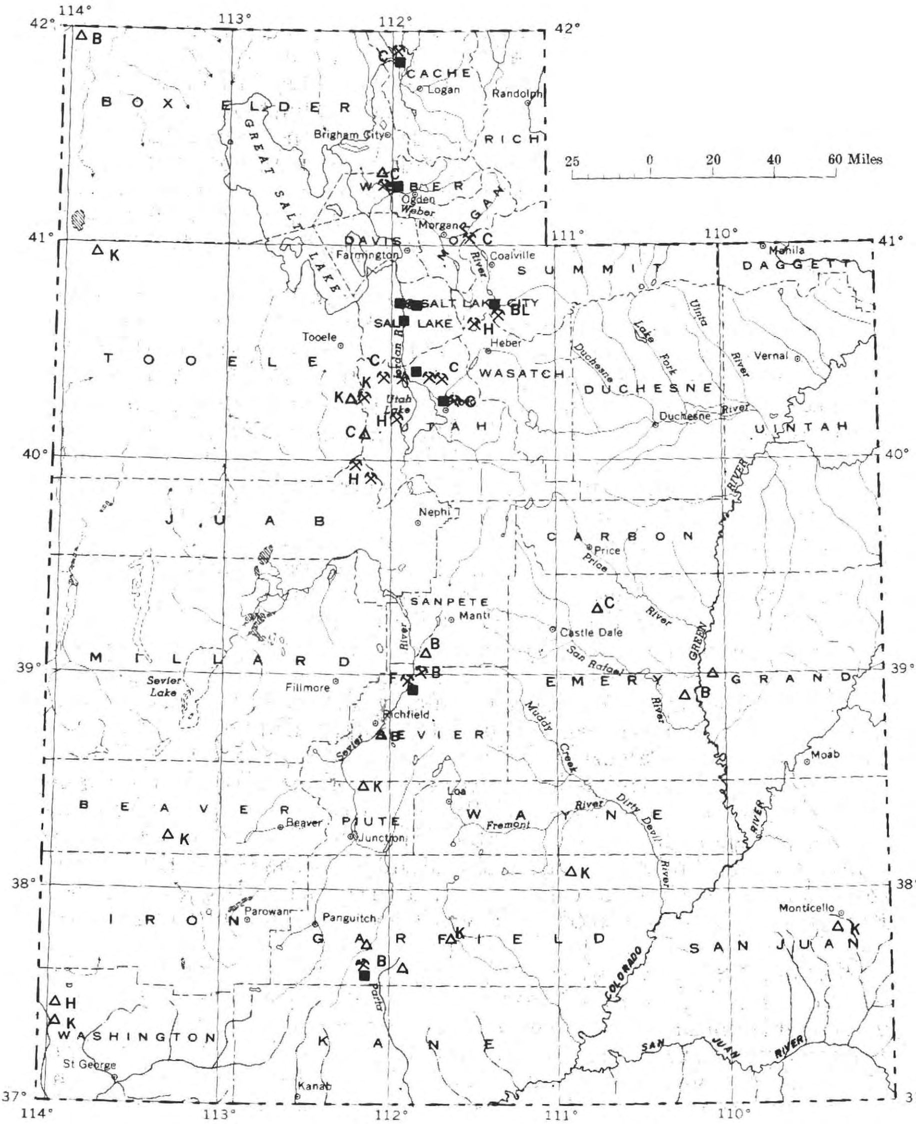
TABLE 12.—*Halloysite shipments from the Dragon mine, 1931–62* [1]

Year	Tons	Year	Tons
1931–39	156	1956	84,157
1940–49	12,135	1957	66,867
1950	26,970	1958	55,959
1951	50,928	1959	50,287
1952	65,417	1960	52,243
1953	66,554	1961	37,089
1954	80,195	1962	50,444
1955	65,449		
		Total (1931–62)	764,850

[1] By permission of the Anaconda Co.

The halloysite occurs in two large pipelike bodies in lower Paleozoic limestone near the contact with monzonite porphyry. The clay probably formed by replacement of limestone by hydrothermal processes associated with the introduction of the porphyry. No information on the reserves of halloysite in the Dragon mine have been published, but recent mining activity indicates that the deposit is not exhausted.

Halloysite deposits occur at several other localities in Utah, namely: (1) Packard Peak, 1 mile north of Eureka, Juab County; (2) the Fox



EXPLANATION

Clay deposit (letter indicates type)
- B Bentonite
- BL Bloating clay
- C Common clay
- F Fullers earth
- H Halloysite
- K Kaolin or refractory clay

Clay pit or mine

Clay processing plant (brick and tile, refractory, bloating clay, or other)

FIGURE 33.—Clays in Utah.

clay deposit, on the west side of the south extension of the Lake Mountains, Utah County; (3) in the Park-Bingham tunnel, 3 miles southeast of Park City, Wasatch County; and (4) in the Bull Valley Mountains, Washington County. A substantial tonnage has been mined from the Packard Peak deposit since 1961, when operations started. This clay has been used with other clays in making light-colored brick. The Fox clay deposit also has been mined for brick, and the deposit in the Park-Bingham tunnel yielded some material for use as a catalyst. There is no recorded production from the Bull Valley deposit.

Fire clays.—Clays suitable for use in low-heat duty refractory products are present in several parts of Utah. Much of the Utah clay used for refractories is mined in the Five Mile Pass area and in the Lake Mountains, Tooele and Utah Counties (Hyatt, 1956, pp. 1–53). Other potential sources of fire clay are the extensive hydrothermal alunite-kaolinite deposits near Marysvale, Piute County (Kerr, and others, 1957) and possibly south of Frisco, Beaver County (Stringham, 1963) (see section on alunite, p. 151). Sedimentary clays occur in the Dakota sandstone of Cretaceous age near Escalante, Garfield County, the Barney deposits in north-central Garfield County, and deposits near Monticello, San Juan County (Van Sant, in preparation). A dickite-type kaolin deposit located 30 miles northwest of St. George, Washington County is noted by Kerr and Kulp (1949, pp. 38–39). Probably the highest grade fire clays in the State are in the Barney deposits (Van Sant, in preparation). In addition, pyrophyllite, a high temperature refractory mineral, occurs in clay pits in the vicinity of Lake Mountain at the northwest end of Utah Lake (Ehlmann, 1959). At this locality, late Paleozoic shales, which contain from 40 to 70 percent pyrophyllite, are believed to be hydrothermally altered; generally the occurrences are spatially related to faults. Pyrophyllite also occurs sporadically in less abundance elsewhere in the Manning Canyon shale, the Long Trail Shale Member of the Great Blue Limestone, and in a shale member of the Precambrian Big Cottonwood Formation (Ehlmann, 1959). There is no known production of pyrophyllite in the State.

Bentonite and fuller's earth.—Bentonite occurs at several localities in Utah (fig. 33). A bed of nearly white bentonite, in a series of variegated sandstones and siltstones, north of Redmond, is mined and processed in a plant at Aurora, Sevier County. Bentonite deposits in shale of Cretaceous age are also mined north of Cannonville, Garfield County, and processed there. Other bentonite deposits occur near Tropic and Henrieville, Garfield County, in parts of Emery and Grand Counties near Green River, and in the northwestern part of Box Elder County. Extensive bentonitic sedimentary rocks of Mesozoic and Tertiary age in the southern half of Utah probably contain large resources of bentonite. However, many of these deposits are in remote areas, and others are too low grade for profitable exploitation.

Fuller's earth is mined near Aurora, Sevier County, and processed in the plant that prepares the Redmond bentonite. The deposit is 30 to 40 feet thick and is probably formed from decomposed dacite (Crawford and Cowels, 1932). Also, undeveloped fuller's earth deposits occur near Mayfield, Sanpete County, and others may be present near Vernal, Uintah County.

Common clays and shales.—Deposits of clays and shales suitable for making brick, tile, and other heavy structural products are scattered throughout the State (fig. 33). The materials used for this purpose include: the clays that accumulated in the basin of Pleistocene Lake Bonneville; shales from the Manning Canyon Shale and Great Blue Formation and other formations of Paleozoic age; clays associated with coal beds of Cretaceous age; weathered schists; and clay deposits formed by hydrothermal processes. Also red silty clay is mined near Henefer, Summit County, for use in heavy clay products. Plants using common clays at Harrisville, Murray, Sandy, Ogden, Provo, Salt Lake City in the Utah and Salt Lake Valleys, and at Smithfield in Cache Valley, are adequately supplied by the above sources.

Some clays, shales, and other materials in Utah are suitable for bloating, when heated to about 1150° C. to form lightweight aggregate. Recently, from the Frontier Formation, shale has been mined and bloated near Wanship, Summit County, for use in lightweight aggregate. Lightweight aggregate is discussed more fully on p. 185.

Reserves of common clays now used appear to be adequate for several years, and very large resources are available when current sources are exhausted. Deposits of common clay occur at many places in north-central Utah in the basin of Pleistocene Lake Bonneville (Hunt and others, 1953; Williams, 1962); however, much of this clay contains large quantities of alkalies and alkaline earths and is of little value for ceramic products (Greaves-Walker, 1911, p. 277). Deposits of common red clay near Henefer used in making red brick (Stringham and Cahoon, 1959) are presumably large, and deposits developed on ancient soils located in the northern part of the Utah Valley may also be large and suitable for several structural clay products (Hunt and others, 1953, pp. 58–59). Very large resources of common clay are present in shales of Cretaceous age in the east-central part of the State (Hyatt and Cutler, 1953). These shales and common clays at several other localities (Van Sant, in preparation) are located far from existing markets and, therefore, have little immediate value. In addition to the bloating clays now mined at Wanship, there are several other possible sources of this type of clay. Bloating materials in the vicinity of Salt Lake City have been investigated by Anderson (1960). Clays from deposits in the eastern part of Utah County may be suitable for lightweight aggregate (Hyatt, 1956, p. 66), and some bloating was noted in clays from a few scattered localities that were tested for refractory properties (Van Sant, in preparation).

ECONOMIC CONSIDERATIONS AND RESOURCE POTENTIAL

One group of clays in Utah is suitable for structural clay products, low-heat duty refractories, and lightweight aggregate that primarily supplies local markets, and a second group is also used locally but competes with clays from other States for distant markets. Most of the clays for local markets are made into heavy, low-cost products, and the clays used must be inexpensive and located close to processing plants and consumers. This economic control results in the concentration of plants and clay pits in the most densely populated north-central part of the State (fig. 33). The group of clays capable of competing for distant markets includes catalytic-grade halloysite, fuller's earth, and bentonite. The value of these clays depends primarily on quality, chemical and physical properties, and availability of transportation facilities, and to a lesser extent on their location with respect to local markets. The catalytic halloysite is made into a product which competes with high-value catalysts made from other materials. Fuller's earth and bentonite both have special properties and are in demand in other states which lack deposits of these clays.

Supplies of clay currently used in Utah appear adequate for the immediate future, and probably new discoveries will keep pace with demands for most types of clay. Resources of common clay and shale are virtually inexhaustible, though depletion of local deposits and changing consumer requirements will, no doubt, result in periodic adjustment in the raw materials used for structural clay products. The prospects for future supplies of bloating materials are generally good, because clay and shale of several types occur in the State, but very few investigations have been made, and no real basis for appraising the future of this material exists. Present sources of low-grade refractory clays will probably continue to meet demands for some time, and other clays suitable for this purpose are present at several localities less favorably located with respect to plants and markets. The prospects for the discovery of large favorably located deposits of clay suitable for high-heat duty refractory products are not good, and most of these materials used in Utah will probably continue to be imported. Bentonite and fuller's earth resources are probably adequate for many years. Deposits are known at several localities other than where they are now mined, and thorough prospecting and testing would probably reveal large resources of these clays. The total resources of halloysite are virtually unknown; however, the Dragon mine remains in operation and other deposits are worked or have been prospected, and supplies are probably adequate for the State to maintain its position as the leading producer of this mineral for several years.

New demands for Utah clays can be expected as research on deposits progresses and information on size, quality, and physical properties becomes available. Many deposits cannot be appraised for several uses because they have not been adequately studied, and others have been investigated only by private interests and the information on them has not been released. Improving clays by beneficiation may also develop new markets. Removal of impurities in halloysite from the Fox deposit in Utah County produced a material closely approaching standards for paper-grade clay (Hyatt, 1956, p. 61). Methods of beneficiation may eventually be developed for other types of clay. Possibly a product of value for several uses could be obtained if the potassium were removed from the alunite-kaolinite mixtures which occur in several deposits.

FLUORINE

(By M. D. Dasch, Washington, D.C.)

Fluorine is a corrosive, pungent, poisonous, greenish-yellow gas that attacks, among other things, glass, metal, and asbestos. The principal fluorine-bearing minerals in Utah are fluorite and fluorapatite. Fluorite (CaF_2), commercially called fluorspar, is the most important source of fluorine in the United States and fluorapatite ($Ca_5(PO_4)_3F$), the major phosphate mineral, has a large potential as a byproduct source of fluorine. In northern Utah fluorapatite is present in commercial phosphate rock. Fluorapatite also occurs in replacement iron ore bodies in southwestern Utah, and fluorine is recovered in processing the ores.

Fluorite commonly occurs as well-formed, translucent or transparent cubic crystals which range from clear, or colorless, to shades of yellow, green, purple, blue, black, brown, and rarely, red. This moderately hard mineral is softer than quartz and harder than calcite, two minerals with which it is intercrystallized in many places. Fluorite is heavier than calcite and quartz, a useful property when the ore is upgraded by gravity methods. Fluorite occurs as crystal aggregates or in granular, compact, or earthy masses. In Utah it generally is of the massive type, although well-formed cubes are present in some deposits.

Fluorite occurs in veins as the chief constituent or, more commonly, as a gangue mineral associated with metallic ores, especially lead and silver. It also is found as bedded replacement deposits in limestone and dolomite, as cement in sandstone, and as cavity and joint fillings in granitic rocks. In Utah, fluorite occurs primarily in vein deposits and less importantly, as replacement deposits.

The most important use of mined fluorite, or fluorspar, is in the production of hydrofluoric acid. The mineral is pulverized and combined with sulfuric acid to form hydrogen fluoride (hydrofluoric acid) and calcium sulfate. The acid is used in the production of high octane gasoline, in the manufacture of synthetic cryolite and aluminum fluoride which are used in the extraction of aluminum from bauxite, and in other fluorine compounds.

Second in importance is the use of fluorspar as a flux in the manufacture of steel. Before 1954 the amount used in steel production was much greater than that used in making hydrofluoric acid. Since 1954, however, the quantity used in acid production has equaled or been greater than that used in the steel industry. This shift reflects the growth of the aluminum industry, the need for hydrofluoric acid in the petroleum industry, and an increase in the production of fluorine chemicals. Recent developments in the use of oxygen converters by the steel industry suggest that more fluorspar will be used as this method increases in importance.

Considerable amounts of fluorspar also are consumed in the manufacture of glass, enameled products, and fluorine plastics. Organic fluorides are used as refrigerants, aerosol propellants, solvents, and in many other ways. Fluorocarbon chemistry has assumed increasing importance in developments for the electrical industry. No adequate substitutes have been found for fluorine in its primary industrial uses.

Fluorspar generally is concentrated, after mining, by mechanical methods such as hand-sorting, screening, washing, gravity separation by jigs and tables, and heavy-medium sink-float or froth flotation. The concentrates are then marketed as acid, ceramic, and metallurgical grades, which have the following specifications:

Market grade	Minimum percent CaF_2	Other specifications [1]	Primary use
Acid	97	Limitations on silica, calcium carbonate, and sulfide sulfur content.	Manufacture of hydrofluoric acid and aluminum.
Ceramic	[2] 95	Limitations on iron oxide content	Manufacture of glass and enameled products.
Metallurgical	60	Penalties imposed for excessive silica content.	Manufacture of steel.

[1] Specifications on impurities are often negotiable between the buyer and seller.
[2] Approximate.

Utah's fluorspar production from its inception in 1918 through 1961 totals about 155,000 tons valued at about $3,750,000. Through 1958, its recorded production had amounted to only 1.5 percent of the total U.S. production (McDougal, 1960, table 3). As shown in fig. 34, the small output between 1918 and 1924 came from a single mine, the Silver Queen in Tooele County. Production in the period from 1935 to the midforties came principally from three mining districts in Beaver County and since 1948 the major part of the production has come from mines in the Thomas Range, Juab County. Lowered prices in 1953 brought production down sharply, and conversely, production increased markedly under increased demand from steel mills and the stockpile purchase program between 1955 and 1958. With the termination of the purchase program at the end of 1958, fluorspar mining in Utah was interrupted for a year, and then resumed on a small scale.

The significant fluorspar localities of Utah are described in summary form in the following paragraphs and their locations are shown on figure 35.

The Thomas Range fluorspar district (fig. 35, locality Nos. 3–6) on Spor Mountain in western Juab County is Utah's largest fluorspar producer. A dozen mines in the district have yielded a total of 144,000 tons of ore from 1943–62. The fluorspar occurs in a north-trending belt principally in Ordovician and Siluran dolomites and less importantly, in Tertiary volcanic rocks. The fluorspar deposits are along faults and in intrusive breccia bodies, and are classified as pipes, veins, and disseminated deposits. The pipes have yielded more than 99 percent of the production (Staatz and Osterwald, 1959, p. 46). Veins are common but only three have yielded fluorspar (Staatz and Griffitts, 1961, p. 944); the disseminated deposits are low grade, spotty, and have not been mined. The ore is purple, brown, or white, and occurs as pulverulent masses or boxworks containing 65–95 percent fluorspar. It is radioactive and locally contains as much as 0.33 percent uranium (Staatz and Osterwald, 1959, p. 53). Beryllium deposits on the eastern and western flanks of Spor Mountain, along the periphery of the fluorspar district, contain low-grade fluorspar that may furnish some byproduct fluorine. Only traces of beryllium, however, are associated with the high-grade fluorspar in the central part of Spor Mountain.

Three areas have yielded fluorspar in Beaver County, the Indian Peak district, the Pine Grove district, and the Star district (fig. 35).

Production in the Indian Peak district came from the eastern side of the Indian Peak Range. Fluorite, and associated calcite and quartz, are concentrated along faults and shear zones in altered

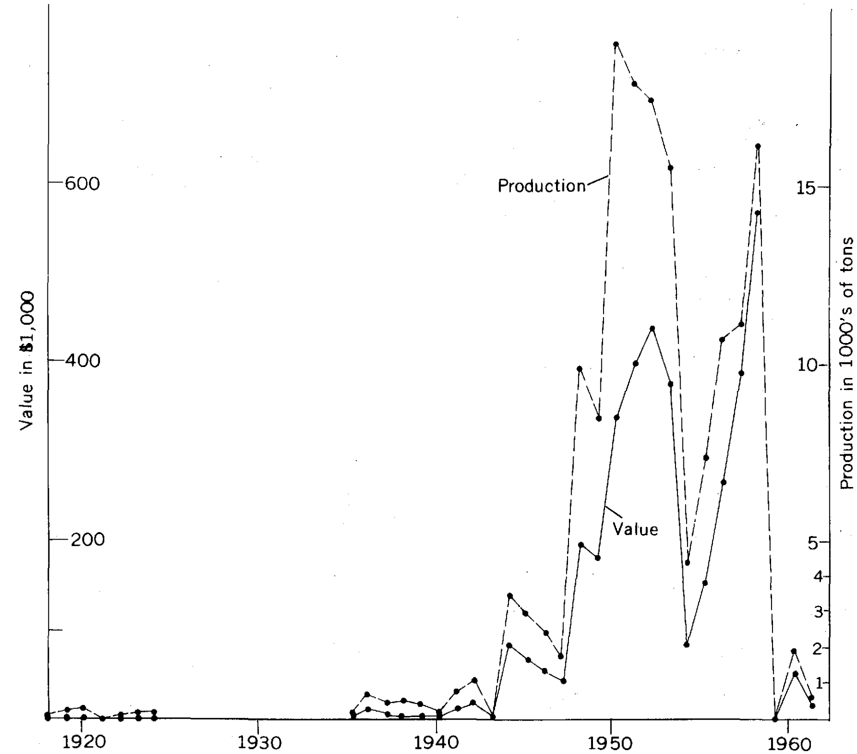
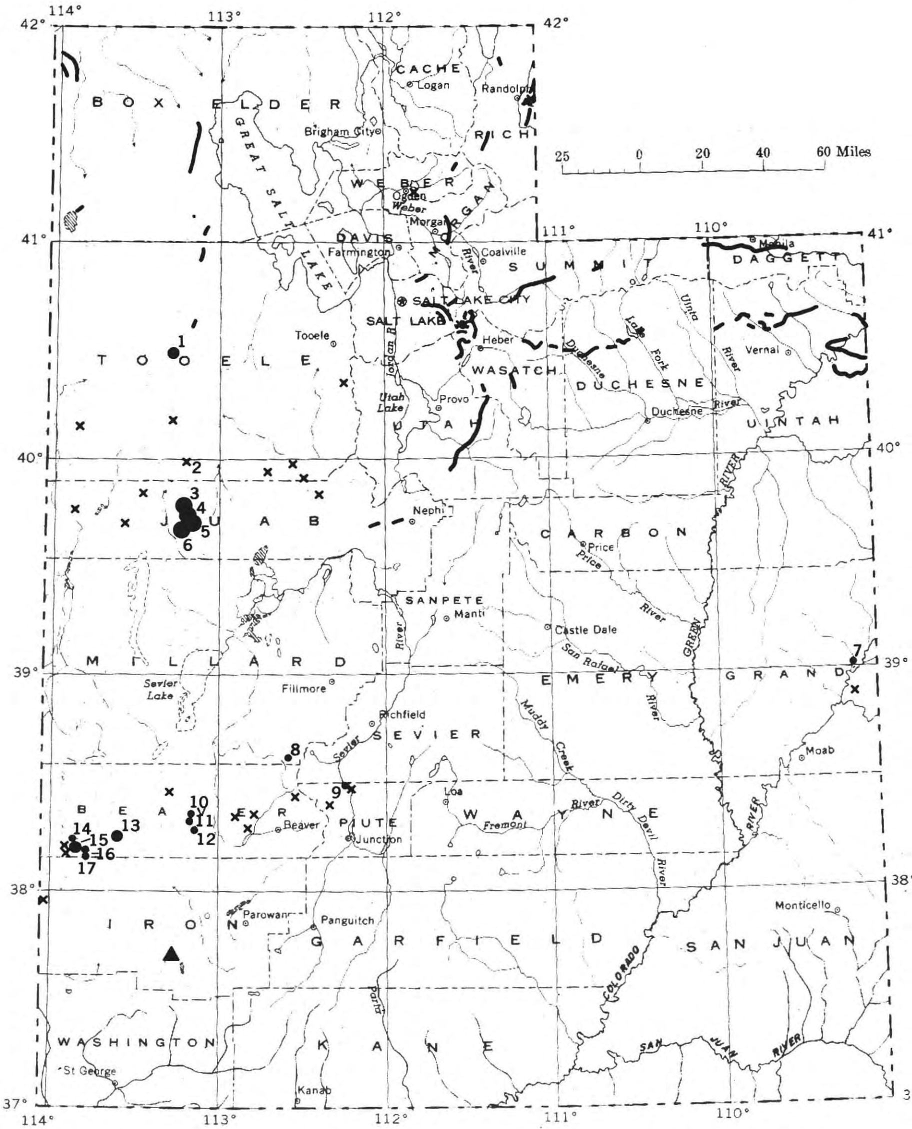


FIGURE 34.—Fluorspar production in Utah. (Data from U.S. Bureau of Mines, Denver, 1918–52; and from U.S. Bureau of Mines Minerals Yearbooks, 1953–61.)



EXPLANATION

Mine output in short tons of fluorspar concentrate, 1918-62

- ● More than 10,000
- ● 1,000 to 10,000
- • Less than 1,000

× Fluorite occurrence

▲ Fluorapatite-bearing iron ore deposit

Outcrop of fluorapatite-bearing Phosphoria and Park City Formations

Numbered deposits are referred to in text

Figure 35.—Fluorine in Utah.

Tertiary volcanic rocks, and along the contact with a quartz diorite stock (Thurston and others, 1954, pp. 6–16). The Cougar Spar mine (No. 15) produced several thousand tons of concentrate during World War II; smaller tonnages were shipped from the Blue Bell (No. 14), JB (No. 16), and Utah (No. 17) mines at that time. The ore, which averaged about 40 percent CaF_2, was concentrated before shipment.

The Pine Grove mining district in the Wah Wah Mountains, western Beaver County, includes the Monarch (Staats) fluorspar area. Fluorspar, in places coated with uranium minerals, occurs along the faulted and brecciated contact of intrusive Tertiary rhyolite porphyry and Cambrian limestone. About 3,500 tons of fluorspar were mined between 1935 and 1946; hand-sorted ore shipments averaged more than 85 percent CaF_2 (Thurston and others, 1954, p. 17).

In the Star district, central Beaver County, fluorspar is known at 18 localities. Fluorspar is locally associated with sulfide minerals, and occurs as fissure fillings in quartzite, intrusive quartz monzonite, and Paleozoic limestone; in some areas it replaces limestone near the contact with quartz monzonite. Small quantities of fluorspar have been produced from the Brown Thrush, Fluorine Ledge, and Manassa (No. 10); Virginia Nos. 2 and 3 (No. 11); and Quartzite (No. 12) (Thurston and others, 1954, pp. 19–24).

At the Rain Bow mine (No. 8), southeastern Millard County, fluorspar fills fractures in limestone. This mine produced some fluorspar in 1947 (Davis, 1949, p. 510).

The Silver Queen (Wildcat) mine (No. 1) in central Tooele County produced about 1,200 tons of high-grade ore (Thurston and others, 1954, p. 45) containing from 85 to 97 percent CaF_2 (Burchard, 1933, p. 21). At this deposit fluorspar occurs in veins along fissures in Carboniferous limestone; in places the limestone has been replaced by fluorite.

Many deposits in the Marysvale uranium area, northern Piute County, contain fluorite veins, and fluorite occurs in broad alteration zones (Kerr and others, 1957). The veins are in Tertiary intrusive quartz monzonite and related igneous rocks and the fluorspar is commonly associated with quartz and uranium minerals, primarily pitchblende. In 1949, a carload of fluorspar ore was shipped from the Bullion Monarch mine (No. 9) (Davis, 1951, p. 524).

The Blue Spar property (No. 7) in Grand County near the Colorado border is the only property in eastern Utah from which fluorspar has been shipped. A few tons of ore were mined in 1948 (Davis, 1950, p. 539).

Other fluorspar occurrences are known in Utah, but their small size or low grade has made them unprofitable to mine. These scattered small occurrences are shown on figure 35 and are mainly in areas mined for other mineral commodities (Thurston and others, 1954, table 3). Fluorite, for example, is present in the Mystery Sniffer uranium mine in Beaver County (Wyant and Stugard, 1951, written communication), and in several tungsten mines in the Granite district of Beaver County (Crawford and Buranek, 1945, pp. 29, 46; Butler and others, 1920, p. 534).

The known fluorspar reserves in Utah have been estimated at about 450,000 tons with a minimum grade of 40 percent CaF_2 (Thurston and others, 1954, p. 1). This material is in rather small deposits, when compared with those in other States. Exploration for, and study of, fluorspar in Utah, however, has been limited and the potential for new discoveries is good.

The greatest potential for future discoveries in the known fluorspar districts of Utah is in the Thomas Range and the Indian Peak Range. Staatz estimated in 1950 that 62,000 tons of indicated and 300,000 tons of inferred fluorspar reserves remained in the Thomas Range (Thurston and others, 1954, p. 48). Thurston estimated that the Indian Peak Range had reserves of about 50,000 tons of 40 percent CaF_2 (Thurston and others, 1954, p. 49).

The Monarch (Staats) area in the Wah Wah Mountains very likely will yield more fluorspar; perhaps the clayey low-grade ore can be profitably processed in the future (Thurston and others, 1954, p. 49). Most of the known fluorspar pockets in the Star district, however, have been mined as a byproduct of the metallic ores. No new deposits are known to exist in or near the Silver Queen (Wildcat) mine.

A fluorspar locality in the Dugway district, Tooele County, primarily on the Bryan, Lauris, Rattler, and Black Maria claims (No. 2) is a potential source as a byproduct from sulfide ore. The fluorspar is present in veins in Cambrian quartzite and limestone as an important gangue mineral of sulfide ores, second only to quartz (Staatz and Carr, in preparation).

Phosphate rock is a large potential source of byproduct fluorine, for it contains about 2 to 3.5 percent fluorine in the form of fluorapatite. The 15.5 million tons of phosphate rock mined every year in the United States contain more than 500,000 tons of fluorine (Grogan, 1960, p. 374). In northeastern Utah, the Permian Phosphoria formation and its partial stratigraphic equivalent, the Park City Formation (see outcrop pattern, fig. 35), contain phosphorite beds with a combined thickness of up to 50 feet containing more than 18 percent P_2O_5 (Swanson and others, 1953, fig. 11). Fluorine very likely will become an important byproduct of future phosphate recovery. Large quantities of phosphate rock are mined in Rich County, and phosphate has recently been produced from Uintah County. (See phosphate section, p. 195.)

To date, commercial recovery of fluorine from phosphate rock in a form other than as fluosilicate, has been on a small scale. A recent study of methods for the recovery of fluorine from such rocks offers some promise (Hall and Banning, 1958). In 1960 the United Heckathorn Co. recovered 1 to 3 percent fluorine from phosphate rock at a wet-process phosphoric acid plant at Garfield. Synthetic cryolite was produced from the fluorine (McDougal and Roman, 1961, pp. 489, 491).

Replacement iron ore deposits in the Jurassic Homestake Limestone in the Iron Springs district (fig. 35), south-central Iron County, contain less than 1 percent fluorine as fluorapatite. In order to prevent air pollution, fluorine is currently being extracted during the processing of this ore at the Geneva steel plant in Provo (Engineering and Mining Journal, 1958, p. 154).

Work of Griffitts and Rader (1963) indicates the beryllium deposits of Spor Mountain contain as much or more fluorine than beryllium. This fluorine represents a potential resource if recovery is technically feasible or required.

GEM MATERIALS

(By M. D. Dasch, Washington, D.C.)

Gem materials are minerals and closely allied naturally occurring substances that are used as gem stones or as ornamental stones. Gem stones are used for personal adornment. Ornamental stones are used for ornamental objects such as vases or statuettes, and for other decorative purposes.

Gem materials generally possess one or more of three major qualities: beauty, determined by personal taste; durability, determined by hardness and lack of ready cleavage; and rarity. Three other qualities that may be equally important are portability, fashion, and "make," that is, the degree to which workmanship has enhanced the natural attributes of the raw material. The terms "precious" and "semiprecious" are used by some to distinguish gem materials on their recognized value. Precious gem materials must exhibit all three of the major qualities—beauty, durability, and rarity—whereas semiprecious materials must possess one or two of the major attributes. For centuries, diamond, emerald, ruby, and sapphire have been regarded as precious gems. Although these gem stones do not occur in Utah, semiprecious gem materials are abundant.

From 1906 through 1916, $103,600 of gem materials was produced in Utah. With few exceptions, figures of State production between 1917 and 1954 are not available. The output of gem materials steadily increased from 1955 through 1958, and totaled $68,000. Production of this 4-year period was nearly doubled in one year, 1959, when Utah shipped $134,000 of gem materials. During that year Utah led the Nation in output of petrified wood with 200 tons valued at $60,000. Production of gem materials dropped to $72,000 in 1960, rose slightly to $73,000 in 1961, and increased again to about $75,000 in 1962.

During 1961, the most recent year for which detailed production figures are available, Utah shipped gem materials from 18 of the State's 29 counties, and led the country in obsidian production—42,000 pounds valued at $13,000. The State was fourth in petrified wood production and sixth in agate output (Hartwell and Brett, 1962, pp. 586, 587). Juab County produced $21,500 of gem materials, more than twice any other county. Agate and petrified wood were shipped from Garfield County, which ranked second in importance. From Millard County came $7,765 of gem materials, mainly obsidian, and from Utah County came $2,500, primarily variscite and calcium carbonate, commercially called onyx (Howes, 1962, pp. 1043, 1050, 1051, 1056).

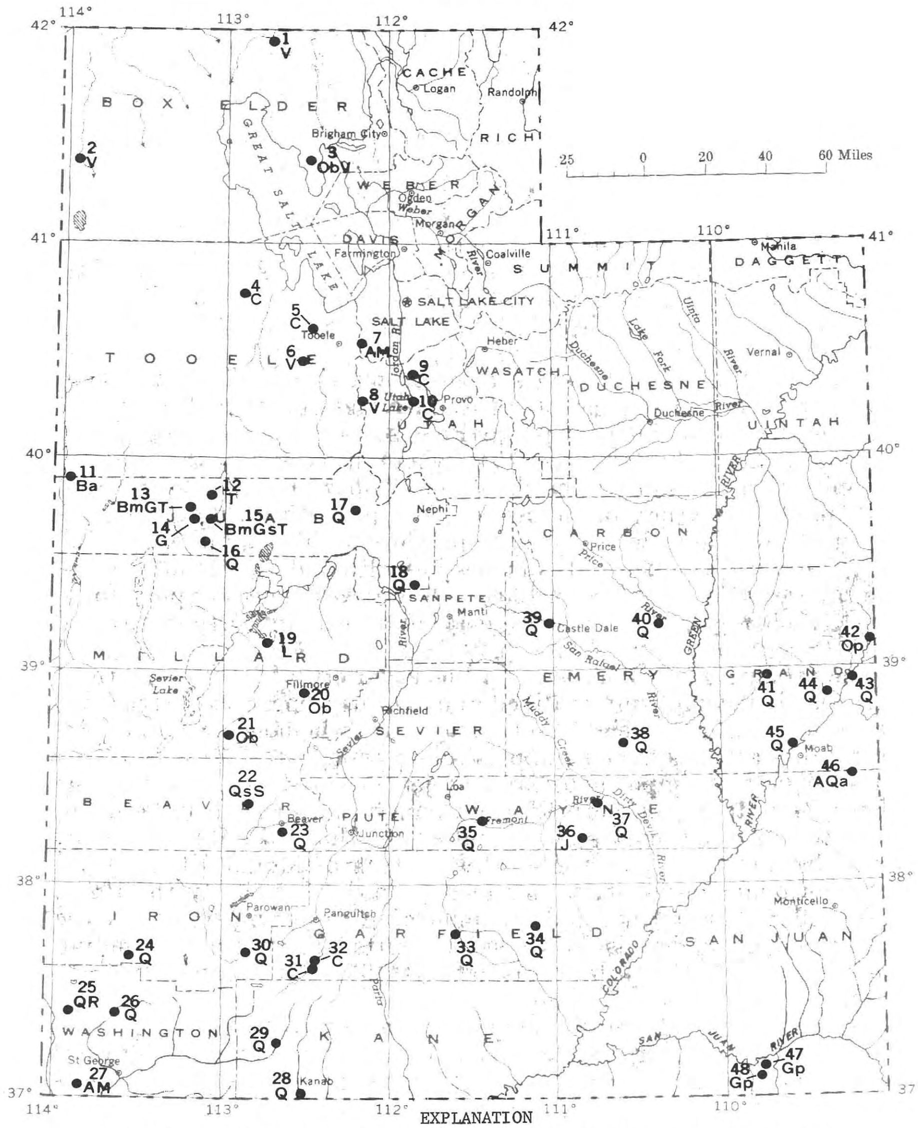
Production trends of Utah gem materials are dependent upon known deposits, the discovery of new ones, and the current demand for specific commodities. Jet was mined in significant quantities during the early 1920's when it was fashionable as mourning jewelry; today it is not in vogue and no market for it exists. Pyrope garnet from the Navajo Indian Reservation, topaz from the Thomas Range, and variscite from several localities in western Utah have been produced sporadically since the turn of the century. Agate, jasper, and petrified wood, currently in demand, were little mentioned earlier in the century. Obsidian, first worked in Utah by the Indians, has been produced commercially since the early 1940's, and "onyx" has been quarried since the early 1950's.

In Utah, gem materials are produced by both amateur and professional collectors. The gem industry, for the most part, is operated by individuals, rather than by large companies. For this reason, production information is incomplete, and the location of individual deposits is often vague. The following discussion of Utah gem localities does not pretend to be a complete listing; it merely summarizes some of the better known occurrences. Commodities are described alphabetically, and the approximate locations of significant deposits are shown on figure 36.

Azurite and *malachite*, the azure blue and bright green copper carbonate minerals that commonly occur together in the oxidized zone of copper deposits, are the alteration products of other copper minerals. Azurite is less common than malachite and occurs as transparent to subtranslucent prismatic crystals and radiating spherical groups. Malachite occurs in translucent to opaque botryoidal and stalactitic masses. Both minerals, though soft are used extensively for ornamental objects, such as vases and table tops, and occasionally for jewelry. Azurite and malachite occur in the near-surface parts of many copper deposits of Utah; those localities containing gem-grade material, however, are not always specified. Some of the copper ore mined from Bingham (fig. 36, locality No. 7), Salt Lake County has been used as gem material (Ball, 1941, p. 1402). Excellent quality azurite and malachite were recovered in the 1940's from the Dixie Apex mine (No. 27) west of St. George, Washington County (Ball, 1945, p. 1561). Small specimens of deep-blue azurite sandstone from the La Sal district (No. 46), southeastern Utah, have been suggested for finishing doorways and for ornamental purposes (Sterrett, 1907, p. 1214).

Two gem varieties of *beryl*, a hard transparent to translucent beryllium aluminum silicate, are present in small amounts in Utah. *Aquamarine* occurs as long slender crystals of bluish-green beryl. Blue beryl containing patches of gem-quality material, later reported as aquamarine, is present in gulch gravels on Ibapah Mountain (No. 11), in Tooele or Juab Counties, western Utah (Sterrett, 1909, p. 811). The beryl-bearing gravels very likely were derived from beryl that occurs in quartz veins [or pegmatite] in the Ibapah stock of the Deep Creek Range (Butler and others, 1920, p. 112). One beryl-bearing pegmatite occurs in Fifteenmile Canyon near the southwestern margin of the stock, Juab County (see section on beryllium, p. 71). *Morganite* occurs as squat, tabular crystals of pale pink to deep rose beryl. On the west side of Spor Mountain (No. 13), western Juab County, morganite is associated with topaz and garnet in Tertiary rhyolite flows (Staatz and Griffitts, 1961, p. 943). In the Topaz Mountain amphitheater (No. 15), a drainage basin at the southeast end of the Thomas Range, rose-red beryl crystals are attached to topaz crystals and to lithophysal cavity walls in Tertiary Topaz Mountain Rhyolite of Erickson, 1963 (Palache, 1934, p. 14; Erickson, 1963, p. 32).

Garnet includes a group of six minerals with similar physical properties, crystal forms, and a basic chemical formula in which elements replace one another to form a series. Two garnets are produced in



EXPLANATION

● Deposit of gem material (Numbers refer to localities mentioned in text)

A	Azurite	Q	Cryptocrystalline quartz (One or more varieties: agate, chalcedony, jasper petrified wood, dinosaur bone)
Ba	Aquamarine	Qa	Amethyst
Bm	Morganite	Qs	Smoky quartz
C	Calcite, referred to as "onyx"	R	Banded rhyolite
G	Garnet, unspecified	S	Scheelite
Gp	Pyrope	T	Topaz
Gs	Spessartite	V	Variscite
J	Jet		
L	Labradorite		
M	Malachite		
Ob	Obsidian		
Op	Opal		

FIGURE 36.—Gem materials in Utah.

Utah. *Pyrope*, a magnesium aluminum silicate and the most popular mineral of the garnet group, occurs in mafic igneous rocks, such as peridotite and serpentine. It is a hard mineral that ranges in color from deep red to nearly black. Pyrope is produced by Indians from topsoil and gulch gravels from the Navajo Indian Reservation in San Juan County, Utah, and northeastern Arizona. The deposits are associated with rocks of funnel-shaped volcanic vents in the vicinity of Comb Ridge. At Moses Rock (No. 48) garnet-bearing material is present in a dikelike body, and garnets which have weathered from the outcrop occur in small patches of alluvium. At the Mule Ear deposit (No. 47) garnets are scattered through alluvium (Gregory, 1917, pp. 146–147; Kiersch, 1955, pp. 91–94). *Spessartite* is a manganese aluminum silicate that occurs in granite, quartzite, and rhyolite. It is a hard garnet that ranges from brown to red. Production of rough spessartite from San Juan County was reported during 1907 (Sterrett, 1908, p. 810). Spessartite also is present in the Topaz Mountain amphitheater (No. 15), where it occurs with topaz in lithophysal cavities in (in the rhyolite of Topaz Mountain) (Sterrett, 1909, p. 842). Garnets of an unspecified type and varying quality are present 3 to 4 miles west of the Topaz Mountain amphitheater (No. 14). They are as much as 1½ inches in width and are found in rhyolite cavities (Patton, 1908, p. 190). On the west side of Spor Mountain (No. 13), garnets occur with beryl and tonaz in Tertiary rhyolite flows (Staatz and Griffitts, 1961, p. 943).

The organic gem stone, *jet*, is a black variety of lignite or brown coal that is incompletely coalified and retains some woody structure. Jet is soft, light in weight and, because it is homogenous and compact, takes a velvety polish and is tough enough to be worked on a lathe. The most important source of jet in North America is in the Henry Mountains, southern Wayne County. It forms disklike inclusions in a narrow coal seam found along the precipitous sides of Coaly basin (No. 36) on the northwest flank of Mount Ellen. Considerable quantities of jet were mined from this locality in the 1920's and used for ornaments and for mourning jewelry. Although the gem stone no longer is in vogue, a California dealer was selling specimens from Coaly basin as late as 1956 (Sinkankas, 1959, p. 605).

Labradorite, a calcium-sodium aluminum silicate of the plagioclase feldspar mineral group, occurs in both extrusive and intrusive igneous rocks. It is moderately hard and characteristically exhibits a beautiful play of colors. Fine straw-yellow labradorite is present northeast of the Clear Lake Railroad Station (No. 19), east-central Millard County. Small squarish fragments, many of them flawless and more than an inch wide are abundantly distributed in crumbly andesite. Material from this locality often appears on the market; in 1947 brilliant cut stones sold for $3 to $6 a carat in Salt Lake City (Sinkankas, 1959, p. 149).

Obsidian is a volcanic glass that forms from acid magmas or lava which cooled so rapidly that crystallization was not possible. Most of it is black, but it may also be brown, red, or green; it is transparent to translucent and has the same hardness as window glass. Primitive peoples used the rock for fashioning arrowheads and for ornamental purposes. Today, transparent and variegated pieces are cut as gem stones. Utah obsidian comes primarily from southern Millard County, where considerable quantities have been mined near Black Rock (No. 21) since the early 1940's. The locality is well known for *flowering* or *snowflake obsidian*, a black variety with bluish-gray spots composed of radiating needle-shaped crystals in clusters called spherulites. West of the Black Rock Railroad Station is an abandoned Indian arrowhead-chipping ground littered with numerous fragments of obsidian. At White Mountain (No. 20), near Black Rock, black and red varieties occur both separately and mixed. Obsidian also is present in Box Elder County south of Promontory (No. 3) (Sinkankas, 1959, p. 507).

True *onyx* is a form of chalcedony, a variety of quartz. It is hard and is typified by straight parallel bands of contrasting color. Unfortunately, the term *onyx* is also used in referring to a special kind of limestone, sometimes called *onyx marble*. Limestone is composed primarily of *calcite*, or calcium carbonate, which is colorless when pure. In contrast to quartz, calcite is a soft mineral unsuitable for use as gem stones. Fine-grained masses of calcite deposited from cold water solutions are fairly tough, however, and are suitable for table tops, bookends, and other decorative purposes. In recent years onyx production has been reported from several counties in Utah. None of these deposits appear to be true onyx. For the sake of consistency with popular usage the incorrect term "onyx" will be continued in this discussion.

Translucent green onyx has been quarried at Hatch (No. 32), southwestern Garfield County. Large flawless blocks have also been mined on Mammoth Creek (No. 31), 1½ miles south of Hatch. Two onyx deposits have been worked in Utah County. Dark and light amber onyx has been quarried near Pelican Point on Utah Lake (No. 10), and beautiful translucent yellow, orange, buff, and white onyx has been mined near Lehi (No. 9). In Tooele County, white, pink, lavender, and yellow onyx has been produced from veins, up to 4,500 feet long, in the Cedar Mountains (No. 4) south of Low. Onyx has been quarried near Grantsville (No. 5), Tooele County, and used for terrazzo, chicken grit, and stucco, as well as for ornamental purposes (Sinkankas, 1959, p. 556).

Opal is an amorphous mineral; that is, it has no definite crystalline structure. It is deposited in cavities and cracks as a gelatinous form of silica that loses some of its water content upon hardening. Opal occurs in igneous, metamorphic, and sedimentary rocks, and its formation often is associated with volcanic activity. The mineral is moderately hard, transparent to opaque, and is white, or one of a number of colors. Precious opal has an internal play of delicate colors; common opal may be colored but it does not exhibit these internal reflections. Opal frequently is a replacement material in fossilized wood. An opalized wood field along the Colorado River valley extends from western Colorado into eastern Utah (No. 42) (Sinkankas, 1959, p. 116). Opal also has been reported from several metal mines in the State.

Quartz, an oxide of silicon, is the most common of minerals and occurs in nearly every rock type. It is hard, may be transparent, translucent, or opaque, and commonly is colorless or white, although it may be any color when impure. Quartz can be separated into two categories: *phenocrystalline* or *vitreous* varieties and *cryptocrystalline* varieties. Phenocrystalline quartz has a luster similar to broken glass, and individual crystals can be distinguished with the unaided eye; selected material is faceted as gems. Cryptocrystalline quartz is massive and the indistinct crystalline structure can be seen only with a microscope; several varieties are used for ornamental purposes or cut as cabochons.

Two phenocrystalline varieties have been produced in Utah, *amethyst* and *smoky quartz*. Amethyst crystals are colored violet or purple, probably by the presence of manganese. Small quantities of amethyst have been produced in the Dugway area, northwestern Utah (Ball, 1948, p. 548), in the La Sal Mountains, southeastern Utah (No. 46), and in the San Rafael swell, Emery County (Ball, 1943, p. 1520). Smoky quartz crystals are shades of yellow, brown, or nearly black. Pockets of lustrous dark smoky quartz crystals are present in pegmatites of the Mineral Mountains (No. 22), eastern Beaver County. Gem-grade material from this area has been satisfactorily faceted (Sinkankas, 1959, p. 377).

Cryptocrystalline varieties that have been produced in Utah include several forms of *chalcedony*, *jasper* and *silicified wood* and *bone*. Chalcedony lines or fills rock cavities. It was deposited from aqueous solutions and may contain some opal. Common chalcedony has a waxy luster, is transparent or translucent, and is dull gray, blue, brown, or white, and often is botryoidal or mammillary in shape. *Agate*, or variegated chalcedony, is the more colorful and more sought variety, due to various coloring inclusions. It is a common constituent of many gravel deposits. The contrasting colors of agate may be banded, irregularly clouded, or distributed throughout the mass. Distinctive agate patterns are referred to by popular names: visible impurities, generally manganese oxide, form the moss-like patterns in *moss agate;* distinct angular bands are characteristic of *fortification agate;* and impurities which take on feathery shapes are typical of *plume agate*. *Jasper*, a variety of impure opaque cryptocrystalline quartz is red, and less commonly yellow, blue, or green. The coloring material typically is iron. *Petrified wood* is a term loosely applied to wood that has been replaced by mineral matter, commonly some form of silica. Wood that has been mineralized by a variety of quartz, such as agate or jasper, properly should be termed *silicified wood*. It is generally used for ornamental objects, such as bookends, table tops, and rarely as a unique building stone. Petrified wood contributes substantially to the gem industry of Utah. Most of it occurs in Triassic Petrified Forest and Shinarump Members of the Chinle Formation. *Dinosaur bone*, likewise, is often replaced by varieties of quartz. Agatized bone has been cut as cabochons and used for ornamental objects. Most dinosaur bone occurs in the Jurassic Brushy Basin Member of the Morrison Formation.

Varieties of cryptocrystalline quartz occur together in many places. For this reason, they will be discussed by deposit, rather than by cryptocrystalline variety.

Juab County: agate and jasper are present on the north slope of the Drum Mountains (No. 16) (Sinkankas, 1959, p. 376); moss agate, plume agate, and jasper are reported from near Jericho (No. 17) (Ball, 1948, p. 547; Sinkankas, 1959, p. 376); fine fortification agate occurs in seams and veins in low hills about 13 miles south of Levan (No. 18) (Sinkankas, 1959, p. 376). Beaver County: black agate with blue bands has been found in Blue Valley, south of Beaver (No. 23) (Sinkankas, 1959, pp. 376–377). Iron County: excellent red and yellow moss agate is present in the area surrounding Cedar Breaks National Monument (No. 30); chalcedony geodes, up to 2 feet in diameter, occur in the vicinity of Newcastle (No. 24) (Sinkankas, 1959, p. 377). Washington County: agate and petrified wood are present northwest of Castle Cliff Station in the upper reaches of Beaver Dam Wash (No. 25) (Sinkankas, 1959, p. 510); common gray chalcedony occurs as vein fillings and geodes in basaltic rocks near the town of Central (No. 26), and over 500 pounds of material was produced from one basalt cavity (Sinkankas, 1959, p. 377). Kane County: petrified wood has been reported in the vicinity of Kanab (No. 28); agate and petrified wood are present near Orderville (No. 29) (Hartwell and Waters, 1958, table 2). Garfield County: agate, agatized wood, and dinosaur bone are reported from the vicinity of Escalante (No. 33) (Thomson and others, 1956, table 1); petrified logs, some measuring from 10 to 12 feet in diameter, are abundant in the Circle Cliffs area (No. 34). Reportedly this is one of the finest petrified forests in the country (Sinkankas, 1959, p. 377). Wayne County: agate, jasper, dinosaur bone, and petrified wood are present in the vicinity of Torrey (No. 35) (Thomson and others, 1956, table 1); petrified wood and small but fine agate pebbles are scattered over several square miles west of Hanksville (No. 37) (Sinkankas, 1959, p. 376). Emery County: agate has been collected from the Castle Dale area (No. 39) (Hartwell and Waters, 1958, table 2); chalcedony, agate, jasper, silicified wood, and dinosaur bone are present in the Jurassic Morrison Formation about 5 miles south of Woodside (No. 40), and in the San Rafael Swell (No. 38) 30 miles southwest of Green River (Sinkankas, 1959, p. 376). Grand County: jasper, agate, and dinosaur bone are reported from the vicinity of Thompson (No. 41) (Hartwell and Blankenbaker, 1958, table 2); agate, chalcedony, petrified wood, and silicified dinosaur bone occur 5 miles north of Moab (No. 45) (Sinkankas, 1959, p. 376); jasper, petrified logs up to a foot in diameter, agatized clams almost 5 inches long, and silicified dinosaur bone are present in the hills along the Colorado River near Cisco (No. 43) (Sinkankas, 1959, p. 376); extensive beds of red, pink, and flesh- and salmon-colored agate are 7 miles south of Cisco (No. 44) (Kunz, 1893, p. 774).

Rhyolite is a fine-grained volcanic rock primarily composed of orthoclase feldspar and quartz. When porous rhyolites absorb water that contains oxides of manganese and iron, recurrent waves of infiltration produce colorful banded patterns in shades of cream, brown, red, and yellow. The bands, which are seen when the rock is broken open, parallel the exterior planes of the rhyolite blocks and are curved toward the interior. The rock is called *banded rhyolite*, or more popularly, "wonderstone." It is used for making coarse ornaments, such as bookends, and less commonly for making cabochons. Boulders of good quality "wonderstone" are present in the upper reaches of Beaver Dam Wash (No. 25) northwest of Castle Cliff Station, western Washington County (Sinkankas, 1959, p. 509–510).

Scheelite, calcium tungstate, is a valuable ore mineral of tungsten

26-803 O-69—13

that occurs in pegmatites, contact metamorphic deposits, and in veins. Transparent scheelite can be cut into moderately hard, brilliant gems that resemble diamonds. Deposits of the mineral have been mined in the Mineral Mountains (No. 22), eastern Beaver County. Rich orange-brown scheelite crystals with clear tips are present in the area and Sinkankas (1959, p. 460) reports that he cut an 8-carat stone from gem-quality material.

Topaz, an aluminum fluosilicate, occurs as crystals that are very hard, transparent, and occur in a wide range of color. Numerous topaz crystals are present at Topaz Mountain amphitheater (No. 15), a favorite collecting locality since 1884. The mineral occurs with quartz, fluorite, garnet, and beryl in lithophysal cavities of Tertiary Topaz Mountain Rhyolite of Erickson, (1963) the uppermost volcanic unit in the Thomas Range (Erickson, 1963, pp. 30–32). Well-developed crystals weather out of the rhyolite and are scattered over the ground and concentrated in washes. They are clear and colorless and, in places, sherry-brown before exposure to the sun. Most specimens are a fraction of an inch in length and flawless cut stones seldom weigh more than several carats. In the northeastern part of the Thomas Range (No. 12) topaz is found in a rhyolite similar to that at the Topaz Mountain amphitheater. Gray opaque crystals from this locality measure as much as 2 inches in length and clear specimens measure as much as 1 inch (Sinkankas, 1959, pp. 102–103; Patton, 1908, pp. 177–192). Topaz, associated with garnet and beryl, also is present in Tertiary rhyolite flows on the west side of Spor Mountain (No. 13) in the Thomas Range (Staatz and Griffitts, 1961, p. 943).

Variscite, a hydrated aluminum phosphate, is deposited in breccias or cavities where phosphatic meteoric water reacts with aluminous rocks at or near the surface. It occurs as crusts, rounded nodules, veinlets, and fine-grained masses. Since its discovery in America it has, at one time or another, been called amatrice, utahlite, lucinite, and chlor-utahlite. Variscite is a soft, translucent to opaque, green to colorless, mineral that generally occurs with white phosphatic material, chert, and chalcedony in a dark to light green matrix stone of intricate and varying patterns. Although variscite resembles turquoise and is used similarly in jewelry, it is softer and does not wear as well. Significant quantities of variscite have been mined in Utah and during the peak yield in 1909 and 1910, Utah and Nevada together produced about 12,500 pounds of variscite worth $62,000 (Sterrett, 1912, p. 1077). At the Utahlite mine (No. 8) west of Fairfield, Utah County, variscite and associated rare phosphate minerals were discovered in 1894, in nodules and concretions in brecciated zones in a black limestone (Sinkankas, 1959, p. 231–232). At the Amatrice mine (No. 6), eastern Tooele County, fissured and brecciated zones in limestone and quartzite contain variscite (Sinkankas, 1959, p. 233–234). The Lucin deposit (No. 2) in western Box Elder County was first opened for gold, but has produced variscite since 1909. Balls, nodules, veins, and seams of variscite and associated phosphates occur in sheared and brecciated zones in a Carboniferous quartzite. Small cavities contain perfectly formed crystals of variscite which, although too small to be used as gems, are valued for their uniqueness (Sinkankas, 1959, pp. 232–233). Two other variscite deposits have been reported in Box Elder County, one near Promontory (No. 3) (Ball, 1941, p. 1401) and the other near Snowville (No. 1) (Foshag and others, 1954, p. 605).

Gem materials, such as barite nodules, tourmaline, and willemite, have been reported in the State, but information about specific deposits is incomplete.

Resource figures for Utah gem materials are not available. There is no indication that deposits of those materials currently in demand will soon be exhausted. Agate is abundant throughout much of southeastern Utah—in Emery, Garfield, Grand, Kane, and Wayne Counties. Petrified wood, jasper, and chalcedony also are plentiful. The pyrope garnet field yields a high percentage of rough garnets but a low percentage of flawless material. Rough garnets, which are not present in large enough quantities to merit production for use as abrasives, are best marketed in novelty pieces, rough ring settings, and small ornaments (Kiersch, 1955, p. 94). Topaz, obsidian, "onyx," and variscite continue to be supplied from a number of deposits, several of them only recently discovered. If demand were renewed, jet would be available. The possibility of new gem discoveries in unexploited areas of Utah is excellent.

GYPSUM AND ANHYDRITE

(By C. F. Withington, Washington, D.C.)

Gypsum and anhydrite are formed by precipitation of calcium sulfate from natural saline water. They occur in considerable quantities in many parts of the United States, and resources of both minerals are great, though many deposits are too far from consuming centers to be worked profitably. Gypsum is the more useful of the two minerals; about 9.5 million tons were produced in the United States in 1961. Comparable figures are not available for anhydrite production, but probably no more than 200,000 tons were produced in 1961.

Most gypsum mined in the United States is calcined for plaster, which is used primarily in the manufacture of wallboard, lath and other prefabricated gypsum products. Uncalcined or raw gypsum is used in portland cement as a setting retarder, and as an agricultural mineral. Gypsite is used extensively as a soil conditioner. Anhydrite is used in the United States as an agricultural mineral and to a lesser extent as a retarder for portland cement. In Europe anhydrite is used in making sulfuric acid and ammonium sulfate.

Gypsum, hydrous calcium sulfate ($CaSO_4.2H_2O$), is one of the softest minerals, and can be easily scratched with the fingernail. Pure gypsum is generally white or light to dark gray; impurities may color it pink, black, green, or yellow.

Anhydrite, calcium sulfate ($CaSO_4$), occurs as fine- to coarse-grained masses or as lenses or beds within gypsum deposits. Calcium sulfate was originally deposited as anhydrite, but hydration by surface and ground waters has altered it to gypsum. In semiarid climate such as that found in Utah, hydration has seldom progressed more than 30 feet below the surface, and in many places, anhydrite may be found mixed with gypsum on the outcrop.

The most common form of gypsum is massive rock gypsum, a compact aggregate of small crystals. Alabaster is a compact, very fine-grained gypsum. Other varieties include satin spar and selenite, neither of which are abundant nor economically important. The presence of selenite in gypsum deposits is detrimental for most uses as the selenite crystals cannot be ground fine enough to be used for plaster.

Gypsite is earthy secondary gypsum mixed with silt, sand, and clay. Gypsum sands are made up of crystals that have been transported by wind and deposited in dunes of remarkable purity.

Utah has an abundant supply of gypsum, but few deposits have been developed. Since 1882, an estimated 4.1 million tons with a value of about $11.8 million has been produced. The first deposits to be exploited were along Salt Creek near Nephi, Juab County (Stone and others, 1920, p. 261), and were worked almost continuously from 1882 until the early 1940's for plaster and for portland cement retarder. Small production also has been reported from a deposit east of Levan, Juab County. A deposit of gypsum dune sand was worked briefly in the 1940's for portland cement retarder. Present production is from two deposits in Sevier County that are being worked by open-pit methods.

The resources of gypsum in Utah are among the largest in the United States. Beds within 30 feet of the surface and at least 4 feet thick contain an estimated 2 billion tons of material that averages more than 85 percent gypsum. Most of these resources are in the southern and eastern parts of the State. The reserves of gypsum for any given deposit depend on the depth at which anhydrite is present, for even a few percent of anhydrite mixed with gypsum will render the deposit useless for plaster.

Gypsum-bearing rocks are widely distributed in the State and are found in several stratigraphic units, as shown in table 13. The distribution of these potential resources is described below by geographic regions.

TABLE 13.—*Distribution of stratigraphic units that contain gypsum beds in Utah*

Geologic period	Geographic regions and counties ( )				
	Southeastern (Grand and San Juan)	East-central (Emery and Wayne)	Central (Juab, Sanpete, and Sevier)	Southwestern (Iron, Kane, and Washington)	Northeastern (Duchesne and Uintah)
Jurassic		Summerville formation. Carmel formation.	Arapien shale.	Curtis formation. Carmel formation.	Carmel formation.
Triassic	Moenkopi formation.			Moenkopi formation.	Thaynes formation.
Permian				Kaibab formation.	
Pennsylvanian.	Paradox member of Hermosa formation.				

DISTRIBUTION OF GYPSUM AND ANHYDRITE

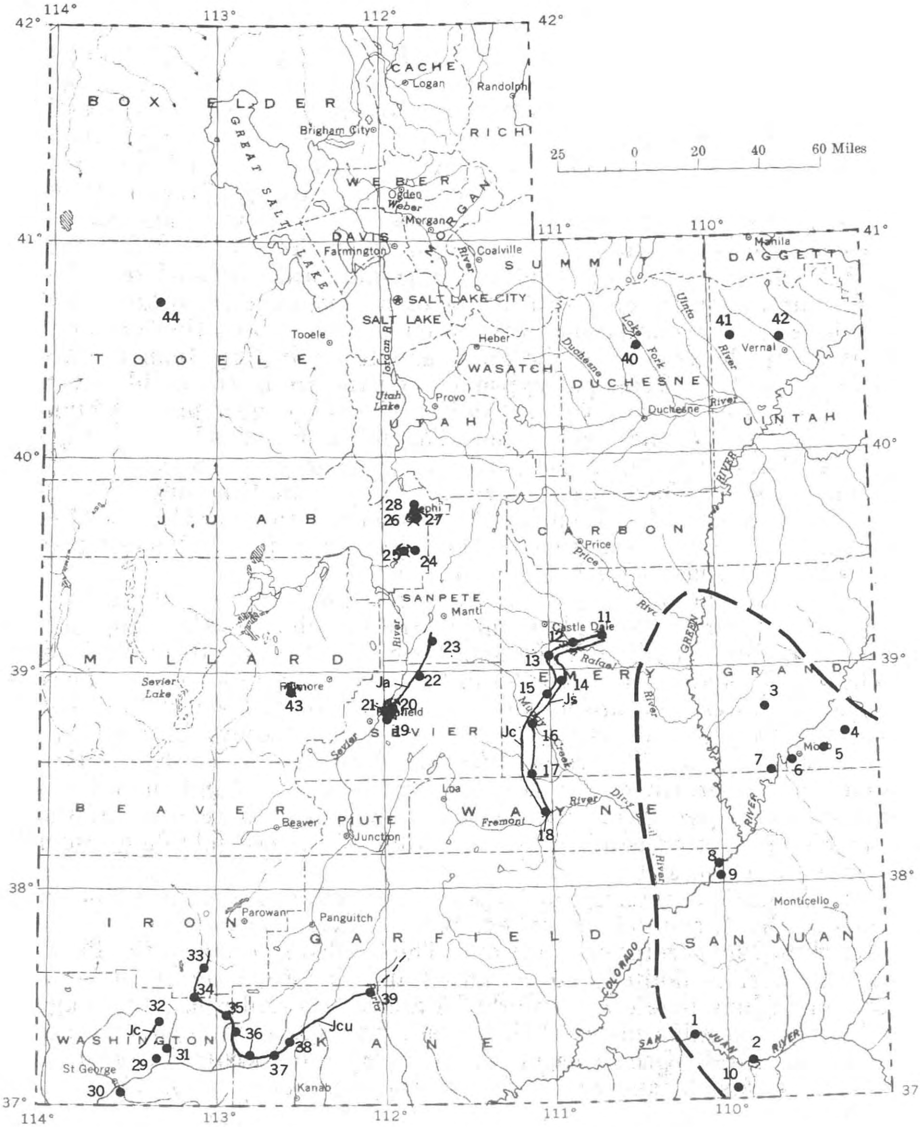
In southern Utah the gypsum and anhydrite-bearing Paradox Member of the Hermosa Formation of Pennsylvanian age underlies most of the Paradox basin, which was an elongate, northwest-trending basin of deposition for saline minerals during Pennsylvanian time. The basin deposits now underlie most of Grand and San Juan Counties, parts of the adjacent counties (see fig. 37), and extend into northeastern Arizona, northwestern New Mexico, and southwestern Colorado. In the Paradox Member three units (Wengerd and Matheny, 1958, pp. 2065–2075) contain calcium sulfate. The upper unit contains only thin lenses of no economic importance and the basal unit contains some thin calcium sulfate beds that crop out only along the canyon of the San Juan River in San Juan County (No. 1, fig. 37). Principal gypsum resources are in the middle unit, which consists chiefly of salt (sodium chloride) with some calcium sulfate, dolomite, and black shale. The unit crops out along the edge of the Paradox basin in southern Grand County and northern San Juan County. Thick beds of gypsum of the middle unit also are exposed along the San Juan River in southern San Juan County (No. 2, fig. 37), where Wengerd and Matheny (1958, p. 2061) show that gypsum is in beds as much as 40 feet thick.

In the salt anticline region of southern Grand County and northern San Juan County, the middle unit of the Paradox Member crops out along the bottoms of Salt, Onion Creek, Castle, and Moab Valleys. These valleys are as much as 25 miles long and 2 miles wide. They trend northwest and are underlain by elongate piercement-type salt masses that formed when the salt in the Paradox Member was squeezed upward. The valleys developed as a result of the solution and removal of salt due to near-surface weathering, and the accompanying collapse of adjacent rock strata. Solution removal of the salt also permitted residual accumulation of the less soluble gypsum impurities in the salt.

A tremendous tonnage of gypsum and anhydrite is available in each of the salt anticlinal valleys but the exact amount can only be determined by careful exploration. The bedded gypsum of the Paradox Member is faulted and fractured and so intimately mixed with shale and limestone that it might be difficult to find a large tonnage of easily accessible material that would average 85 percent or more gypsum. Most of the area in which the gypsum occurs, however, is readily accessible, and exploration of the deposits would not be difficult.

In Salt Valley (No. 3) the gypsum is light to medium gray, laminated to massive, and interbedded with dark gray siltstone (Elston and Shoemaker, 1960, p. 52). The surface of the gypsum has been weathered to gypsite. A mantle of buff gypsite blankets the original exposures and covers much of the floor of the valley, so that more gypsum appears to be present than is the case. Dane (1935, p. 31) reported that some of the gypsum is dark blue, suggesting the presence of some anhydrite in the outcrop.

Onion Creek and Fisher Valley probably have the best exposed but least accessible gypsum in the middle unit of the Paradox. Gypsum as much as 70 feet thick is exposed along Onion Creek (No. 4). The gypsum in both valleys is white to light gray, but badly faulted and fractured and mixed with black shale.



EXPLANATION

Approximate trace of gypsum- and anhydrite-bearing stratigraphic units; formations identified by initials: Upper Jurassic Summerville (Js), and Arapien (Ja); Upper and Middle Jurassic Carmel (Jc) and Curtis (Jcu).

Approximate outline of basin of sedimentation containing extensive gypsiferous and associated saline units of the Paradox Member of the Pennsylvanian Hermosa Formation.

●6 Gypsum locality described in text

Gypsum mine or quarry

FIGURE 37.—Gypsum and anhydrite in Utah.

Some gypsum crops out in the southeastern end of Castle Valley, Grand County (No. 5), as an almost circular mass that surrounds a plug of igneous rocks. At least a 30-foot thickness of contorted, faulted, and fractured gypsum is exposed. This material is mixed with black shale and thin beds of limestone. Additional prospecting along the floor of the valley would probably reveal additional gypsum.

In Moab Valley, west of Moab, gypsum is exposed in a mound that rises about 50 feet above the valley floor (No. 6). The gypsum is faulted and fractured and mixed with black shale, sandstone, and thin limestone beds. Additional gypsum deposits probably are present under the thick mantle of alluvium.

The Cane Creek anticline west of Moab Valley has not undergone as extensive deformation as the other salt anticlines and the calcium sulfate is not exposed at the surface. Anhydrite, however, has been reported directly overlying the salt in holes drilled by Texas Gulf Sulfur Co. in development of a potash deposit (No. 7) (Fogarty and Tippie, 1961, p. 54).

Gypsum in the middle unit of the Paradox is exposed in two places in the canyon of the Colorado River in San Juan County near Gypsum Creek (No. 8) (Baker, 1946, p. 23). The extent of this nearly inaccessible gypsum is unknown.

In San Juan County, gypsum in the Moenkopi Formation of Triassic age has been reported by Anthony and others (1955) from two areas (Nos. 9 and 10). The gypsum is in thin lenticular beds that crop out in the middle of cliffs, and as such are not of economic importance.

In east-central Utah gypsum beds in the Carmel and Summerville Formations, both of Jurassic age, can be traced for about 50 miles along the west flank of the San Rafael Swell, an elongate north-trending dome about 70 miles long and 30 miles wide. The Carmel ranges in thickness from 320 to 650 feet, and consists of beds of green shale and sandstone, gray limestone and white gypsum. Gypsum beds are found only in the upper part of the formation and range from less than 1 to more than 30 feet in thickness.

The Summerville Formation is about 1,000 feet above the Carmel and consists of thin uniform beds of sandstone and siltstone, and a fairly persistent uppermost bed of white to reddish or greenish gypsum as much as 10 feet thick. This bed almost has an alabaster texture.

Outcrops of gypsum along the west side of the swell have been described by Lupton (1913) and some of those on the north edge of the swell by Gilluly (1929). Seven beds of gypsum ranging from 1½ to 17 feet in thickness are present on the south side of Cedar Mountain, Emery County (No. 11) (Gilluly, p. 101). Much of this gypsum is impure, but a few beds are reported to be clean and hard. Along the San Rafael River at Fullers Bottom, Emery County (No. 12), Lupton (p. 225) reports two gypsum beds, the upper one 30 to 35 feet thick and fairly pure; the lower one, 10 feet below the base of the upper one, is 7 feet thick, and is reported as "very pure." Some 10 miles southeast of Ferron (No. 13) a single bed of relatively pure gypsum 11 feet thick outcrops in Horn Silver Gulch (Lupton, p. 226).

In Cold Wash, 20 miles east of Emery, the Carmel Formation (No. 14) has more than 35 feet of gypsum exposed near the top of the formation. About 8 miles southeast of Emery in Colt Gulch (No. 15), the gypsum is in three beds one of which contains 10 feet of almost pure white gypsum (Lupton, p. 228).

A gypsum and shale sequence about 50 feet thick is exposed on Muddy Creek, Wayne County (No. 16) (Lupton, pp. 228–229); gypsum of unknown extent has been reported at Last Chance Gulch (No. 17); a bed of gypsum in the Summerville Formation about 8 feet thick is present in the wall of a canyon northwest of Caineville (No. 18).

The gypsum in the northern part of the swell is readily accessible to rail and highway transportation by about 10 miles of unimproved road extending west from U.S. Highway 6–50 and the railroad. Most of the exposures on the west side of the swell are accessible by unimproved roads that extend east from State Highway 10. In both the Carmel and Summerville Formations, the resources are estimated to be about 50 million tons. Much of this material probably will not be in demand for many years, however, for the distance from consuming centers and transportation would prevent the use of this material for anything except as soil conditioner.

In central Utah, gypsum in the middle part of the Arapien shale of Jurassic age crops out on the eastern side of the north- to northeast-trending Sevier Valley in Sevier, Sanpete, and Juab Counties. The Arapien is divided into five units (Hardy 1952, p. 15), the middle unit of which contains one or more beds of gypsum interbedded with bluish-gray, calcareous shale, thin limestone beds, and thin-bedded calcareous sandstone. Lenticular masses of gypsum can be traced laterally from a few hundred feet to a few miles.

Although the Arapien is exposed along much of the length of Sevier Valley, gypsum is found in only a few isolated spots. The most southerly and also the best exposures are east of Sigurd in Sevier County. In this vicinity the Arapien is complexly faulted and folded in a series of *en echelon* folds that trend north-northeast. Only one of the several gypsum beds is thick enough to be considered economic. This bed is as much as 100 feet thick, but averages about 25 feet in thickness. Two miles south of Sigurd (No. 19), the gypsum in this bed consists of badly weathered masses of selenite crystals. The crystals are as much as 6 inches in diameter and so intergrown that they appear to be a solid mass. The gypsum mined by the Bestwall Co. (No. 20) and U.S. Gypsum Co. (No. 21 at Sigurd is white, massive, and fine grained, interbedded with thin, calcareous shale. Thick sections of gypsum occur in the axes of the folds. Below the top foot or so the gypsum averages 90 to 96 percent pure. Near the contact between gypsum and anhydrite, 30 to 40 feet below the surface, the gypsum reaches a purity of 99 percent.

A short distance north of the mining area nine beds of gypsum are present in a 740-foot-thick section of light blue, gray, buff, and red calcareous shales and sandstones. The gypsum beds range up to 15 feet in thickness and average less than 3 feet. North of Sigurd and 3 miles east of Salina, Sevier County, a gypsum bed which dips steeply eastward can be traced for 3 miles (No. 22) (Stone and others, 1920, p. 267).

East of Gunnison, Sanpete County, gypsum crops out along the south side of Twelve Mile Creek (No. 23). Four beds of gypsum that range from less than a foot to as much as 7½ feet in thickness are interbedded with gray, calcareous shale (Hardy, 1952, pp. 88–89).

About 5 miles east of Levan on Chicken Creek (No. 24), Hardy (1952, p. 95) reports a gypsum bed as much as 15 feet thick. The gypsum is massive, white, and mottled with grayish shale and is traceable for 4 miles (Stone and others, 1920, p. 267).

Several other occurrences of gypsum have been reported along Chicken Creek (Stone and others, 1920, pp. 265–266). The largest deposit, about a mile and a half east of Levan at the mouth of Chicken Creek, (No. 25) is a lenslike mass at least 200 feet thick, exposed along the steep valley wall for about 200 feet. The extraordinary thickness of the gypsum is probably due to plastic flowage into the crest of a fold. The gypsum is white and mottled with light brown seams of shale. Other similar bodies of gypsum have been reported further east in the canyon of Chicken Creek (Stone and others, 1920, p. 267). Although these deposits apparently have been prospected by adits, there is no recorded production.

The Arapien is poorly exposed between Levan and Nephi. An extensive lens of gypsum has been worked by open-pit methods (No. 26) about a mile and a half east of Nephi on the south side of Salt Creek. The gypsum deposit, a lens truncated abruptly on all sides, consists of a distorted mass of coarsely crystalline gypsum, mottled with brown shale. It is 250 to 300 feet thick and extends up the wall of the canyon 400 feet. The beds are at the crest of a fold and are nearly vertical. A similar lens of gypsum occurs about 2 miles north (No. 27). Several other small lenses of gypsum have been reported in the vicinity of Salt Creek (Eardley, 1933, p. 333). Only one appears to contain enough gypsum to be of economic interest. This lens (No. 28), which is similar to those that have been mined, is about 4 miles northeast of Nephi, the nearest railroad terminal.

In southwestern Utah, four formations, the Kaibab Formation of Permian age, the Moenkopi of Triassic age, and the Carmel and Curtis both of Jurassic age, contain gypsum in southwestern Utah.

The Kaibab Formation consists of white to yellowish, massive somewhat dolomitic limestones, in part cherty, and locally gypsiferous (Gregory, 1950a, pp. 52–53). The gypsum is white, pink, and gray, and in the southern part of Washington County occurs as both thick and thin beds and lenses; as nodules in limestone; as cement for sandstone grains; and as coatings on fissures. Reeside and Bassler (1922, pp. 69–77) show that the distribution of gypsum in the Kaibab is spotty. About 50 feet of white gypsum is present near Virgin Canyon, one-half mile south of La Verkin, Washington County (No. 29). A 4-foot-thick bed of white gypsum and numerous beds of pink gypsum are exposed in the Kaibab a few miles south of St. George (No. 30), near the Utah-Arizona line. On the eastern edge of the Pine Valley Mountains, northeast of Toquerville (No. 31), as much as 150 feet of gypsum and anhydrite are present in the Kaibab (Cook, 1957, p. 31). The area probably does not have a great tonnage of gypsum because of the near-surface presence of anhydrite.

Gypsum occurs in thin beds throughout much of the Moenkopi formation, but none of these beds are very extensive. The most gypsiferous part of the formation is in the Shnabkaib Member, where massive, fine-grained gypsum occurs as beds and lenses as much as 4 feet thick (Gregory, 1950a, p. 114).

Gypsum has also been reported in the Carmel Formation of Jurassic age. On the east flank of Pine Valley Mountains (No. 32) approximately 225 feet of gypsum and gypsiferous shales are present at the base of the formation. The gypsum is in at least two beds; an upper one about 20 feet thick and a lower one about 10 feet thick, separated by about 50 feet of shale and limestone.

By far the most extensive gypsum deposits are in the Curtis formation of Jurassic age. The Curtis crops out discontinuously from Cedar City, Iron County, southward into Washington County, and eastward into Kane County. A basal gypsum bed in the Curtis ranges in thickness from less than 6 feet to as much as 101 feet in the crest of anticlines. An exposure in Cedar Canyon (No. 33) mentioned by Thomas and Taylor (1946, p. 25) showed 101 feet of massive resistant white alabaster apparently in one bed. About 4 miles east of Kanarraville (No. 34), Gregory (1950b, p. 84) reported about 92 feet of gypsum mixed with clay.

In the northeast corner of Washington County (No. 35), the gypsum in the Curtis has thinned to about 6 feet, is white to gray and contains lenses of red silt (Gregory, 1950b, p. 89). Southward in Washington County, the gypsum thickens to 15 feet. In an exposure 11 miles west of Orderville and also further eastward in Kane County (No. 36) the gypsum is in a 30-foot thick bed (Gregory, 1950a, p. 125). About 3 miles southwest of Orderville, Kane County (No. 37), Gregory (1950a, p. 126) reported three beds of gypsum, ranging from 3 to 16 feet in thickness and separated by sandstone and shale.

The gypsum in the Curtis thickens eastward, and 3 miles east of Glendale (No. 38), Gregory (1950a, p. 126) reported a 28-foot-thick bed of white, massive gypsum—part of it a waxlike alabaster.

Eastward from Glendale, the area of the outcrop of the Curtis becomes relatively inaccessible. According to Gregory (1951, p. 29), the gypsum is a persistent stratigraphic marker that ranges in thickness from 3 to 16 feet. Near Cannonville (No. 39), on the border of Kane and Garfield Counties, two thin beds of gypsum, both impure, are present (Gregory 1951, pp. 57–58). Eastward the Curtis becomes less gypsiferous, and in the eastern parts of Kane and Garfield Counties gypsum is absent (Gregory and Moore, 1931, p. 22).

In northeastern Utah, thin beds of gypsum have been reported in both the Thaynes Formation of Triassic age and the Carmel Formation of Jurassic age. The gypsum in the Thaynes is restricted to thin veins of satin spar and beds of gypsum. Gypsum beds in the Thaynes exposed at the surface are only a few feet thick along Lake Fork Creek (No. 40), but beds as much as 10 feet thick are found in the subsurface (Huddle, Mapel, and McCann, 1951).

Kinney (1955, p. 78) reports four thin, impure beds of gypsum, generally white, light pink, or light green, and none more than 2 feet thick, in the Carmel Formation along Whiterocks River (No. 41) and a single bed, 2 to 4 feet thick, along Steinaker Draw east of Leota (No. 42).

OTHER OCCURRENCES

Gypsite and gypsum sand are found in several places in Utah. Small and impure deposits of gypsite are adjacent to nearly all outcrops of gypsum but are not exploitable. In Millard and Tooele Counties, however, gypsum sand and gypsite occur either singly or together to form deposits of economic interest.

In Millard County, about 8 miles west of Fillmore, gypsite extends over several square miles (No. 43) (Dennis, Maxey, and Thomas, 1946, pl. 1). The gypsite is in beds of greenish-gray gypsiferous clay, with beds of granular gypsum as much as 7 feet thick in the upper part. The maximum thickness of the gypsite is 20 feet. It was formed by the evaporation of calcium sulfate-bearing waters. Gypsum sand, formed by the winnowing of crystals of gypsum from the gypsite, has collected in dunes as much as 10 feet thick. Stone and others (1920, p. 269) estimated the dunes contained as much as 450,000 tons of pure gypsum. This material was mined briefly during the 1940's for use as a portland cement retarder. Although many millions of tons of gypsite are present, the low-grade gypsiferous clay presently is useful only locally and as a soil conditioner.

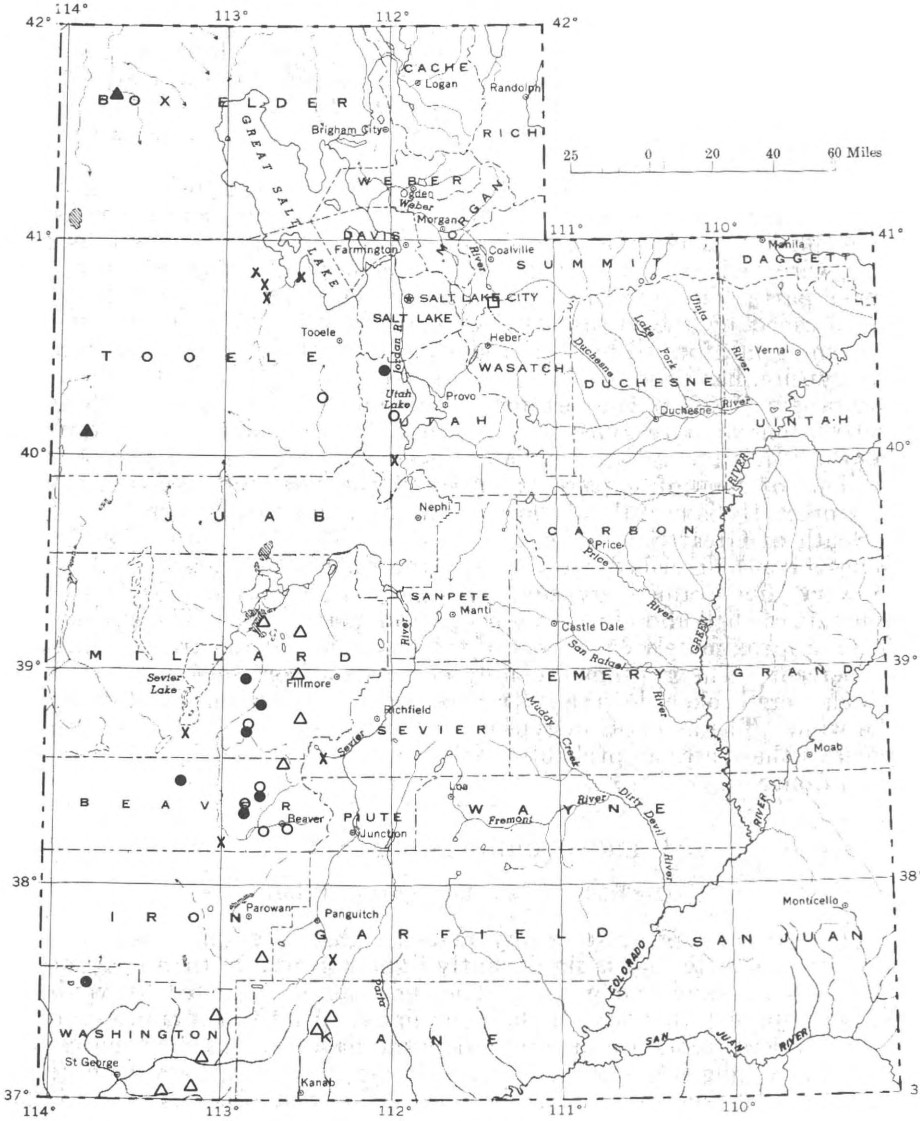
South of Great Salt Lake, near Knolls (No. 44), Tooele County, Jones (1953) described a series of large dunes that consist of fine- to very fine-grained gypsum crystals, calcareous oolites, lesser amounts of shell and algae fragments, and quartz sand. The gypsum forms approximately 65 percent of the sand, and the calcareous oolite, 30 percent. The gypsum probably originated from selenite crystals which were broken down and transported to the present location by the wind. The amount of gypsum is not known, but because of impurities the material probably could be used only locally as a soil conditioner.

LIGHTWEIGHT AGGREGATE

(By Richard Van Horn, Denver, Colo.)

Lightweight aggregate is any material that is suitable for producing a concrete that is significantly lighter in weight than concrete made with a sand and gravel. The lightness is imparted by voids (empty spaces) that are in the aggregates. In Utah, pumice, volcanic cinders (scoria) and perlite deposits have been used as sources for lightweight aggregate. Other possible sources include deposits of pumicite (volcanic ash), obsidian and other siliceous volcanic glass, vermiculite, diatomaceous earth (diatomite), clay, shale, and byproducts from industrial processes, such as slag. Diatomite, pumice, and volcanic cinders may contain sufficient voids in their natural state and only have to be crushed and sieved to be used as a lightweight aggregate. Voids are imparted to the other materials by heating them, using one of several manufacturing procedures. Distribution of deposits and reported sources of these materials are shown on figure 38.

Large-scale commercial production of pumice and volcanic cinders in Utah started in 1947, although small amounts had been produced earlier. From 1947 through 1961, some 328,000 short tons of pumice, pumicite, and volcanic cinders were produced with a value of $985,-000. The 1961 production of 60,000 short tons value at $95,000 was



□ Bloating shale

X Diatomaceous earth

○ Pumice and pumicite

● Perlite and other silicious volcanic glass

△ Scoria (volcanic cinder)

▲ Vermiculite

FIGURE 38.—Lightweight aggregate in Utah.

used entirely for lightweight aggregates in concrete. Perlite production was first reported in Utah in 1948, but annual production figures have been revealed only for 1951 and 1962; in those years, production was 3,000 tons valued at $16,000 and 900 tons valued at $3,000. Of the perlite produced nationally in 1961, 50 percent was used for aggregate in lightweight building plaster, 16 percent for concrete aggregate, 21 percent for filter aids, and 13 percent for insulation and other miscellaneous uses.

The principal sources of lightweight aggregate in Utah have been the pumice and cinder deposits in Millard, Beaver, and Utah Counties, and the perlite deposits in Beaver and Millard Counties (Nackowski and Levy, 1959; Buranek and Needham, 1949). Additional deposits of pumice, pumicite, perlite, and other siliceous volcanic glasses are probably present in the siliceous volcanic rocks in the southwestern part of the State. Volcanic cinder deposits west of Fillmore (Gilbert, 1890) and others south of Parowan (Gregory, 1950a, 1951) are of basaltic composition. Although the quality of these deposits are mostly unknown, they constitute a large potential source of lightweight aggregate.

Diatomaceous earth is used principally for filtering agent, insulation, adsorbent, and pozzolan. Although only small amounts have been produced in Utah (Wimbler and Crawford, 1933), there are extensive deposits in the sedimentary rocks of the State. Most of these occur in the white marl deposited in Pleistocene Lake Bonneville (Gilbert, 1890; Bissell, 1963, pp. 117, 120, 121; Dorsey Hager, 1963, oral communication) and contain many impurities. The McCornick soil (Wilson, 1959, pp. 38, 39) of eastern Millard County is developed on these diatomaceous deposits. In addition to the ones shown on figure 38, there are probably many other deposits within the confines of the old lake, which is outlined on figure 4. Small deposits of diatomaceous earth not associated with Lake Bonneville have been reported in southwestern Sevier County (Wimbler and Crawford, 1933) and in southwestern Garfield County (Crawford, 1951). Suitability of these deposits for use as lightweight aggregate has not been evaluated.

Two deposits of vermiculite of unknown extent and suitability for use as lightweight aggregate are in the northwestern part of the State (Nolan, 1935, p. 115; Buranek and Needham, 1949). Both deposits are associated with igneous rocks. Vermiculite is used principally as a source for insulation and as a soil conditioner, although minor amounts are used as a source for lightweight aggregate.

Many of the clay deposits discussed in the clay section may be suitable for sources of lightweight aggregate. The use of expanded clays for lightweight aggregate is increasing rapidly, for these materials are widespread and processing costs are competitive with natural lightweight materials. In processing, the clay particles expand and glaze slightly, so that the finished product tends to absorb less water. This results in further desirable properties in fabricated products such as requiring less cement, having lower shrinkage, less finished weight, and lower shipping costs. Shale beds in the North Horn, Colton, and Green River formations have bloating characteristics (Hyatt, 1956, p. 66) and may be possible sources of lightweight aggregate. Part of the Manning Canyon shale also has bloating characteristics according to Anderson.[1] Lightweight aggregate is made by expanding shale, from the Frontier Formation mined near Peoa, Utah, about 30 miles east of Salt Lake City.

The demand for lightweight aggregate for the past 20 years, as reflected by production figures, has been erratic but in general has increased. The demand will probably continue to increase in the future. The use of lightweight aggregate in prestressed and prefabricated concrete structures, a relatively new development, may have broad applications in the construction industry. For example, its use in the building of large structures reduces the load on reinforcing steel, permits easier handling, and lowers transportation costs. The good acoustical and thermal insulating properties also account for the increasing demand for lightweight aggregate. In the future, depletion and unavailability of normal sand and gravel deposits, because of expanding urban growth, will favor further growth in use of lightweight aggregate.

LIMESTONE AND DOLOMITE[2]

(By H. T. Morris, Menlo Park, Calif.)

The natural-occurring carbonates of calcium and magnesium—limestone and dolomite—are among the most abundant and most widely used of all our mineral resources. In some form or other they occur in all parts of the United States and throughout the World, and are produced from countless localities. Their low cost, relative accessibility, and their chemical and physical characteristics make them basic resources for a wide variety of industries including agriculture, manufacturing, construction, and smelting.

In Utah, limestone and dolomite are quarried for use as basic raw materials in the production of cement, lime products, calcium carbide, chemicals, and refractories, and are crushed or pulverized for concrete aggregate, roadstone, fill material, fluxstone, coal mine rock dust, filtration, railroad ballast, riprap, poultry grit, and filler. According to Patterson (1960, p. 463), the calcined limestone products, quicklime and hydrated lime, alone have more than 7,000 essential uses.

The limestone and dolomite produced on a continuing basis in Utah are principally used as fluxstone in smelting and for manufacturing cement. Of 1,621,128 tons of limestone and dolomite produced in the State in 1961, which was valued at $2,815,852, nearly 70 percent was used for these purposes. A large part of the remainder was burned for the production of lime. The value of lime produced in Utah in 1961 is $2,626,000, but the value of cement is not reported to avoid disclosure of individual company confidential data (Howes, 1962, p. 1029).

Limestone, which is largely calcium carbonate or calcite, is chiefly formed in shallow marine waters by organic and inorganic precipitation and the mechanical accumulation of limestone or organic-

---

[1] Anderson, P. L., 1960, Bloating clays, shales and slates for lightweight aggregate, Salt Lake City, and vicinity, Utah; University of Utah unpublished thesis.

[2] Includes lime, cement rock, calcite, and aragonite, excluding dimension stone.

detrital sands. To a lesser extent an impure variety of limestone, termed "marl," which contains calcite, clay, and some carbonaceous matter, is formed in lakes and rivers. Dolomite, consisting of about 55 percent calcium carbonate and 45 percent magnesium carbonate, is formed in the oceans in a manner similar to limestone, but also is commonly derived from the replacement of the calcium carbonate of limestones by magnesium carbonate carried in hydrothermal solutions. Veins of calcite, dolomite, and aragonite, which is a variety of calcium carbonate, are also formed by natural heated solutions, especially hot springs.

Most deposits of limestone and dolomite contain chemical and mechanical impurities. Chemically, all gradations exist between pure limestone and pure dolomite, the intervening rocks being termed "magnesian limestone," "dolomitic limestone," and "limy dolomite." In addition, iron carbonate and manganese carbonate commonly are intimately admixed with the calcium and magnesium carbonates of the principal rocks. The mechanical impurities consist of sand, clay, iron minerals, chert nodules, and shale partings. Thus siliceous, sandy, or cherty limestones and dolomites contain considerable quantities of silica; ferruginous limestones contain iron compounds; and argillaceous limestones and dolomites contain shale or dispersed clay. Manganiferous, pyritic, and other types of limestone and dolomite are less common.

In general usage the term "limestone" denotes a rock consisting of at least 50 percent of the carbonates of calcium and magnesium (Twenhofel, 1932, p. 283); however, to the lime manufacturer, and to most other commercial users, the content of calcium and magnesium carbonate must be at least 80 percent for the rock to be termed a limestone (Pettijohn, 1957, p. 381). Rocks containing more than 95 percent calcium carbonate are termed "high-calcium limestones." They are used chiefly in the manufacture of cement, lime, and chemicals, and should contain less than 2 percent magnesium carbonate and less than 3 percent of alumina, silica, and other insolubles. The high-calcium lime required by the sugar industry to neutralize the free acids in the juice of sugar cane and sugarbeets must also be free from impurities that would impart a taste to the finished product.

Limestones containing 10 percent or less of magnesium carbonate, less than 1.5 percent of silica, and no more than 0.5 percent of sulfur and 0.1 percent of phosphorous are used as flux or "stone" in the smelting and refining of iron and other metals. A silica content as high as 5 percent is sometimes permitted. Dolomitic limestones containing more than 10 percent of magnesium carbonate are unsuited for flux and the manufacture of lime, and are unfit for manufacture of cement, but they are useful for concrete aggregate, roadstone, ballast, riprap, agricultural limestone, and many other purposes.

Dolomite, especially those varieties containing relatively large quantities of iron oxide and only small quantities of calcite, silica, and alumina, is widely used as a refractory lining in place of magnesite, the more expensive nearly pure magnesium carbonate. Iron is commonly added to iron-deficient varieties, often in the form of iron sulfide as the dolomite is calcined. High-purity dolomite is also used in the manufacture of high-magnesium construction limes and rock wool, and in the recovery of magnesium from sea water.

Cement rock is a low-magnesium limestone containing clay and silica in the correct proportions to make Portland cement. Cement is made by crushing and firing the cement rock to incipient fusion. Large tonnages of cement rock are mined in Utah, but elsewhere much cement is made from appropriate mixtures of limestone and clay or shale. High-calcium limestone is also used to "sweeten" cement rocks containing excess silica and alumina.

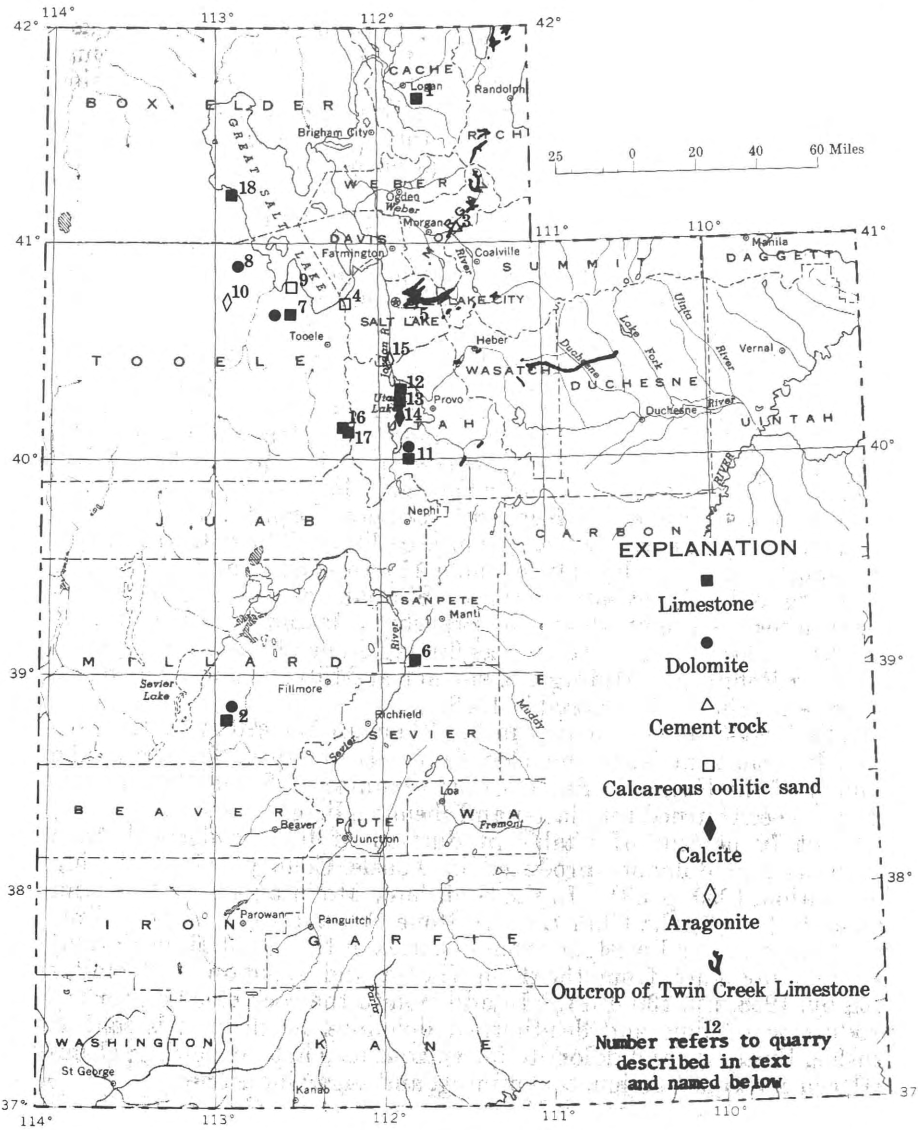
The calcite and aragonite deposits of Utah occur as hydrothermal veins consisting almost entirely of crystalline calcium carbonate. Some of the aragonite is used as building stone (see section on stone, p. 222), but most of the calcite and aragonite is crushed or pulverized for use as poultry grit, fluxing stone, coal mine rock dust, roofing granules, whiting, and aggregate, or is burned for the production of lime.

In Utah, limestone and dolomite are such abundant commodities that the overriding factor in the location of most of the quarries, pits, and mines is the proximity to transportation facilities and markets. In the western and northern parts of the State, which also contain the largest centers of population, carbonate rocks form the principal part of a sequence of sedimentary rocks of Paleozoic age that is from 15,000 to 45,000 feet thick. The greater part of this sequence is limestone, but dolomite is predominant in beds of Middle ages and Late Cambrian, Late Ordovician, Silurian, and Devonian age. Much of this limestone and dolomite contains deleterious quantities of chert, sand, shale, and other impurities, but more than adequate supplies of the special grades of limestone and dolomite are available for all commercial uses. In the east-central and southeastern parts of Utah, limestone is far less abundant, but the requirements of this sparsely populated area are easily met from sources elsewhere.

The principal rock units from which limestone is produced in Utah are the Teutonic, Dagmar, and Herkimer Limestones of Cambrian age, the Deseret and Great Blue Formations, and the equivalent Brazer Formation of Mississippian age, the Flagstaff Limestone of Tertiary age, and limestone oölitic sands which are dunes and near shore sediments in modern Great Salt Lake. Dolomite is produced from the Bluebird and Cole Canyon Dolomites of Cambrian age, the Fish Haven Dolomite of Ordovician age, the Laketown Dolomite of Silurian age, and the Water Canyon Dolomite of Devonian age. All of these formations are widespread throughout northern and western parts of the State (see table 1), and many exposures are adjacent to highways and railroads where the principal quarries have been developed.

The chief source of cement rock in Utah is the Twin Creek Limestone of Jurassic age (fig. 39). This formation consists of silty and argillaceous limestone and shale and thus contains the principal ingredients required for the manufacture of cement. It is exposed chiefly in the Wasatch and adjacent ranges. An equivalent unit, the Carmel Formation, is exposed widely in southern and southeastern Utah, and locally contains potential cement rock in its lower portion.

The principal quarries and mines in Utah that produce, or have produced, limestone, dolomite, cement rock, calcite, and aragonite are shown on figure 39. In Cache County the Amalgamated Sugar Co. quarries the Brazer Limestone in Providence Canyon (fig. 39, loc. 1) for use in sugar refining plants in Utah and Idaho (Williams, 1958,



1. Amalgamated Sugar Co.
2. Cricket Limestone and Dolomite Co.*
3. Ideal Cement Co.
4. Kennecott Copper Corp.
5. Portland Cement Co. of Utah
6. Gunnison Sugar Co.
7. Utah Lime and Stone Co.
8. Utah Marblehead Co.
9. United States Smelting, Refining and Mining Co.
10. Utah Calcium Products Co.
11. Columbia-Geneva Steel Co.
12. Lakeside Lime and Stone Co.
13. Utah Lime and Stone Co.
14. Roger Cedarstrom
15. Evans Lime Co.*
16. United States Smelting, Refining and Mining Co.*
17. American Smelting and Refining Co.*
18. Southern Pacific Co.

*Denotes quarries inactive in 1963

FIGURE 39.—Limestone and dolomite in Utah.

26-803 O-69—14

p. 82). In Millard County the Cricket Limestone & Dolomite Co. has opened a quarry in carbonate rocks of Late Cambrian age in the Cricket Mountains near Black Rock (loc. 2). In July 1958 it was announced that the Columbia-Geneva Division of the United States Steel Corp. would mine about 70,000 tons of fluxing stone annually from this deposit (Utah Mining Association, 1959, p. 60), but the quarry was inactive in 1963.

In Morgan County cement rock is produced by the Ideal Cement Co. from two quarries in the Twin Creek Limestone at Devil's Slide (loc. 3). The value of the cement, which is processed in a plant adjacent to the quarry, is estimated to be several million dollars per year (Utah Mining Association, 1959, p. 62). Crushed limestone from this quarry is also sold for various uses in the construction industry and in agriculture. Cement rock is also produced at another quarry in the Twin Creek Limestone in the Wasatch Mountains in Salt Lake County (loc. 5). This quarry is operated by the Portland Cement Co. of Utah and the cement rock is processed in a plant in Salt Lake City.

Also in Salt Lake County, near Garfield (loc. 4), recent calcareous oolitic sands are mined by Kennecott Copper Corp. for fluxing stone for their smelter nearby and as a source of lime. The oolite sand pits are reported by Eardley (1938, table 17) to consist of 90.7 percent aragonite and 3.2 percent dolomite. Similar oolitic sands were formerly mined at the south end of Stansbury Island near Grantsville (loc. 9). These sands were used as fluxing stone at the United States Smelting Refining & Mining Co. smelter at Midvale, and as a source of lime until the smelter closed in 1958.

In Sanpete County a quarry in the Flagstaff Limestone on the Wasatch Plateau near Redmond (loc. 6) yields limestone for use in the refinery of the Gunnison Sugar Co. at Gunnison. Some of this limestone has been burned for plaster and chemical lime.

About 70 percent of Utah's production of lime is derived from limestone and dolomite produced in Tooele County (Utah Mining Association, 1959, p. 88). In the Stansbury Mountains near Flux and Dolomite (loc. 7) the Utah Lime & Stone Co., a division of the Flintkote Co., produces limestone from quarries in the Great Blue Formation and dolomite from the Fish Haven and Laketown Dolomites (Rigby, 1958, pp. 130–131). In addition to the rock calcined for the production of lime and deadburned dolomite, much rock is sold as crushed limestone and dolomite for various uses in the smelting, chemical, cement, construction, coal mining, and sugar industries.

In the southern Lakeside Mountains near Delle (loc. 8) the Utah Marblehead Co., a subsidiary of the Marblehead Lime Co. of Chicago, has established Utah's newest major rock quarry, which began production in 1958. The principal product of the quarry is dolomite, which is produced from the Fish Haven, Laketown, and Water Canyon Dolomites and calcined to produce deadburned dolomite and other refractory products for use by the Columbia-Geneva Division of United States Steel Corp. The reserves of dolomite at the quarry site are reported to be 20 million tons; the calcining plant is reported to have a capacity of 410,000 tons of raw rock annually (Kerns, and other, 1959, p. 949).

Aragonite is also produced in Tooele County in the Cedar Mountains near Aragonite (loc. 10). At this locality, the Utah Calcium Products

Co. mines this orthorhombic form of calcium carbonate from a vein cutting the Oquirrh Formation for the production of poultry grits and lime supplement in cattle feed. Some of the aragonite is also used as building stone, decorative aggregate, and roof granules.

Utah County is Utah's largest source of crushed limestone and dolomite. Most of the crushed stone is produced from the Keigley quarries of the Columbia-Geneva Division of the United States Steel Corp. at West Mountain, near Payson (loc. 11), which yield about 60 percent of the total output of crushed limestone from the State of Utah (Utah Mining Association, 1959, p. 96). The limestone is quarried from the Teutonic, Dagmar, and Herkimer Limestones, and the dolomite from the Bluebird and Cole Canyon Dolomites. Most of the crushed rock is used as fluxing stone, but large amounts are also sold for roadstone, coal mine rock dust, and chemical uses. Production from the Keigley quarries averages about 360,000 tons per year; reserves are estimated to be adequate for 50 years (Bullock, 1962, p. 86).

Quarries in the Lake Mountains also contribute to the production of limestone and calcite from Utah County. The Lakeside Lime & Stone Co. quarry near Pelican Point (loc. 12) is opened in the Deseret Limestone. According to Crawford and Buranek (1951, pp. 26–27), chemical analyses of the rock average 53 percent CaO, 0.87 percent MgO, 2.77 percent SiO_2; however, much of the limestone quarried contains less than 0.5 percent MgO and 1.0 percent SiO_2. It is used chiefly for the production of lime, but some crushed limestone is also sold for fluxing stone, whiting, and coal mine rock dust. The Utah Lime & Stone Division of the Flintkote Co. also operates a quarry in the Pelican Point area (loc. 13) in the Deseret Limestone. The crushed limestone from this quarry is also used for fluxing stone, whiting, rock dust, and for the production of lime.

Large calcite veins in the Pelican Point area (loc. 14) are mined by Roger Cedarstrom for processing as poultry grit and cattle food supplement. The veins are vertical, from 1 to 12 feet wide, and have been mined to depths of 300 feet. The mines yield about 2,000 tons of calcite per year (Crawford and Buranek, 1951, pp. 24–26).

Many inactive or abandoned limestone and dolomite quarries are found throughout Utah. The great majority of these were small operations that provided lime and stone for local use, such as the Evans travertine quarry in the Traverse Mountains south of Salt Lake City (loc. 15). Others are quite large and apparently were abandoned because of increased costs related to exhaustion of easily accessible limestone of acceptable composition, quarrying problems, or increased transportation costs. The quarries of the United States Smelting, Refining, & Mining Co. (loc. 16) and the American Smelting & Refining Co. (loc. 17) at Topliff became inactive when the calcareous oölitic beach sands at Great Salt Lake were developed as a source of limestone, and the branch of the Union Pacific Railroad to Topliff was abandoned shortly afterward in 1938. Near sites of heavy construction, limestone and dolomite quarries are temporarily operated for the production of limestone aggregate, fill, roadstone, and riprap, which are utilized in the construction of dams, causeways, and similar installations. Some of these quarries, like the Southern Pacific Railroad quarry in the Great Blue and Oquirrh formations in the northern Lakeside Mountains (loc. 18), have yielded tremendous quantities of limestone and other rocks during the relatively short period of their active production.

The limestone, dolomite, and cement rock resources of Utah are virtually inexhaustible. Current exploration for new sources is, in general, directed toward the discovery of large deposits of easily quarried limestones and dolomites that are essentially free of chemical and mechanical impurities. A second major consideration is the proximity to transportation facilities and markets. Fairly accessible exposures of the various stratigraphic units that elsewhere produce limestone and dolomite are still undeveloped. In addition, other stratigraphic units offer promise of future production. Among these are high-calcium limestones in the Madison Limestone of northern Utah, the Fitchville and Gardison Limestones of central Utah, and any of several limestone units of Cambrian age in western Utah.

The Simonson Dolomite and Guilmette Formation in western and central Utah are sandy in part, but the sand-free parts of these formations have not been extensively used as a source of high-magnesium dolomite for which they seem to be suited. The Twin Creek Limestone will continue to be the dominant source of cement rock in Utah, although the argillaceous limestones of the Pogonip, Opohonga, and the Garden City Formations would seem to warrant investigation and development.

The resources of vein calcite and aragonite in Utah are distinctly limited; however, the known deposits have adequate reserves for many years.

PEGMATITE MINERALS

(By J. W. Adams, Denver, Colo.)

Pegmatites can be a source of minerals of economic value; they are commonly dikelike bodies found in crystalline intrusive and metamorphic rocks and are characterized by large, but extremely variable, grain size. Most pegmatites are granitic in composition, having as their dominant minerals quartz, feldspar, and mica. They range from a few inches to thousands of feet in length, and may have a simple or complex assemblage of minerals.

Pegmatites are considered to have formed from late fluid fractions of crystallizing magmas; fluids that are enriched in some constituents in comparison with earlier crystallized fractions or parent rock. Many valuable elements such as beryllium, lithium, cesium, niobium, tantalum, tin, zirconium, the rare earths, and scandium may be effectively concentrated, and crystallize as accessory minerals of the pegmatite.

Most pegmatites are mined for feldspar or mica with or without recovery of whatever valuable accessory minerals may be present. In a few areas, however, mining is primarily for these accessory minerals, notably those of beryllium and lithium. Some pegmatites are now mined solely for quartz for use in the building trades.

Nearly all pegmatites of economic interest are zoned; that is, they exhibit roughly concentric layers of contrasting mineralogy and texture which commonly surround a nucleus or "core" of nearly pure quartz. In such zoned pegmatites specific minerals are apt to be more abundant within certain zones rather than being generally dispersed throughout the entire body. Pegmatites showing little or no zoning are, however, much more numerous than the zoned pegmatites.

Pegmatites are found in several areas in Utah, notably near Willard, Box Elder County, in Devils Hollow near Morgan, Morgan County, and in the Sheeprock Range and at Granite Mountain in Tooele County. Rare earth minerals occur in pegmatites in the Willard and Sheeprock areas (see section on thorium and rare earths, p. 115 and fig. 26), some scrap-grade mica in the Morgan occurrence (Buranek, 1942c) and beryl-bearing pegmatites have been described from Granite Mountain (Hanley and others, 1950, pp. 121–122).

There has been no recorded production of valuable minerals from pegmatites in Utah, but the large areas of Precambrian crystalline rocks exposed in the State may contain undiscovered pegmatite deposits of economic significance.

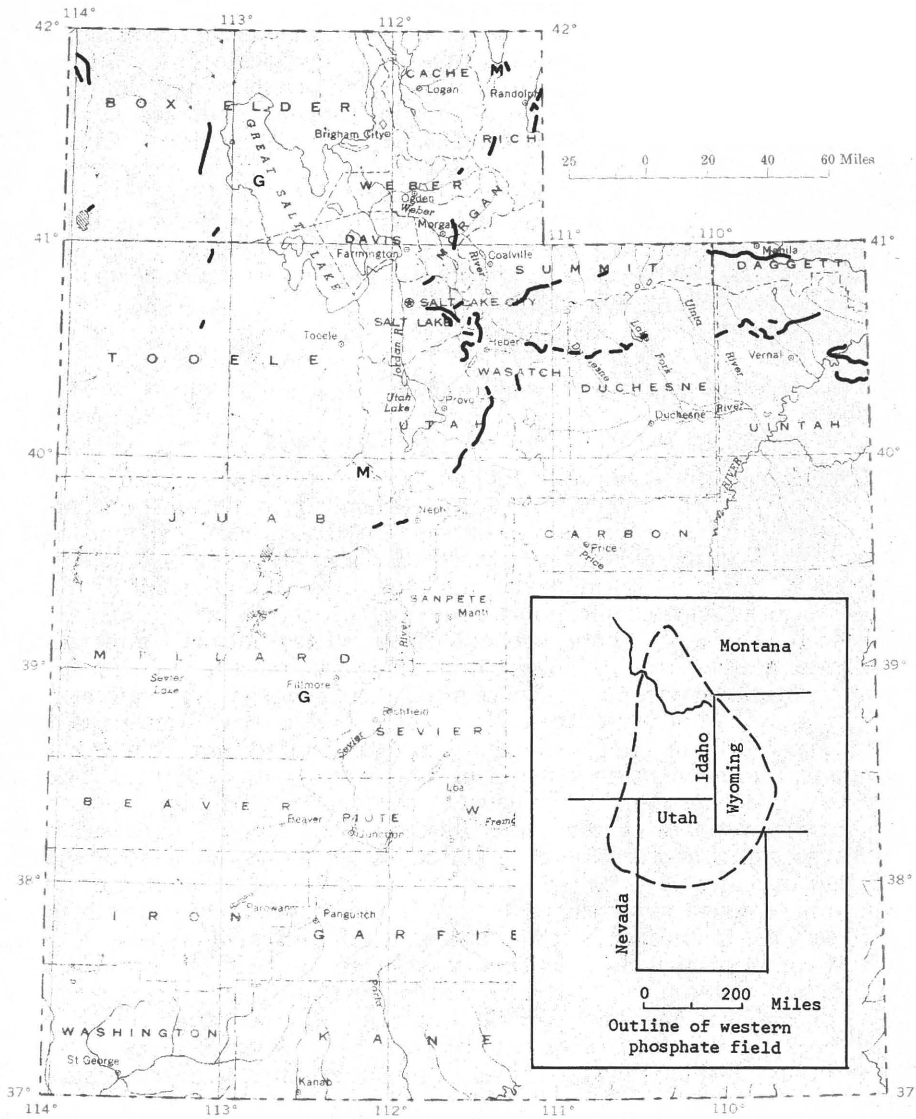
PHOSPHATE

(By W. C. Gere, Salt Lake City, Utah)

The element phosphorus is not found in a free state in nature, but is combined with oxygen and other elements into phosphate compounds. The major primary occurrence is disseminated in igneous rocks in the mineral fluorapatite $(CaF)Ca_4(PO_4)_3$, and less abundantly in chlorapatite, monazite, and xenotime. Weathering of the igneous rocks releases phosphorus, much of which ultimately is transported to the oceans where carbonate fluorapatite phosphate minerals are precipitated through biologic and other chemical activity. In favorable marine environments concentrations of such deposits may form important off-shore resources. In ancient oceans that transgressed over many present land areas, similar deposits were buried beneath younger sedimentary rock material, and were compacted into rock strata called phosphorite. In general, these strata maintain a rather uniform phosphate content and thickness over many square miles. Through uplift and erosion these phosphorites are now exposed at the surface in many parts of the world. Another source of phosphate is animal excrement and body parts high in phosphorus content, such as bird and bat guanos, that accumulate under highly arid climatic conditions or in protected caverns and caves. In less arid environments the water-soluble phosphates are readily leached by meteoric waters. The phosphorus may be redeposited by the phosphatization of adjacent rocks in forms of carbonate fluorapatite in calcareous rocks, or aluminum phosphate in clay shales. Igneous apatites, guano deposits, and phosphatized rocks are mined in many parts of the wörld, but the greatest resource consists of the marine phosphate rocks.

Northern Utah is included in the western phosphate field (fig. 40), which also includes eastern Idaho and adjacent parts of Montana, Wyoming, and Nevada and is one of the major phosphate areas of the United States. Phosphorites in this field are in marine formations of Mississippian and Permian age, the latter containing the major part of the phosphate resources.

Phosphatic shales in rocks of Mississippian age were first recognized in Ogden Canyon (Blackwelder, 1910, p. 543), and have been observed from localities as far north as southern Idaho, as far east as the Crawford Mountains, and as far south as the Confusion Range. On the basis of present information, only two widely separated locali-



EXPLANATION

Outcrop of Phosphoria and Park City Formations

M
Location of outcrop of Mississippian age formations containing important amounts of phosphate rock.

G
Guano localities

FIGURE 40.—Phosphate in Utah.

ties (see fig. 40) contain sufficient phosphate to be considered as future reserves; the Laketown Canyon area, Rich County, and the East Tintic Mountains area in Juab County (Cheney, 1957a, pp. 12, 13, 35). The phosphatic unit consists of thin interbeds of pelletal and oolitic phosphorite, siltstone, claystone, chert, carbonate rock, and rocks containing mixtures of two or more of these lithologies. The rocks are usually carbonaceous, suggesting deposition in a restricted marine environment. The thickness of the phosphatic interval is quite erratic due perhaps to erosion prior to the deposition of the overlying rocks, or to being deposited on an irregular surface.

The great phosphate deposits of Permian age in the western phosphate field were discovered in the Utah portion along Woodruff Creek, Rich County, in 1899, by prospectors seeking gold ore (Jones, 1907). Subsequent studies of the origin, nature, and extent of the phosphate deposits and related rocks have provided valuable information for exploration and development of this resource area (Gulbrandsen, 1960; Cheney and Sheldon, 1959; McKelvey and others, 1953 and 1959; Cheney, 1957a and 1957b; and Mansfield, 1927).

The phosphatic units include pelletal, oolitic, bioclastic, and nodular phosphorite, concretionary and bedded chert, siltstone, claystone, carbonate rock, and mixtures of these rock types. The local variability of rock types is coupled with regional variations in amount of diluting impurities, so that only in places are the beds rich enough in phosphate to warrant development. Apparently the configuration of the basin of deposition changed frequently, and even minor fluctuations produced differences in rock types and phosphate content. Because of the reducing conditions, large amounts of organic material were preserved which contributes the darker colors to the rocks. The accumulation of significant amounts of vanadium, chromium, uranium, and trace amounts of many other elements(see sections on fluorine, p. 162 vanadium, p. 133 and uranium, p. 124) is associated in part with this carbonaceous organic matter (Gulbrandsen, 1960, pp. 82–86). The carbonaceous content decreases shoreward so that a halo of lighter colored phosphorites and related sedimentary rocks appears in the shoreward facies, accompanied by a decrease in phosphate and trace element content, with few exceptions. The Mississippian and Permian rocks are similar in lithologic types and appearance.

Two phosphatic shale units are recognized in the Permian rocks in the western phosphate field, the Meade Peak (lower), and Retort (upper) Phosphatic Shale Members of the Phosphoria Formation. In much of Utah these two members extend as tongues into the lighter colored carbonate rocks, sandstones, and siltstones of the Park City Formation, and the entire interval has been called by the latter name. Only in northernmost Utah where the major rock types are chert, phosphatic and cherty shales, and minor carbonate rock is the name Phosphoria Formation applied. Although the Retort (upper) Phosphatic Shale Member is present in Utah, it is poorly developed and sparsely phosphatic. The major Utah reserves are in the Meade Peak Phosphatic Shale Member.

Bat guano is commonly found on the floors of caves and caverns of Utah, especially in the western part. The deposits vary in thickness and purity and, at most places, only very small tonnages are available. Because the material is easily produced and requires no treatment, it can be exploited for its easily soluble phosphate and other organic fertilizer content. Some prospecting activity has taken place at the two localities shown on figure 40. The more northerly locality consists of two small islands that are nesting areas for waterfowl. The best known and perhaps the most important locality is the Tabernacle Mountain area in T. 22 S., R. 6 W., of the Salt Lake meridian, Millard County, where guano is distributed irregularly along the floors of lava tubes and crevasses in the volcanic rocks over an area of several square miles. In the few areas prospected the average thickness of the guano is 1.75 feet. Impurities include wind-blown silt and rock falls from the walls and roofs or from the collapse of lava tubes.

ECONOMICS

Phosphate rock is a term used in commerce for rock containing one or more phosphate minerals of sufficient grade and composition to permit their use, either directly or after concentration, in the manufacture of commercial phosphatic products. About 70 percent of the phosphate produced in the world is utilized as agricultural fertilizer, and is basic to the food supply of the world. Phosphate ores are classified according to grades amenable to processing by industry. Phosphate content is calculated and expressed either as tricalcium phosphate, $Ca_3(PO_4)_2$, also referred to as bone phosphate of lime (BPL), or more commonly as phosphorus pentoxide, P_2O_5; 1 percent P_2O_5 equals 2.18 percent $Ca_3(PO_4)_2$. Pure carbonate-fluorapatite contains 39.1 percent P_2O_5. High-grade (acid grade) rock must contain a minimum of 31 percent P_2O_5; medium-grade (furnace grade) requires 24 percent P_2O_5; and low-grade rocks, containing at least 18 percent P_2O_5, may be utilized by blending or beneficiation. Except for many guano deposits, the phosphates must be processed to free the phosphorus from the fluoride to form a water soluble product. Guano from which the water soluble phosphates have been leached must also be processed.

For fertilizer product, the simple application of sulfuric acid to phosphate rock is the most widely used procedure today. This operation yields "superphosphate," containing 20 percent P_2O_5. Triple superphosphate is made by the addition of more sulfuric acid to form phosphoric acid. The phosphoric acid is filtered and applied to phosphate rock to yield a product containing 41 to 48 percent available P_2O_5 most of which is water soluble. Presently, there is a definite trend to produce less superphosphate and more triple superphosphate. Phosphoric acid also is combined with postassium and ammonia compounds to form potassium phosphates and ammonium phosphates.

Various impurities reduce the value and limit the use of some phosphate rocks. Organic content is removed from western phosphate rocks by calcining and, to avoid excessive acid consumption, carbonate content is held to the minimum consistent with economic mining. Iron oxides and alumina content, and for some uses, magnesium content are restricted. In electric furnace operations, high carbonate content requires excessive silica flux, and iron oxide content, above a few percent, causes excessive loss of phosphorus in the slag.

Electric and blast furnace operations require phosphate rock averaging about 24 percent P_2O_5. The rock is smelted with coke and siliceous flux to produce elemental phosphorus, ferrophosphorus and calcsilicate slags, and carbon monoxide. The phosphate is volatilized, condensed, and collected as elemental phosphorus, which is utilized by the food, drug, and chemical industries, and is also used to make triple superphosphate. Although furnace operations are expensive, the purity of the product results in a lower freight cost per unit of P_2O_5.

In the processing of phosphate rock a number of byproducts and potential byproducts may be recoverable. Some uranium has been recovered from plants processing Florida phosphates, and fluorine is removed both to prevent pollution and to recover a byproduct. Ferrophosphorus slag provides a concentration of vanadium, chromium, and other metals. Additional roasting of the ferrophosphorus slag from the western phosphate field has yielded concentrations of as much as 15 percent V_2O_5, 10 percent Cr_2O_3, and 40 percent P_2O_5, all of which may be recovered in the future as byproducts. Ferrophosphorus slag from the Food Machinery Corp. furnace operation at Pocatello, Idaho, was utilized for recovery of vanadium at the Susquehanna Minerals mill west of Salt Lake City during 1962, and the Vitro Chemical Co. Salt Lake plant is presently recovering vanadium from the FMC slag. The phosphate rock also contains a number of other elements that may at some future time be considered worth extracting as a byproduct. These include molybdenum, nickel, selenium, silver, zinc, and zirconium, all of which occur in concentrations greater than in most common rock (Gulbrandsen, 1960, pp. 82–86).

Western Phosphates, Inc., located 14 miles west of Salt Lake City, manufactures triple superphosphate, ammonium phosphates, and phosphoric acid. This company has been in operation since 1954. In excess of 130,000 tons of these products are distributed annually over the area from the Mississippi River west to California and Canada to Mexico. Prepared phosphate rock is obtained from the San Francisco Chemical Co. mine north of Vernal, Utah; sulfuric acid is delivered by pipeline from the Kennecott Copper Corp. smelter; and ammonia, ammonium sulfate, and ammonium nitrate are received largely from the United States Steel Geneva plant at Orem, Utah.

PRODUCTION

The United States is the leading producer of phosphate rock, contributing 18,559,000 long tons of the world production of 43,770,000 in 1961. Of this amount 2,772,000 tons were produced from the western phosphate field, and 374,406 tons from the Utah portion. Utah output increased to 835,859 tons in 1962 with the opening of new mining operations in the Vernal area. Utah presently ranks third in the western field after Idaho and Montana, and fifth in the nation. Utah production figures are as follows (modified from U.S. Bureau of Mines data):

	Phosphate rock mined	Value
	Long tons	
Rich County	1,660,231	$11,762,111
Uintah County	463,522	1,165,425
Utah County	16,225	126,433
Wasatch County	45	270
Total, Utah	2,140,023	13,054,239

Phosphate rock has been produced intermittently in Utah since 1907, and most of the tonnage has been mined from the Crawford Mountains in Rich County. After 1 year of operations, the Brush Creek area north of Vernal, Uintah County, has become second in total production, ahead of the Diamond Fork area in Utah County and the Park City district in Wasatch County.

In Rich County during the years 1907–12 and 1915–20, Bradley Bros. produced 18,050 tons of phosphate rock by underground methods from the northern part of the Crawford Mountains. Since 1954 the San Francisco Chemical Co. has produced 1,582,728 tons (372,337 during 1962) from the Bradley claims also by underground mining, the highest total production in Utah. The Pearl & Tolland Phosphate Co. mined about 1,650 tons during 1951–53 from a small operation in the southern part of the Crawford Mountains, and in 1954-55 the J. R. Simplot Co. recovered 57,802 tons from the central part of the range by strip mining. The rock contains high to medium grades of P_2O_5.

A reported tonnage of 16,225 tons has been mined by strip methods at the Little Diamond Fork area in Utah County. Medium-grade rock was shipped by the Garfield Chemical & Manufacturing Corp., during the periods of 1941–42, 1946–48, and 1953, to steel plants near Provo and to fertilizer companies.

During 1962 the San Francisco Chemical Co. also started production from the Humphrey claims in the Brush Creek area north of Vernal, Uintah County, Utah. Large tonnages (463,522 in 1962) have been recovered by stripping methods. The company owns two plants for preparation of the rock for shipment; one at Leefe, Wyo., to process rock from the Crawford Mountains and the Leefe mine in Wyoming, and the other adjacent to the Brush Creek operations. At both plants the ore is crushed, calcined, deslimed, and beneficiated to 31 percent P_2O_5.

Minor production from the Park City mining district in 1942 has been reported but the details are unknown.

RESERVES AND DISTRIBUTION

Estimates of the phosphate reserves of Utah, derived from differing criteria, have been published by Williams (1939), Williams and Hansen (1942), and Mansfield (1942).

The reserves in this report are restricted to grades of rock that are presently exploited in the western phosphate field. Available geological and analytical data for each area serve as the basis for the estimates shown in table 14.

TABLE 14.—*Utah phosphate reserves in zones at least 3 feet thick*

County	Above entry level (rounded to nearest 50,000 long tons)			Within 1,000 feet below entry level (rounded to nearest 500,000 long tons)		
	High grade 31+ percent P_2O_5	Medium grade [1] 24+percent P_2O_5	Low grade [1] 18+percent P_2O_5	High grade 31+ percent P_2O_5	Medium grade [1] 24+ percent P_2O_5	Low grade [1] 18+percent P_2O_5
PERMIAN: MEADE PEAK PHOSPHATIC SHALE MEMBER						
Rich	39,150,000	[1] 195,650,000	[1] 354,350,000	40,500,000	144,000,000	232,000,000
Uintah	------------	516,350,000	1,679,000,000	------------	198,000,000	700,000,000
Daggett	------------	70,550,000	256,250,000	------------	29,000,000	96,000,000
Salt Lake	------------	2,900,000	12,000,000	------------	9,500,000	40,000,000
Utah	------------	2,750,000	3,700,000	------------	13,500,000	18,500,000
Wasatch	------------	1,050,000	5,500,000	------------	3,500,000	25,000,000
Duchesne	------------	------------	500,000,000	------------	------------	14,000,000
Summit	------------	------------	6,250,000	------------	------------	11,000,000
Totals	39,150,000	789,250,000	2,817,050,000	40,500,000	397,500,000	1,136,500,000
MISSISSIPPIAN: BRAZER FORMATION AND EQUIVALENTS						
Rich	------------	1,300,000	1,300,000	------------	4,500,000	4,500,000
Juab	------------	------------	2,100,000	------------	------------	7,000,000
Totals	------------	1,300,000	3,400,000	------------	4,500,000	11,500,000
GUANO						
Millard	------------	------------	15,000	------------	------------	------------

[1] For calculations of any one grade cutoff, no bed was used more than once, but the same bed may be averaged with adjacent beds for different grades.

A depth cutoff of 1,000 feet below entry may appear excessive, but Utah rock has been mined to a depth of 300 feet. The tonnages shown below entry level are of doubtful value in the foreseeable future, especially the medium- and low-grade rocks, which may more logically be considered as resources.

The reserve estimates are purposefully conservative because the available analytical data are from samples that have mostly been collected from surface trenches. Weathering agents leach the lime from phosphate rock, thus yielding P_2O_5 analyses higher than will be found in rock beneath the zone of weathering. A variation of up to 6 percent P_2O_5 has been encountered in weathered zones in some areas. No attempt has been made to translate this factor into the reserve estimates. An estimate for the guano deposits in Millard County is included although tonnages appear to be small and the value of these deposits is questionable. The fact that much of the material contains 10 percent water-soluble P_2O_5 plus some nitrogenous compounds and does not require additional processing justifies recognition as a resource.

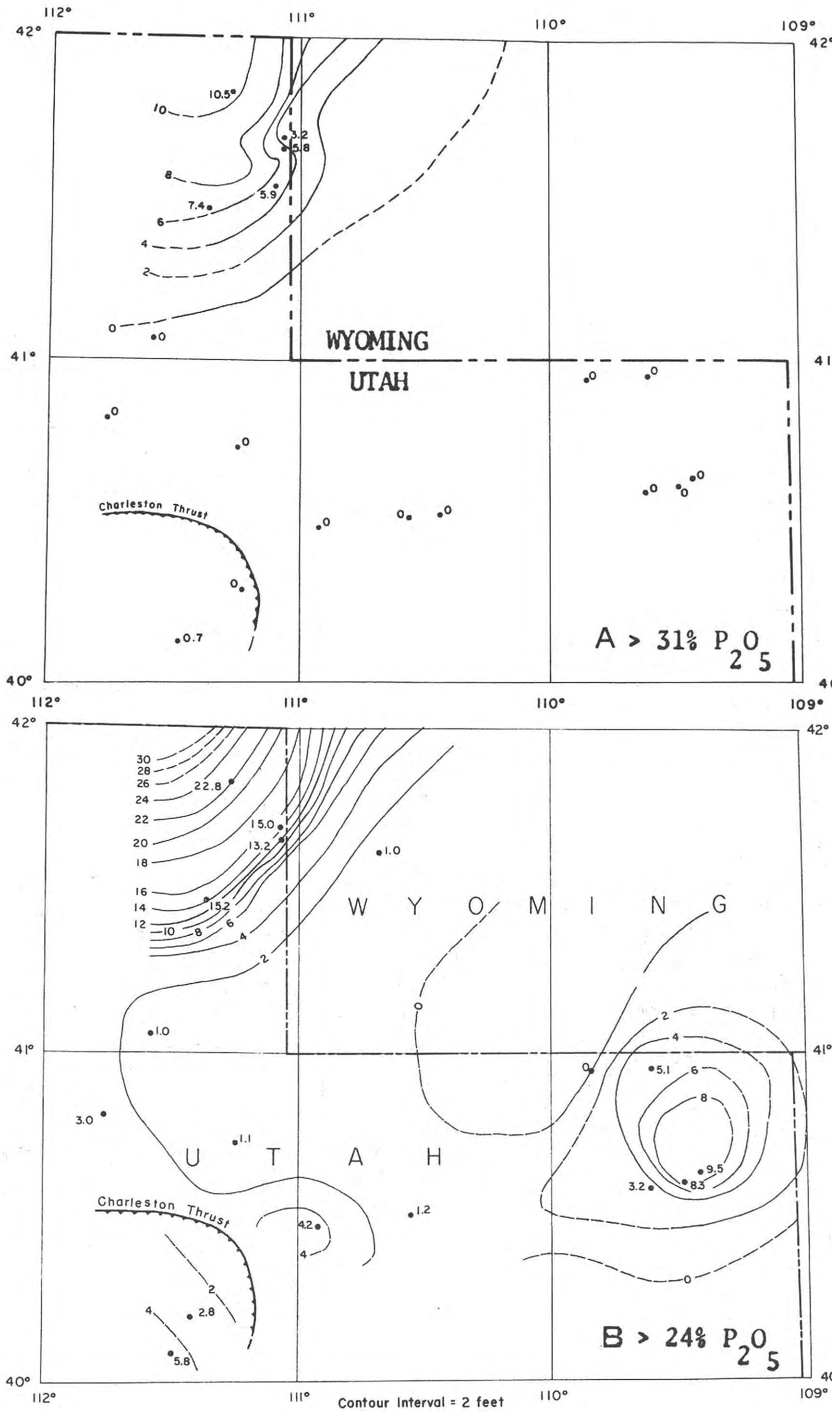


FIGURE 41.—Total thickness of beds in the Meade Peak phosphatic shale member of the phosphoria formation that contain more than 31 percent P_2O_5 (A) and more than 24 percent P_2O_5 (B). Eroded areas not indicated. (Modified from

Figure 41 reflects the pattern of phosphate deposition in the Permian Meade Peak Phosphatic Shale Member of the Phosphoria Formation in the Utah portion of the western field.

Rich County

The richest deposits and the bulk of Utah's reserves are located in Rich County. Permian phosphate rocks are exposed throughout the length of the Crawford Mountains (Richardson, 1941, pp. 44–48) along Woodruff Creek in a structurally complicated exposure (Gale and Richards, 1910, pp. 513–530), and both Mississippian and Permian phosphorites are found at Laketown Canyon. The Mississippian deposits in Laketown Canyon are too small to support an independent operation, but they may be recovered in conjunction with Permian deposits less than 1 mile to the east. Underground mining methods must be utilized to recover the major reserves in Rich County. The San Francisco Chemical Co. is presently producing phosphate rock from the Crawford Mountains.

Uintah County

The Meade Peak Phosphatic Shale Member is exposed along much of the south slope of the Uinta Mountains where in places dip slopes as much as 3 miles wide have formed on this unit (Kinney, 1955, pp. 162–173). The beds dip southward beneath the Uinta Basin and, to the north, have been completely eroded from the Uinta Mountains. A considerable tonnage may be recovered by strip mining on the dip slopes. This is an area of anomalous phosphate deposition (fig. 41). The maximum concentration of medium-grade phosphorite occurs from Rock Creek eastward to the vicinity of Little Brush Creek. To the east of this area, the phosphate content decreases rapidly and the shale interval disappears near the Utah-Colorado line. West of the Rock Creek-Brush Creek area the phosphorites are rapidly diluted with clay, silt, and carbonate material, and, although the shale interval thickens, medium- to low-grade beds 3 feet or more thick are not found in the western part of the county. The San Francisco Chemical Co. is mining rock in the Brush Creek area by strip methods.

Daggett County

The Meade Peak Phosphatic Shale Member is also exposed along the north slope of the Uinta Mountains, where the rocks dip northward beneath the Green River basin. The exposures are terminated to the east by the Uinta Fault (Hansen, 1955) and to the west by concealment beneath rocks of Tertiary or Quaternary age. An anomalous thickness of medium-grade rocks is found in the easternmost exposures (see fig. 41), a northward continuation of the Uintah County occurrence previously mentioned.

Salt Lake County

In Dry Canyon, northeast of Salt Lake City, the Meade Peak Phosphatic Shale Member contains 3 feet of medium-grade and 13 feet of low-grade rocks. The outcrop extends about 7 miles up the canyon. Other localities in Salt Lake County are apparently too lean to be considered as reserves.

Utah County

In the eastern part, a band of the Meade Peak Phosphatic Shale Member, is exposed irregularly over a distance of 21 miles, but only that part in the vicinity of Little Diamond Creek is known to contain significant amounts of medium- to low-grade phosphate rock. An anomalous thickness of sandy phosphorite occurs at the base. More than 16,000 tons of phosphate rock has been mined from this area by the Garfield Chemical & Manufacturing Co.

Wasatch County

Two localities contain medium- and low-grade phosphate rocks of sufficient thickness to be included in the reserve estimate. North of Midway, a sandy phosphorite bed 3.5 feet thick contains an average of 26.7 percent P_2O_5, but such sandy phosphorites generally have limited areal distribution. Low-grade beds, over 3 feet thick, are exposed along the southwestern flank of the Uinta Mountains.

Duchesne County

The Meade Peak Phosphatic Shale Member is exposed along the south flank of the Uinta Mountains in the western half of the county. To the east, the Meade Peak is concealed beneath Tertiary rocks. Most of the exposures in the western part include 5 to 6 feet of low-grade phosphate rock.

Summit County

Several bands of the Meade Peak Phosphatic Shale Member crop out in Summit County. However, only at Franson Canyon near the western margin of the Uinta Mountains do the rocks contain low-grade phosphate rock in excess of 3 feet in thickness.

Juab County

According to Cheney (1957, p. 35) the basal part of the Deseret Limestone of Mississippian age in the East Tintic Mountains is phosphatic. Reserve estimates are restricted to the immediate area of the sample locality until additional data become available to determine the distribution of phosphate in these rocks.

Millard County

A small resource is represented by the guano deposits at the Tabernacle Mountain locality.

Other areas

As shown on figure 41, the Meade Peak Phosphatic Shale Member is exposed in many areas of northwestern Utah. The location and distribution of the phosphatic formations have only recently been outlined (Stokes, 1963) and analytical data are not yet available to determine resources in this part of the State.

OUTLOOK

Utah should experience a gradual increase in production of phosphate rock as the demand for the western product continues. Most of the production and the bulk of the reserves are in Rich and Uintah Counties. Increased production of acid-grade rock from the Crawford Mountains and development of the Laketown Canyon deposits is anticipated. The Brush Creek area in Uintah County, with vast deposits amenable to stripping and beneficiation, should continue as a major producing locality. Low-cost electric power would place the Vernal area in a highly competitive position for development of a furnace operation.

Industry has and will continue to find improved and more efficient methods of recovery, beneficiation, and processing of this resource.

Much remains to be learned concerning the Utah phosphate resources. The U.S. Geological Survey is presently mapping phosphate areas and collecting new sample data. The results of this work, especially in northwestern Utah and in the central Wasatch Mountains, should significantly increase the reserve figures presented here.

REFRACTORY MINERALS

(By K. B. Ketner, Denver, Colo.)

Kyanite, *andalusite*, and *topaz* are aluminous silicate minerals and *magnesite* and *brucite* are magnesium minerals; both groups are used as raw materials in the manufacture of refractories that have useful chemical and physical properties at very high temperatures. Silica, principally in the form of quartz, also has refractory uses and is discussed in a following section, page 218. Although Utah has limited known resources and little production of the aluminous silicate and magnesian refractory minerals, intensified search for them has not been made.

Uses and specifications were recently summarized for all refractories by Clark and McDowell (1960), for kyanite, andalusite, and topaz by Foster (1960), and for magnesite and brucite by Wicken (1960).

ALUMINOUS REFRACTORIES

Kyanite commonly occurs in regionally metamorphosed aluminous rocks, and *andalusite* is more likely to be found where highly aluminous rocks are altered locally by contact with granitic intrusives. *Topaz* is commonly associated directly with granite and rhyolite.

In Utah the only rocks sufficiently metamorphosed to contain kyanite are some of the Precambrian rocks that crop out in the Uinta Mountains, the northern Wasatch Mountains between Salt Lake City and Brigham City, and in several ranges of the Great Basin including the Grouse Creek, Raft River, and Deep Creek Ranges. (See figs. 3, 4 and 5). Kyanite has been reported in the Grouse Creek Range in regionally metamorphosed rocks (Crawford and others, 1948). (See fig. 44). Granitic intrusives and rhyolite extrusive rocks are common in many ranges of the Great Basin and a considerable deposit of andalusite is known to be associated with one of the granitic intrusives in the Deep Creek Range (Nolan 1935; Kemp and Billingsley, 1918). A large low-grade deposit of topaz is associated with rhyolite in the Thomas Range (Staatz and Osterwald, 1959).

The large areas of regionally metamorphosed Precambrian rocks have not been thoroughly explored for kyanite and related minerals but the great predominance of silicic over aluminous rocks in the Precambrian System of Utah militates somewhat against discovery of large deposits. Although the contact zones of granitic intrusives in the Great Basin have been thoroughly investigated for metaliferous deposits, they have not yet been prospected thoroughly for andalusite. Minable deposits might be found but the scarcity of highly aluminous sedimentary rocks in the eastern Great Basin is somewhat discouraging. Although topaz is a common mineral in the volcanic rocks of the Thomas Range and elsewhere, the known deposits are too low grade to be of importance as sources of refractory material.

Utah has not produced any of these minerals for refractory use because the known deposits are not of sufficiently high grade and large size. The outlook for discoveries of large deposits of high alumina refractories in Utah is not favorable.

MAGNESIAN REFRACTORIES

The minerals *magnesite* ($MgCO_3$) and *brucite* ($Mg(OH)_2$) commonly are formed where limestone, dolomite, or serpentine are enriched in magnesium by contact with magnesian waters emanating from intrusive rocks. Unaltered, or primary, sedimentary deposits formed by precipitation of magnesium carbonate on the floor of the sea or of lakes are less common. Synthetic brucite increasingly is produced from sea water and mineral brines which contain high concentrations of magnesium.

In the part of Utah occupied by the Great Basin there are widespread limestone and dolomite formations and abundant intrusive igneous rocks. The large, commercially successful magnesite deposit at Gabbs, Nev., is in similar terrane. Magnesite veins have been reported in the San Francisco mining district of Beaver County (Butler, 1913) and in the Fish Springs district of Juab County (Crawford, 1941, p. 18). Both deposits are small and the only production of magnesite was a limited amount in 1941 from the Fish Springs district.

In view of the widespread association of limestone and dolomite with intrusive rocks and the difficulty of distinguishing valuable deposits from common limestone or dolomite, it seems quite possible that large magnesite-brucite deposits are present in Utah and still await discovery. However, the increasing production of synthetic brucite in competition with natural brucite indicates that only deposits of superlative quality can become commercially successful.

SALINES

(By R. J. Hite, Salt Lake City, Utah)

INTRODUCTION

The term "salines" is widely used but loosely defined. In this report it applies to all mineral salts which have been precipitated from waters of marine or continental origin by evaporation. Deposits of salines are usually referred to as "evaporites," and by the terms of this definition, gypsum and anhydrite and some limestone and dolomite deposits are included. However, because of their singular importance these latter commodities are discussed separately in other sections of this report. Deposits of saline potassium minerals are referred to as "potash," as are other potash deposits of different origin such as alunite. (See section on alunite, p. 151.) All saline deposits were derived by precipitation from concentrated solutions or brines.

Natural brines are found in several environments in Utah and also are commercially exploited for their mineral content.

Although saline deposits contribute substantially to this country's mineral production, up to now Utah's production has been small in view of its large potential saline resources. In 1961, Utah produced some $3,187,000 worth of salt and $1,990,000 worth of potash, each slightly less than 2 percent of the national production. No production was listed for sodium carbonate, sodium sulfate, magnesium compounds, lithium, bromine, and boron.

One of the first minerals used in Utah was common salt (sodium chloride), first by the Indians and later by the Mormon settlers. Most early developments of the saline mineral industry were concentrated around the Great Salt Lake. Salt (sodium chloride) was extracted from the lake brine by solar and artificial evaporation and also from saliniferous mud flats surrounding the lake. A small percentage of early salt production in the State came from opencut mines in the vicinity of Salina, Nephi, and Manti. The reported production of sodium chloride in Utah for the period of 1879 through 1961 is about 6.6 million tons of product valued at $34 million.

Saline minerals have a wide variety of uses and the most widely used and best known is common salt ($NaCl$). Because of the dietary dependence of man and animals on this mineral, it has played an important role in the development of many countries and civilizations. Today, however, dietary use consumes less than 5 percent of this country's production, while about 70 percent is utilized by the chemical industry, particularly in the manufacture of chlorine, caustic soda, and soda ash. Other uses include food preservation, ice manufacture, ice removal, and use in textiles and dyes, ceramics, etc. A new and indirect use of salt deposits is as underground storage sites for petroleum products. The estimated storage capacity in salt deposits for petroleum products that was available for use in the United States in 1958 was 36 million barrels. This storage space can be created cheaply (about $2 per barrel of capacity) by simply dissolving the salt with fresh water (Pierce and Rich, 1962, p. 77). Storage space of this type is also well suited for the disposal of radioactive wastes.

The production of potash in Utah began in 1916 with extraction by several solar salt plants utilizing brines of Great Salt Lake. Up to 1961, Utah had produced 1.3 million tons of crude potash salts, containing 770,000 tons K_2O equivalent, valued at $26 million. In 1917 the Solvay Process Co. began potash production from a new plant at Salduro station, utilizing brines from the Salduro Marsh, now known as the Bonneville Salt Flats. Utah-Salduro Potash Co. acquired Solvay's interests in 1918, and became the largest producer of potash in the United States in 1920. In 1921, the Salduro plant was shut down and brine operations were idle until 1938, when operations were resumed at a new plant by Bonneville, Ltd., which is now a division of the Standard Magnesium Co.; output has continued without interruption since then. The effluent from the potash plant contains a high concentration of magnesium chloride that has been discarded, but plans for the recovery of 33,000 tons of magnesium chloride yearly, from the discarded effluent have been announced.

Bedded deposits of potash were discovered in Utah in 1924 (Dyer, 1945) at the northern end of the Paradox basin, by wells drilled for

26-803 O-69—15

oil and gas. Since that time there have been numerous periods of exploration for potash. After extensive drilling, the Texas Gulf Sulphur Co. installed surface facilities and began sinking a shaft in 1961 on a potash deposit on the Cane Creek anticline south of Moab. Production, which is scheduled to start in 1964, is initially planned for an annual output of 550,000 tons of muriate of potash.

Potash, an essential nutrient for plant growth, is most widely used in the fertilizer industry, but it also has widespread use in the chemical, ceramic, petroleum, munitions, and pharmaceutical industries.

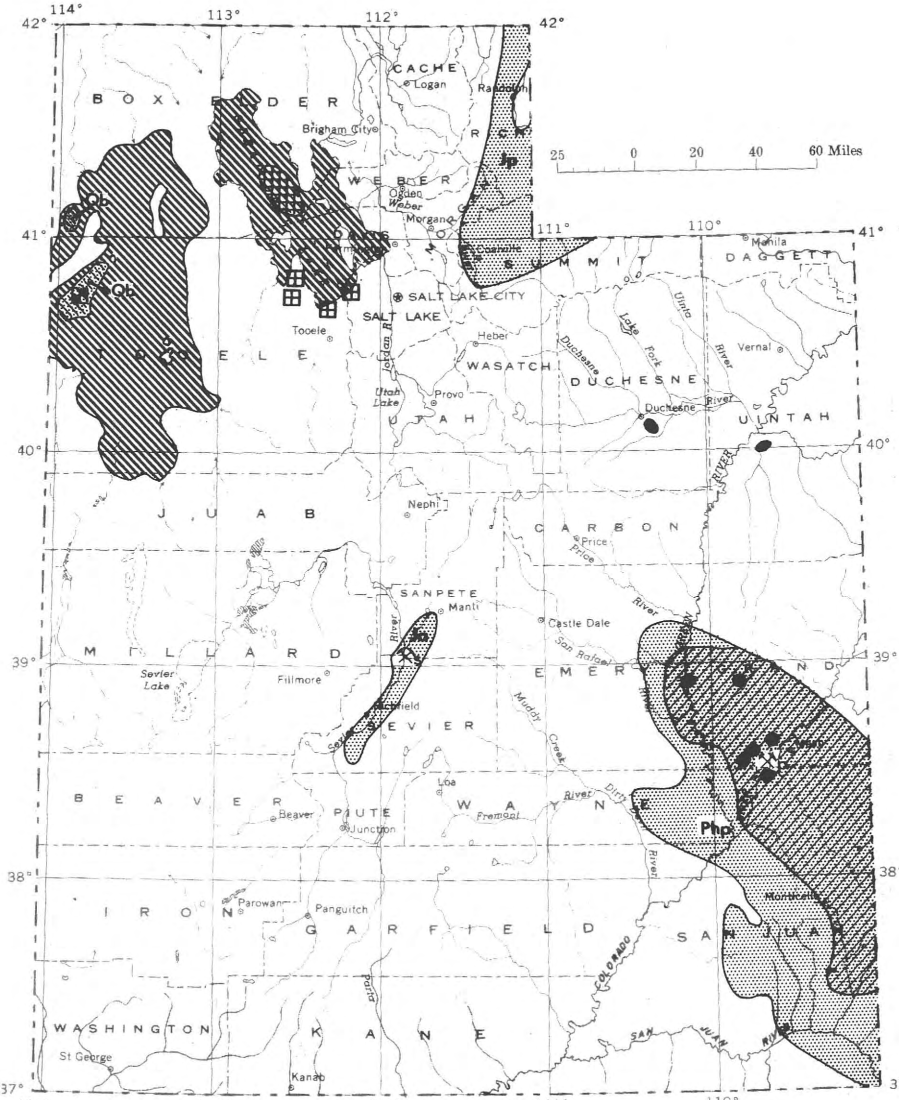
Although many other types of saline minerals are present in Utah they have not yet been exploited by industry. Such exploitation may be near, however. Recently it was reported by the Salt Lake City Tribune (Oct. 19, 1963) that plans are being laid for the extraction of lithium, sodium sulfate, and possibly magnesium from brines of the Great Salt Lake.

BEDDED DEPOSITS

Utah has numerous bedded deposits of saline minerals. Most of these, with the exception of several salt crusts resulting from the desiccation of Lake Bonneville, occur in the subsurface and range in age from the Pennsylvanian to Recent.

Paradox Member of the Hermosa Formation.—The most extensive saline deposits in Utah are in the Pennsylvanian Paradox Member of the Hermosa Formation, in the Paradox basin, in the southeast corner of the State. (See fig. 42.) The Paradox Member contains a thick evaporite sequence of limestone, dolomite, anhydrite, halite ($NaCl$), potash deposits, and interbeds of dark organic-rich shales. The salt-bearing facies of the Paradox Member varies greatly in thickness. The maximum original depositional thickness may have been about 7,000 feet, but subsequently it has been thickened in the salt anticlines, some of which contain as much as 14,000 feet of saline-bearing rocks. This large basin extends into Colorado and New Mexico, and the part underlain by salt in Utah covers an area of about 6,500 square miles. Potash deposits occur in nearly three-fourths of this area.

The halite beds and associated potash deposits of the Paradox Member are components of a series of evaporite cycles (Hite, 1961). At least 29 of these cycles have been recognized and 18 are known to contain potash deposits. Of the 18 cycles, 11 contain potentially valuable potash deposits. Only two potash salts, sylvite (KCl) and carnallite ($KCl \cdot MgCl_2 \cdot 6H_2O$), are present in large quantities. Carnallite because of its low K_2O content (16.9 percent) is not at present considered a commercial ore of potash in the United States. Several of these deposits are remarkable in size. One has been traced through an area 110 miles long and about 30 miles wide, and locally has a penetration thickness in excess of 400 feet. In the Salt Valley anticline this deposit was cored in the Defense Plant Corp., Reeder 1 well (sec. 4, T. 22 S., R. 19 E.), through a thickness of about 300 feet of alternating beds of sylvite and carnallite. One select interval of sylvite, 7 feet thick, averages 30.6 percent K_2O. Many of the carnallite beds are exceptionally rich and constitute a potential source of magnesium. According to Severy and others (1949), the deposit in the vicinity of the well may contain 57,500 tons of magnesium chloride and 55,100 tons of potassium chloride per acre, and because of its thickness and mineral content, may be particularly amenable to solution mining.



EXPLANATION

Saline deposits, occurrences, mines and plants

Sodium chloride, surface and subsurface: Qb, Recent; Jp, Preuss; Ja, Arapien; Php, Paradox

Potash, subsurface

Sodium carbonate, subsurface (Green River and Uinta Fms.)

Sodium sulfate, subsurface (Recent lake beds)

Brines, surface and subsurface

Potash mine

Salt (NaCl) mine

Brine occurrence (Paradox Mbr. of Hermosa Fm.)

Solar salt plant

Solar salt and potash plant

FIGURE 42.—Salines in Utah.

The salt deposits in the Paradox basin in Utah have not been utilized directly by the mineral industry except in the preparation of artificial brines used for drilling fluids. Indirectly, the salt underlying the Moab Valley anticline near Moab has been used by the Suburban Natural Gas Co. for storage of petroleum products.

The salt and potash deposits of the Paradox Member underlie broad areas at some depth. They are thickest and nearest to the surface along a series of northwest-trending salt anticlines. In some of the anticlines, the salt beds have been complexly folded and faulted and have moved upward above their normal stratigraphic position. It is in these structures that minimum depths to potentially exploitable deposits may be located. Shallowest known occurrence of salt beds is in the Salt Valley anticline at a depth of 750 feet. Minimum known depth to potash deposits of economic importance is about 2,400 feet, although there are several areas of potentially shallow depths.

The deposit being developed by the Texas Gulf Sulphur Co. (see fig. 42) on the Cane Creek anticline is high-grade sylvite. According to company information[1] the ore body averages 11 feet thick and 25 to 30 percent K_2O. Throughout an area of some 12 square miles the potash horizon lies at depths of 4,000 feet or less. Using the 11-foot average thickness, this area might contain about 230 million tons of potash-bearing rock.

Preuss Sandstone

Salt beds of Jurassic age are present in north-central Utah in the Preuss Sandstone (fig. 42) which consists of interbeds of red sandstone, siltstone, shale, anhydrite, and halite. The presence of salt in the Preuss is known almost entirely from subsurface information, although the formation crops out in many places. South of Henefer, brackish water in water wells drilled in an area of Preuss exposure, plus local surface efflorescences of sodium chloride (T. E. Mullens, oral communication, 1963), indicate the probable presence of underlying halite deposits. Two deep oil and gas test wells, the Ohio Oil Co. No. 1 Wilde, in the NE¼SE¼ sec. 9, T. 2 N., R. 5 E., and the Utah Southern Oil Co. No. 1 Hatch in sec. 28, T. 6 N., R. 8 E., confirmed the presence of halite. In the No. 1 Wilde, halite was encountered at 8,200 feet and continued at least to 8,635 feet below the surface, and Peterson (1955, p. 76) has described 700 feet of halite with interbeds of anhydrite and sandstone in the Hatch well. Geophysical logs in both the Wilde and Hatch wells indicate the salt is impure. In this respect, it is probably similar to Preuss salt in southeastern Idaho which contains a high percentage of shale fragments.

Arapien Shale

Deposits of halite occur in central Utah in the Arapien Shale of Jurassic age (fig. 42), but because of limited information, the distribution of the halite is conjectural and probably much more widespread than shown. Hardy (1952 divided the Arapien into five lithologic units and designating each unit by letter. The salt deposits occur in his units E and B. The Arapien salt is interbedded with red shale and siltstone, and much of the salt contains finely disseminated red clay as an impurity, which imparts a red color to the halite. An

[1] Vital statistics Texas Gulf Sulphur Co. potash plant, prepared for International Conference on Saline Deposits, Moab, Utah, Nov. 4, 1962.

analysis of rock salt from the Poulson Bros. mine near Redmond is as follows (Gilliland, 1951):

Constituent:	Percent
NaCl	95.60
SiO_2	2.16
SO_4	1.10
Ca	.51
Fe, Al oxide	.04
Mg	.04
I_2	.03
Total	99.48

The total thickness of salt beds in the Arapien is unknown although Hardy (1952, p. 62) mentions at least 200 feet exposed in an abandoned pit east of Redmond. The salt in the Arapien is found in several localities only a few feet below the surface and thus has been amenable to opencut mining. At present, only mines operated by Poulson Bros. are active in the area. Most of the material from these mines is utilized as stock salt.

Green River and Uinta Formations

Deposits of saline minerals occur in the Uinta Basin in both the Uinta and Green River Formations of Eocene age. Picard (1957) described a "saline facies" in the Uinta Formation characterized by disseminated crystals of sodium carbonate minerals, that ranges in thickness from 500 to 1,555 feet. This facies transcends the formational boundary between the Uinta and Green River. The Evacuation Creek Member is the lateral equivalent of the "saline facies" in the eastern part of the Uinta Basin and has abundant solution cavities (Cashion and Brown, 1956) which were probably originally filled with nahcolite ($NaHCO_3$). In 1951, the first significant beds of sodium minerals were encountered in a Sun Oil Co. well in the NE¼NE¼ sec. 22, T. 9 S., R. 20 E., Uinta special meridian. The well was cored continuously through all but the uppermost part of the "saline facies" and penetrated numerous blebs, streaks, and beds of nahcolite, the latter ranging from a few inches to a foot or more in thickness. The nahcolite zone in the well is approximately 525 feet thick, the top of which is 1,745 feet below the surface. The best mineralized interval is 5 feet thick and averages 60 percent nahcolite. Another well, drilled by the Havenstrite Oil Co. in 1956 in the same section, also penetrated the nahcolite zone. Recently a well drilled by Continental Oil Co. in the NE¼SW¼NE¼ sec. 17, T. 4 S., R. 4 W., Uinta special meridian, may also have penetrated bedded deposits of sodium minerals. Descriptions of core from this well, as reported in the Utah Oil Report (1962, vol. 12, No. 19), mention numerous intervals of "brown calcite" (probably a sodium carbonate mineral) between the depths of 2,902 and 3,582 feet. Geophysical logs of the well indicate at least three possible deposits of sodium salts. The mineral is most likely nahcolite although the geophysical logs suggest it is possibly a hydrous mineral such as trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$).

Muddy Creek Formation.—The Pliocene (?) Muddy Creek Formation of southwestern Utah may be salt bearing, because it contains extensive beds of halite in southeastern Nevada near the Utah State line. Raborg (1886, p. 640) reported that 1,000 tons were produced from a "mountain of salt" in the southwestern part of Utah Territory for use in the silver mills at Leeds. This salt may come from a deposit in the Muddy Creek formation, as it crops out nearby and as other formations in the surrounding area are not known to be salt bearing.

Sodium sulfate deposit underlying Great Salt Lake.—The bed of the Great Salt Lake is locally underlain by a thick deposit of mirabilite ($Na_2SO_4 \cdot 10H_2O$), which was discovered during construction of the railroad causeway from Promontory Point to Lakeside during the early 1900's. Extensive coring of the lakebed along the route in 1957–59 provided additional detail concerning this deposit (Eardley, 1962), which extends west from Antelope Island a distance of 9.5 miles. In cross section the deposit is wedge shaped and attains a maximum thickness in excess of 32 feet offshore from Antelope Island. Its north-south dimensions are unknown, so the boundaries shown on figure 42 are conjectural. About 20 percent of the mirabilite deposit consists of interbedded clay layers, 1 to 7 inches thick. The maximum depth from lake bottom to the top of the deposit is about 35 feet.

SURFACE DEPOSITS

Numerous surface crusts and layers of saline minerals occur in the western half of the State, and are the result of the desiccation of ancient Lake Bonneville and the Great Salt Lake. The best known and most extensive of these are the Bonneville Salt Flats, which cover about 150 square miles around Salduro station. The deposit reaches a maximum thickness of about 5 feet and is a white, porous, coarsely crystalline mesh of halite crystals. A chemical analysis of the soluble portion of the bed is as follows (Nolan, 1927, p. 35):

Constituent:	*Percent*
K	0.07
Na	36.85
Ca	1.20
Mg	.10
SO_4	2.88
Cl	58.98
CO_3	None

A smaller deposit, covering an area of about 25 square miles, occurs to the north, between the Silver Island Range and Lucin station. No analyses are available for this salt bed but it is probably similar in composition to the Bonneville Salt Flats.

Large areas surrounding the shore of Great Salt Lake are described as salt flats on many maps. In most cases these are areas of highly saliniferous soils and muds and no crystalline bodies of salt are known to be present.

Within the State, particularly the western half, there are numerous other closed and semiclosed drainage basins which contain waters that tend to become saline unless flushed out by overflow or leakage. Waters that are completely evaporated leave an efflorescence or crust of mineral salts on lake beds. Recurrently these salts are taken back into solution unless the deposit is thick or is covered by a protective layer of sediments. Such deposits are sometimes used locally.

BRINES

Waters containing a high concentration of dissolved solids are an important source of saline minerals, and saline waters containing dissolved solids in excess of 35,000 parts per million are classified as brines (Winslow and Kister, 1956). Most connate waters generally fall in this category, but brines that are exploited for mineral salts usually exceed this concentration. In this country brines are an important source of common salt, potash, bromine, boron, lithium, iodine, magnesium, and soda ash (sodium carbonate) but thus far Utah brines have been processed for potash and salt only. Connate brines are common in many formations in Utah, but at present only those found in the Paradox Member of the Hermosa Formation and in lake beds of the Salt Lake Desert, have had sufficient concentration and favorable composition to be regarded a potential source of saline minerals. The Great Salt Lake is the only known source of surface brine in the State.

Paradox member of the Hermosa Formation.—High density brines associated with the evaporites of the Paradox member of the Hermosa formation are commonly found in the Paradox basin of southeast Utah. There brines have exceptionally high concentrations of dissolved solids and are a potential source of saline minerals. The following analysis, which is typical of these brines, is from a sample collected from a well drilled by Delhi-Taylor Oil Corp. on the Seven Mile anticline in sec. 18, T. 25 S., R. 21 E., Grand County, Utah:

Constituent:	*Parts per million*	Constituent—Continued	*Parts per million*
Al	66	HCO_3	1,010
Fe	750	SO_4	4
Mn	260	Cl	241,000
Cu	6	F	25
Pb	6	Br	3,080
Zn	60	I	42
Ca	52,700	B	660
Mg	39,200		
Na	5,990	Total dissolved solids	366,000
K	18,800		
Li	66	Density	1.331
NH_4	849		

The Paradox brines could be a very attractive mineral resource, if brine reservoirs of appreciable volume can be found in the evaporites. In most cases the reservoirs encountered have been incapable of sustained brine production.

Artificial brines, produced by dissolving sodium chloride from the Paradox Member, are being used by the petroleum industry for drilling through the salt deposits in the Paradox basin. At the present time, the Moab Brine Co. in Moab is producing an artificial brine from the salt underlying Moab Valley. No data is available on the composition of this brine.

Great Salt Lake Desert.—Brines from the Great Salt Lake Desert have been important contributors to Utah's saline mineral industry. These brines are found in both porous, coarsely crystalline salt beds and in clay beds, and occur over a large part of the Great Salt Lake Desert. The depth to brine horizons in both crystalline salt and clay varies but most are within 5 feet of the surface. Deeper brine zones have been penetrated in the desert (Bonneville, Ltd., pumps brine from depths as great as 1,200 feet from several wells near Salduro), but little has been published about their chemical composition or the volumes involved.

The chemical composition of the brines is relatively uniform throughout the salt beds and the average dissolved solid content is as follows (adapted from Nolan, 1927) :

Constituent:	*Parts per million*
Cl	192,000
K	10,600
Mg	6,300
SO_4	5,200

Brine composition is dependent on the location respective to the edge of the desert flat where dilution from springs or rainfall may occur. The most concentrated brines are found in the lowest topographic depressions.

The composition of the brines in the clay layers is much more variable. The following analysis is a composite prepared by Nolan (1927, p. 39) of 126 separate brine samples from the clays:

Constituent:	*Parts per million*
Cl	96,150
Br	0
I	0
SO_4	4.08
CO_3	0
BO_3	0
Na	57,300
K	2,940
Li	2
Ca	1,051
Sr	0
Mg	1,910

Brine from the Great Salt Lake.—The Great Salt Lake is the largest existing body of concentrated brine in North America. According to Hahl and Langford (1963) the lake brine, during the period October 1959 to September 1961, had an average volume of 10 million acre-feet and a concentration of 266,000 p.p.m. dissolved solids. The latter amounts to about 4.4 billion tons of dissolved minerals of which about 500 million tons are magnesium chloride ($MgCl_2$) and 91 million tons potash (K_2O). A significant part of this consists of potassium and magnesium. Detailed brine analyses and the hydrology of the lake are included in the water resource section of this report.

The composition of the Great Salt Lake brine is generally similar to ocean water except that the salinity is much higher. The relative proportions of the major constituents of both waters are shown below as ratios compared to chlorine:

Ratio of element to chlorine (by weight)

	Sea water	Great Salt Lake
Sodium (Na)	1:1.8	1:1.7
Potassium (K)	1:5	1:32
Magnesium (Mg)	1:15	1:18
Bromine (Br)	1:292	[1]
Boron (B)	1:413	1:4,900
Lithium (Li)	1:190,000	1:3,700

[1] No data.

Source: Composition of sea water, Sverdrup et al.; Salt Lake brine, Hahl and Langford.

From the above data certain differences between the lake brine and ocean water are noted. If ocean water were concentrated to the same density as the brine, the composition of both would be much the same in respect to sodium and magnesium; lithium, however, would be about six times as abundant in the lake brine. The lake brine, on the other hand, shows a deficiency in potassium and boron. The latter deficiency is characteristic of most waters in the Bonneville Basin and suggests the improbability of concentrated borate deposits occurring in western Utah. The scarcity of exposed igneous rocks in the drainage basin may account for the relatively low boron content in the brine.

RESOURCE POTENTIAL

The future of the saline mineral industry in Utah appears exceptionally bright. Since its beginning, the industry has shown a slow, steady growth, but the next decade should bring a large expansion. The production of potash from bedded deposits in the Paradox basin will be a major factor in this expansion. A conservative estimate of resources, based on the meager data available in Lisbon Valley anticline, Gibson dome, Lockhart anticline, Rustler dome, and Seven Mile anticline, is about 200 million tons of K_2O. Only sylvite deposits 5 feet or more thick with an average grade of at least 20 percent K_2O, and less than 4,000 feet below the surface are included in this estimate. Other areas, such as Castle Valley, Cache Valley, Moab Valley, and Salt Valley anticlines, are not included in the resource estimate.

Tremendous amounts of potash and other salines are present in the brines of the Great Salt Lake Desert, but only a small portion of these resources have been developed. The large potential resource of saline minerals in the brine of the Great Salt Lake will no doubt receive greater attention in the future. Additional resources of bedded salines most probably were deposited in ancient Lake Bonneville, as shown by the mirabilite bed underlying Great Salt Lake at depth. The salt industry, for which the State has nearly unlimited resources, should continue at a slow, steady rate of growth. The indirect use of salt deposits as storage sites for petroleum products or radioactive wastes, could create a new industry in Utah. In this respect, the salt deposits in the Preuss Formation, because of their proximity to a railroad and to the industrialized Wasatch front, seem most promising.

SAND AND GRAVEL

(By Richard Van Horn, Denver, Colo.)

Sand and gravel deposits consist of unconsolidated rock fragments which have been moved and sorted by natural processes so that most of the finer and very coarse fragments have been separated from them. Sand and gravel are widely used in the construction industry because they provide strength, durability, and bulk at low unit cost. Because they are so abundant, so universally used, and relatively low priced, their mineral resource value has not always been fully appreciated. Value at the source for washed and screened material is generally less than a dollar per ton, and transportation charges may easily exceed the material cost. For this reason, the industry is widely dispersed.

About 167 million short tons of sand and gravel valued at $99 million was produced in Utah from 1906 to 1962 with some production from each county in the State. In 1962, about 20 million short tons valued at $21 million were produced. Of this total, 8 million short tons were for paving, 7 million short tons were for building construction, and 4 million short tons were for fill. Industrial sand, which includes molding, blast, fire or furnace, and engine sand accounted for 23,000 short tons (M. H. Howes, written communication, July 1963).

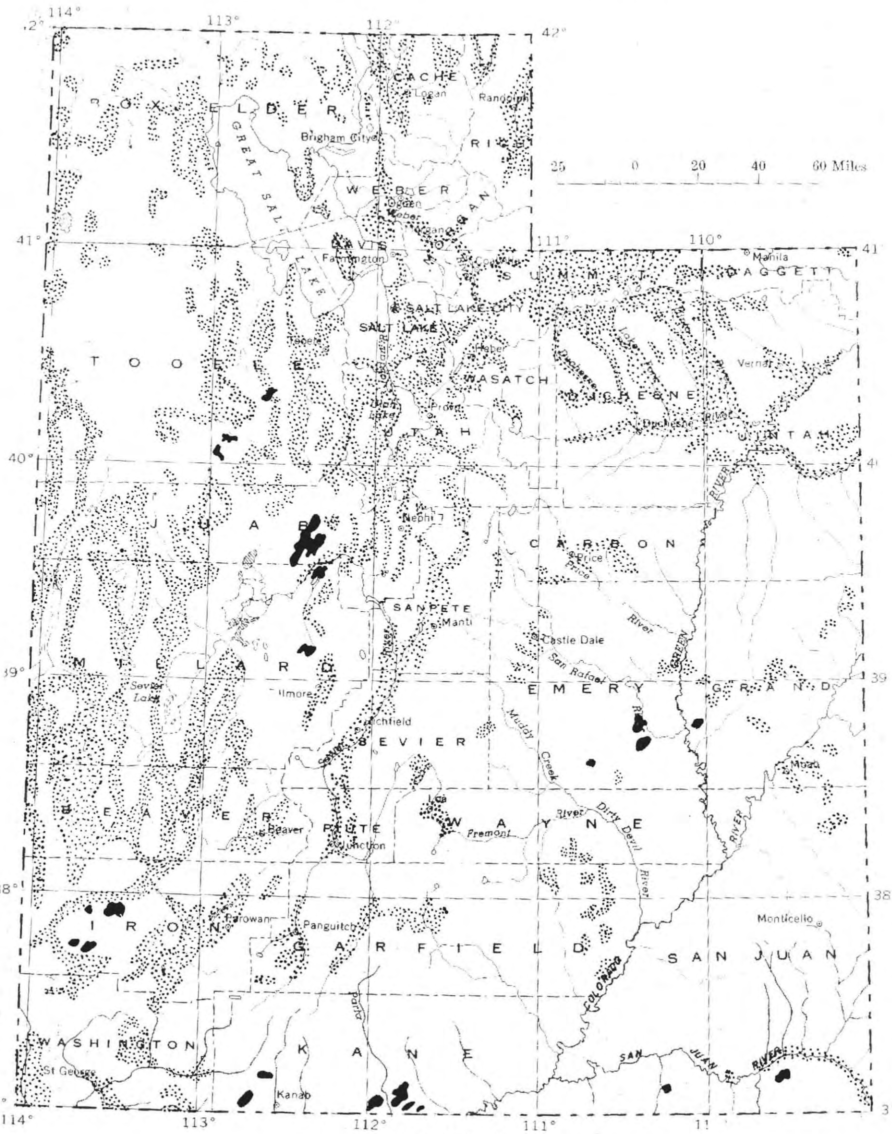
The large quantities of sand and gravel used in the State reflect the abundant supply of high quality material available to the consumer at low cost. Much of the material can be used with minimum screening, washing, and crushing; transportation costs are minimal because of the proximity of many source areas to transportation facilities and to the principal users.

A variety of natural processes produce rock debris, move it, sort it, and redeposit the debris either as heterogeneous mixture or in more familiar forms such as mud, silt, sand, and gravel. The quality of individual sand and gravel deposits depends largely on the strength of individual grains or fragments and on sorting processes that concentrate materials into preferred sizes. The strength factor is related directly to the kinds of rocks that contribute debris; rocks such as granite, basalt, gneiss, quartzite, limestone, and sandstone provide stronger and more durable debris than do shale, tuff, and schist.

Many of Utah's better sand and gravel deposits formed along the ancient shorelines of ice age lakes. In this environment, vigorous stream erosion in the highlands produced abundant debris from even the most resistant rocks. Energetic streams reduced the larger sized blocks to useful sizes and comminuted the softer rocks. The lake shore provided optimum winnowing of the finer materials by both water and wind action, and ample space was available for development of thick sand and gravel deposits in the deep water near the stream mouths. In western Utah, extensive, good deposits of this type, some of them more than 100 feet thick, formed near the Bonneville and Provo shorelines of Pleistocene Lake Bonneville (Gilbert, 1890), at elevations between 4,700 and 5,200 feet above sea level (figs. 4 and 43).

Other deposits of sand and gravel formed adjacent to valley glaciers, along ancient and modern stream valleys and to a limited extent as dunes, caused by wind action. Flood plains and terraces along most perennial streams contain intermittent important sources of sand and gravel. These are limited in size and distribution in the narrow mountain valleys and steep-walled canyons, but generally are less well sorted than the lake deposits. Alluvial fan deposits are present in many parts of the State where steep-gradient tributaries enter more gently sloping valleys of larger streams. They are extensively developed in western Utah where the alluvial fans occur between the bedrock of the desert ranges and the deposits of Lake Bonneville. The fans are extremely variable in composition, are generally poorly sorted, and are partly cemented by caliche.

Glacial deposits, mainly in the form of moraines and some till, are present in scattered places in the high mountain valleys, principally



EXPLANATION

Sand and gravel, including lake, stream, and glacial deposits

Dune sand deposits

(Compiled in part (NE 1/4, NW 1/4, and SW 1/4) from Geologic map of Utah (1961, 1963, in press), W. Lee Stokes, editor; and from Barosh (1960), Butler (1913), Butler and others (1920), Eardley and Beutner (1934), Kiersch (1955), Richmond (1962), Varnes and Van Horn (1951). See list of references at back of chapter.)

FIGURE 43.—Sand and gravel in Utah.

in the Uinta and Wasatch Mountains. These deposits are largely a heterogeneous mixture ranging in particle size from clay to boulders, except where they were reworked locally by melt waters under and around the margins of the ice. The glacial deposits are grouped with the lake and stream deposits on figure 43.

Dune sands are scattered in the broad valley bottoms and basins in the western and southern parts of the State. The principal ones, of quartzose type, are shown on figure 43.

Ample and varied sources of sand and gravel exist in most sections of the State. Selection of the best available source in a given area can be simplified with an understanding of how deposits form, and search of logical sites of deposition.

The market for sand and gravel has progressively expanded up to the present and will probably continue to increase in the future, particularly in the expanding urban areas. The resources of sand and gravel are ample to supply the market in the foreseeable future. Large construction projects, such as the Flaming Gorge Dam, make large but temporary demands on normally little developed deposits away from the large urban areas. Much of the material in the eastern and southern parts of the State is in presently inaccessible canyons. Locally, some sand and gravel deposits are becoming unavailable for use in some of the rapidly expanding urban areas. In such areas, more expensive crushed rock, lightweight aggregate, or other materials may partially supplant sand and gravel in the construction industry.

SILICA

(By K. B. Ketner, Denver, Colo.)

The chemical compound silicon dioxide, or silica, is most abundant in the earth's crust, and most minerals contain some silica. Quartz, the pure silica mineral, is found in a wide variety of rocks, and is the major or only constituent in some. Because of its abundance and many useful properties, such as hardness and chemical stability, silica has important industrial uses as an ingredient in some glass, chemicals, alloys, fluxes, abrasives, refractories, filters, and railroad ballast. The chemical properties of silica used in glass, chemicals, alloys and flux are extremely important. For example, in many uses, the allowable content of minor amounts of impurities is rigidly specified. In the manufacture of glass, iron content cannot exceed 0.03 to 0.08 percent for most quality glasses, and alumina content is limited to 0.2 percent. The maximum allowable lime and magnesia is about 0.05, and the combined alkali content about 0.01 percent. Similar restrictive specifications apply to the content of phosphorus, arsenic, manganese, boron, and cobalt in silica to be used in the manufacture of silicon, silicon carbide, and other industrial chemical use.

The physical properties of silica used as abrasives, refractories, filters, and ballast are as important as chemical properties. Sandblasting requires well-sized materials free from clay or other minerals that would form dust. Silica for refractory use should be sufficiently pure and sound to withstand high heat and stress. Size specifications vary widely according to each of the many refractory uses. Silica in the form of diatomite is used as filter material. The chemically inert and physically porous qualities of diatomite are important in this use. Uses and specifications of silica are described in much greater detail by Murphy (1960), but because industrial requirements are not uniform, producers usually obtain exact specifications from potential customers.

Forms of silica occurring in Utah in presently useful quantities and grades are quartz-bearing sand, quartz-bearing gravel, quartz, sandstone, and quartzite. Low-grade deposits of diatomite, a highly porous, fine-grained form of silica, are known in the Cenozoic rocks of Utah but they are not now competitive with similar deposits in Nevada and California. Sands and gravels with high quartz contents are now in use in Utah where the refractory and abrasive qualities of the contained silica are needed but where high purity is not important. (See section on sand and gravel, p. 215.)

Utah's principal reserves of pure silica are in sandstone and quartzite formations (fig. 44). Much of this will be used in local markets as construction material, but selected parts of several formations could be utilized as chemical or industrial material. The silica of most of these formations must be crushed and screened before use, but it has the advantage of purity unequaled by the unconsolidated deposits. Table 15 indicates the trend in production from sandstone and quartzite units in Utah, and includes both construction and industrial material. The use of large amounts of quartzite for railroad ballast accounts for the very large production of quartzite in 1958–59. The principal continuing industrial use is for refractory material for foundry sands in the smelting industry.

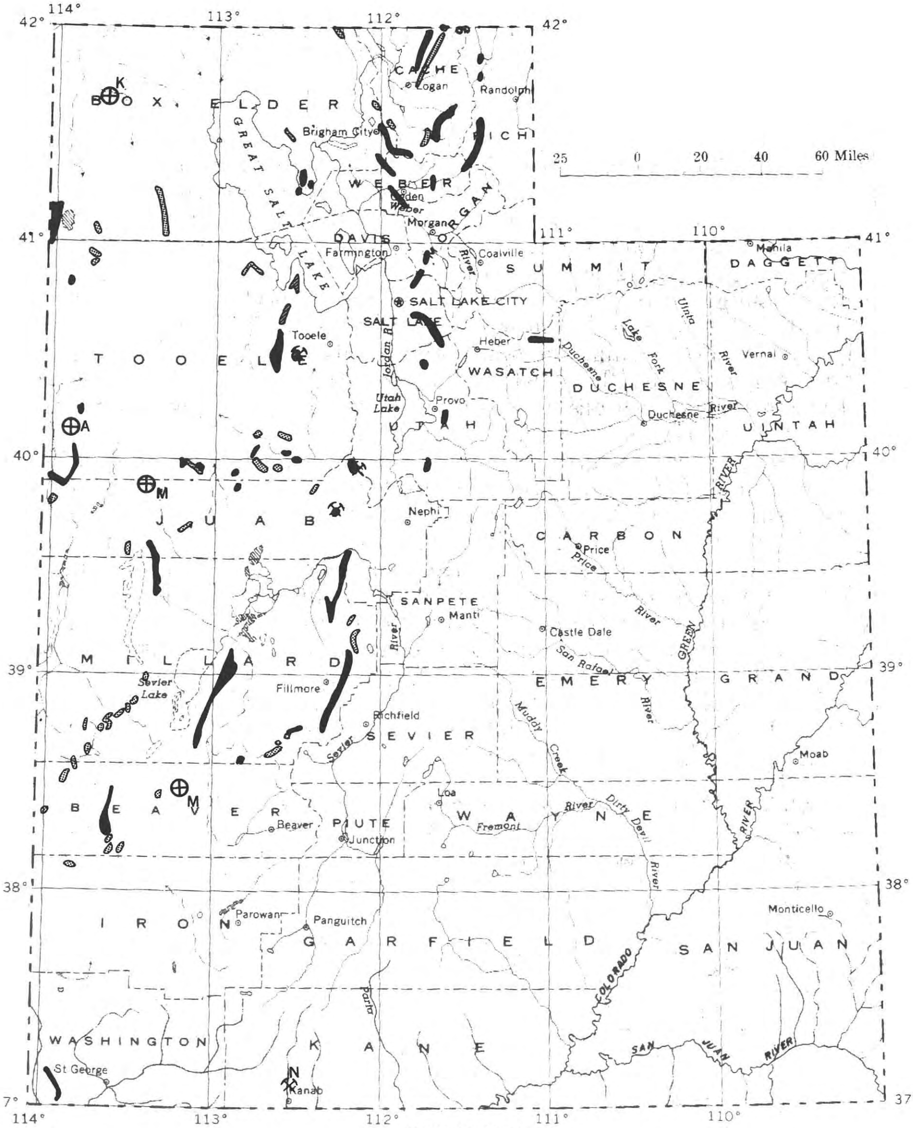
TABLE 15.—*Crushed sandstone and quartzite produced in Utah, 1950–61* [1]

Year	Short tons	Value	Year	Short tons	Value
1950	193,140	$88,014	1957	122,200	$126,800
1951	69,272	80,009	1958	10,089,400	10,119,500
1952	24,278	55,873	1959	1,785,000	1,805,000
1953	(2)	(2)	1960	74,234	81,186
1954	23,786	87,772	1961	121,677	178,203
1955	215,361	287,070			
1956	121,669	347,482	Total	12,840,017	$13,256,909

[1] Data from U.S. Bur. of Mines Minerals Yearbook, 1950–61.
[2] Data unavailable.

Sandstone and quartzite deposits are widespread sheets or strata having nearly uniform characteristics. Once a suitable stratum is selected on the basis of physical and chemical characteristics, pit or quarry sites can be chosen by equating mining and transportation charges with slight differences from place to place in composition and physical properties.

Siliceous formations or units with a high silica content can be roughly evaluated by determining the content of several elements that are generally considered deleterious for most industrial uses. These elements are principally aluminum, iron, magnesium, calcium, sodium, potassium, titanium, and manganese. Table 16 lists the content of



EXPLANATION

Outcrops of principal quartzites:

Devonian Stansbury Formation

Ordovician Swan Peak or Eureka quartzite

Cambrian quartzite

N — Active silica quarry in Navajo Sandstone

Active quarry in quartzite

K — Reported refractory mineral locality: A-Andalusite, K-Kyanite, M-Magnesite

FIGURE 44.—Silica and refractory minerals in Utah.

TABLE 16.—*Spectrographic analyses of 8 deleterious elements in 13 silicious sandstones and quartzites in Utah*

[0, not detected]

Geologic system	Formation	Number of samples	Deleterious elements (average content or range in content, in percent) [1]							
			Al	Fe	Mg	Ca	Na	K	Ti	Mn
Cretaceous	Dakota Sandstone	7	0.8	0.3	0.04	0.08	0.03	0.2	0.05	0.001
Jurassic	Bluff Sandstone	5	1.0	.3	.2	1.0	.08	.7	.05	.02
	Summerville Formation	16	.9	.3	.4	2.0	.08	.7	.03	.02
	Curtis Formation	2	2.0	.5	.5	3.0	.5	2.0	.07	.01
	Entrada Sandstone	12	.8	.3	.4	.7	.1	.8	.04	.008
	Carmel Formation	4	2.0	1.0	.7	2.0	.2	1.0	.1	.02
Triassic	Navajo Sandstone	5	1.0	.2	.08	.3	.1	.7	.04	.008
	Kayenta Formation	3	1.0	.4	.7	1.0	.3	1.0	.06	.03
	Wingate Sandstone	12	1.0	.3	.2	.4	.2	1.0	.07	.008
Ordovician	Swan Peak Quartzite	10	0.15–.7	0.15–.7	0.015–.07	0.02–.2	0	0	.005–.02	0.003–.02
Cambrian	Tintic Quartzite	7	.3–3.0	.07–.5	.02–.1	.015–.07	0–.07	0–1.5	.015–.1	.0007–.007
Precambrian	Mutual Formation	5	.7–1.5	.2–.5	.07–.1	.02–.03	0–.05	0–1.0	.05–.1	.0015–.015
	Big Cottonwood Formation	19	.3–1.5	.1–.7	.02–.3	.01–.07	0–.05	0	.02–.2	.0015–.01

[1] Spectrographic data are approximate only.

these elements in 2 or more samples taken from each of 13 of the principal siliceous sandstones and quartzites in Utah.

The analytical data indicate the siliceous units are generally quite free of deleterious materials and that silica sources of exceptional purity are present in parts of the Precambrian Big Cottonwood and Mutual Formations, the Cambrian Tintic Quartzite and the Ordovician Swan Peak Quartzite. Detailed physical properties of quartzite in these units, however, such as grain size, strength, porosity, thermal response, etc., are not yet known.

In the Wasatch and Uinta Mountains and in some ranges of the Great Basin, such as the Grouse Creek, Raft River, and Deep Creek Ranges, the principal siliceous rocks are Precambrian and Cambrian quartzites. In the Bear River Range and in many ranges of the Great Basin a prominent siliceous formation is the Ordovician Swan Peak and its correlative, the Eureka Quartzite. In the Stansbury Range an important quartzite formation is the Devonian Stansbury Formation. The outcrops of these Quartzites are shown on figure 44. On the Colorado Plateau and in southwestern Utah, the principal siliceous rocks are Triassic and Jurassic aeolian formations such as the Wingate, Navajo, Entrada, and Bluff Sandstone (fig. 5 and table 1).

Although detailed studies of critical chemical and physical properties of Utah silica deposits remain to be done, the obvious abundance and variety of siliceous rocks clearly show that silica resources in Utah are more than ample for any need, excepting possibly high quality glass sand. Careful sampling of the purest formations will be necessary to determine whether the exacting specifications of glass sand can be met.

STONE

(By W. R. Hansen, Denver, Colo.)

Utah, over the years, has had a relatively small and unsteady but growing production of stone (fig. 45). From 1900 through 1962 Utah produced nearly 59 million short tons of stone valued at more than $66 million. Utah's modest past production, however, in no way reflects the vast resources of this commodity within the State; stone resources of Utah far exceed foreseeable consumption. Most population centers in the State, moreover, are within short haulage distance of stone suitable for a wide variety of uses. Every county in the State contains potentially marketable stone. Many deposits have never been studied or evaluated. Important occurrences are shown in figure 46. Stone production of Utah has been mainly in three categories: (1) crushed and broken stone, (2) dimension stone, and (3) field stone.

UTAH PRODUCTION CATEGORIES

Crushed and broken stone.—The bulk of Utah stone production has been quarried, crushed, and broken for such uses as road "metal," railroad ballast, concrete aggregate, riprap for impeding erosion, rubble, and various chemical and metallurgical uses. Crushed and broken stone are obtained in Utah from a wide variety of igneous, sedimentary, and metamorphic rocks.

Suitability of a formation for use as crushed stone depends chiefly on three factors, outlined by Kiersch (1955, p. 27) as follows: (1) physical and chemical qualities of the rock, pertinent to the intended use; (2) uniformity of the available working face: and (3) textural

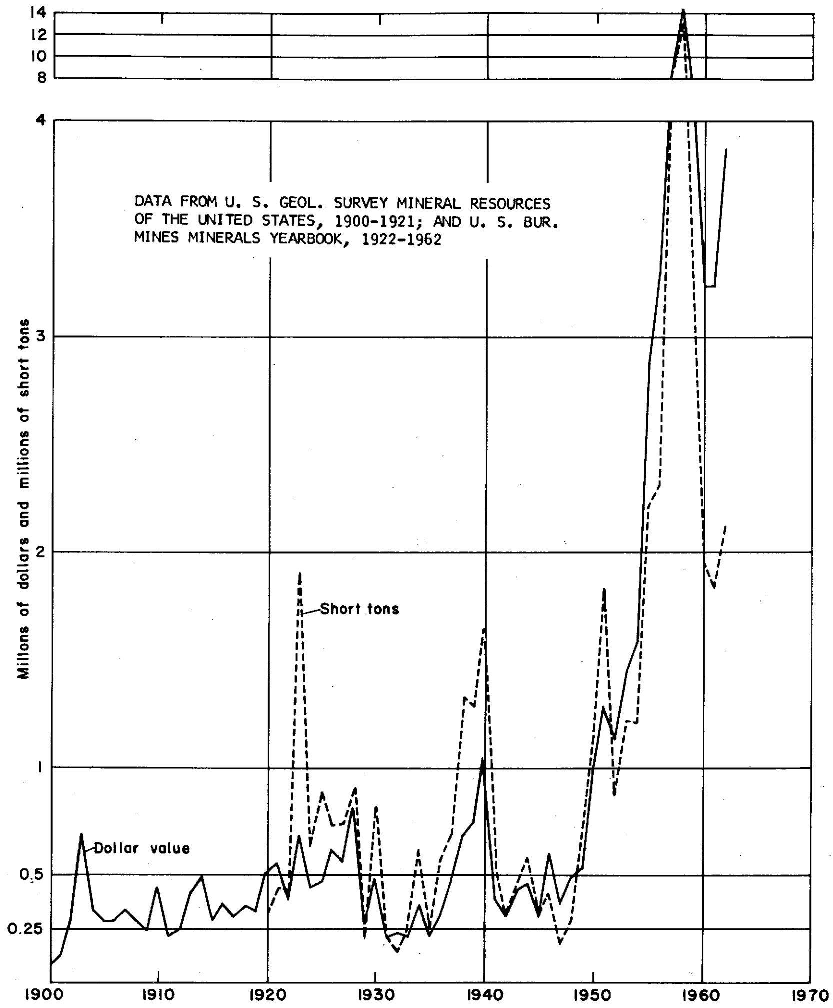
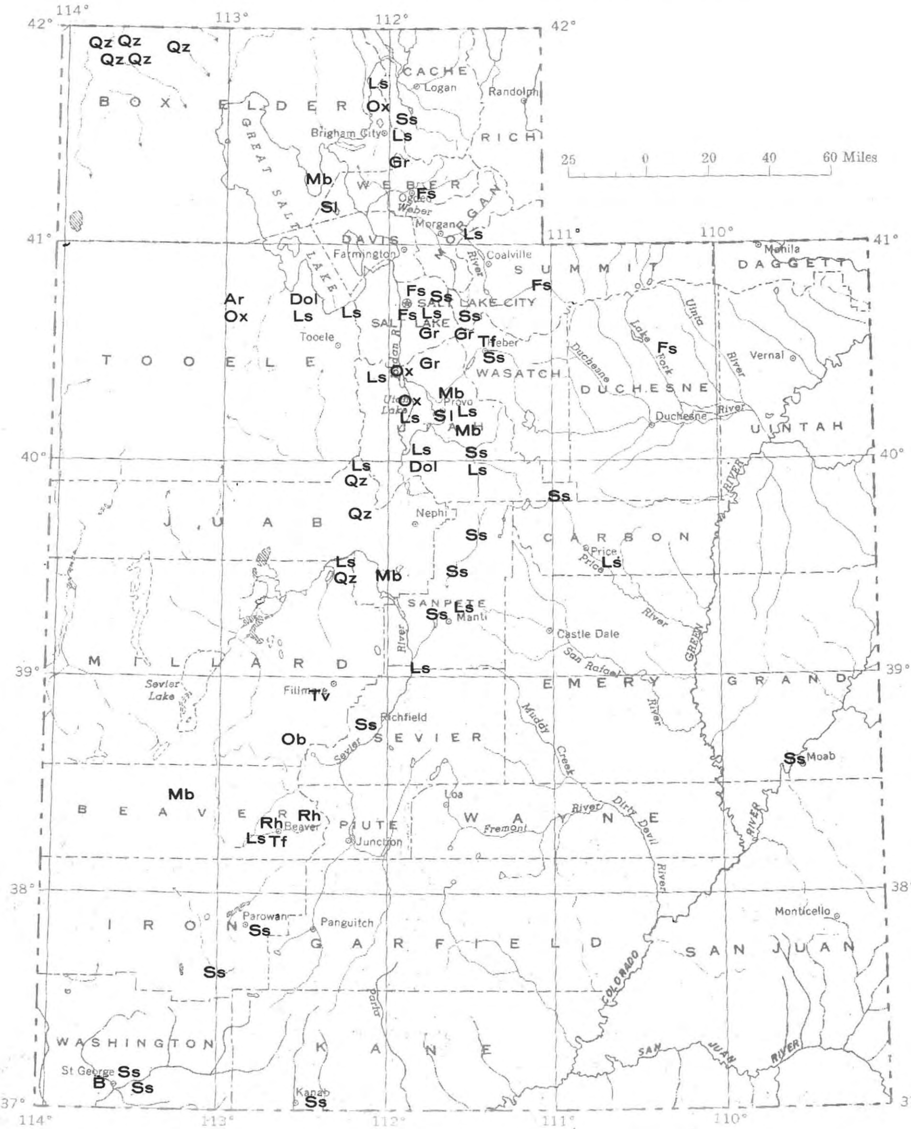


FIGURE 45.—Utah stone production, 1900–62.

and structural characteristics that influence the crushing character of the rock. The rock should crush to firm, roughly equidimensional particles, with minimal powdering. Highly abrasive rock types, such as quartzite, may be undesirable for some crushers.

Bonding quality is important if the crushed stone is to be used as aggregate. Limestone, which is abundant in Utah, ordinarily makes ideal concrete aggregate, and limestone or basalt generally adhere to bitumen better than do granite, sandstone, or conglomerate, although all these rock types may make suitable aggregate.

Stone to be used as riprap ideally consists of irregular cobble- to boulder-size fragments which are free of incipient fractures or planes of weakness and are resistant to freezing, thawing, and abrasion. Stone suitable for use as riprap is widespread in Utah and resources in most counties of the State are virtually inexhaustible.



EXPLANATION

Symbols mark quarry sites or significant localities of the following stone types:

Ar Aragonite	Ls Limestone	Rh Rhyolite
B Basalt	Mb Marble	Sl Slate
Dol Dolomite	Ob Obsidian	Ss Sandstone
Fs Field stone	Ox Onyx	Tf Tufa
Gr Granite	Qz Quartzite	Tv Travertine

FIGURE 46.—Important Utah building stone occurrences.

Broken stone quarried from attractively colored Utah rock formations has become increasingly popular in recent years for use in decorative rubble walls, facings, and fireplaces, especially in homes and other small structures where accents or special architectural effects are desired.

Dimension stone.—Utah's production of dimension stone extends back to pioneer days. Dimension stone includes blocks, sheets, and slabs of rock in either rough or finished forms that satisfy dimensional requirements for structural, decorative, or monumental purposes (Currier, 1960, p. 7). Production in Utah has included building stone, monumental stone, paving blocks, curbing, and flagging, quarried from basalt, granite, limestone, marble, quartzite, rhyolite, sandstone, schist, slate, travertine, and tufa. Of these types, limestone, sandstone, and granite have been used most widely.

In the past, dimension stone was used extensively as building blocks cut to support the full weight of a superincumbent structure. High-bearing strength, therefore, was essential; other desirable qualities such as pleasing color and texture were secondary. Nowadays, supporting structural elements consist more commonly of reinforced concrete or steel, and stone is used chiefly for textural variations and accents.

Field stone.—Field stone has been used as a building material in Utah since pioneer days; its popularity has increased in the past few years. Cobbles and boulders are split or roughly trimmed for use in rubble veneers and walls in both exteriors and interiors of residences and small commercial buildings.

Field stone is collected in many localities from varied geologic environments, and the so-called gleaning of stone has become a sizable business. Much field stone is taken from coarse alluvial deposits at the mouths of canyons, particularly in the Salt Lake City-Ogden area. It also is collected at Holiday Park on the upper Weber River in Summit County and from the Yellowstone River area in Duchesne County. In some areas ready supplies are nearly exhausted. Reportedly, some field stone is taken from outcrops of Knight Conglomerate (Eocene). Rough-textured quartzite of pleasing form and color is collected from talus slopes at the foot of cliffs and ledges particularly from Precambrian terranes in the Raft River and Grouse Creek Ranges, Box Elder County.

CHIEF ROCK TYPES

Dollar values of four major types of stone produced in Utah, 1900–1962, are shown in the following table. Some totals are incomplete, owing to figures withheld to prevent disclosure of confidential information.

	Granite	Sandstone	Marble	Limestone
1900-10	$64,375	$597,278	$12,520	$2,753,281
1911-20	14,184	245,553	----------	2,826,010
1921-30	44,765	584,150	----------	3,939,809
1931-40	90,826	475,317	59,681	2,063,870
1941-50	----------	146,884	635,612	3,181,896
1951-60	135,600	13,333,220	78,050	20,454,468
1961-62	336,207	964,332	2,674	5,701,918
Totals	$703,930	$16,336,743	$788,537	$40,861,252

Limestone.—Limestone has by far the greatest past and present market value of any stone quarried in Utah. From 1900 through 1962 approximately 30 million short tons was produced at a value of about $41 million. Only a small fraction of the limestone produced, however, has been in the dimension stone category. Most of it has been crushed for use as aggregate, smelter flux, portland cement, rock dust, and poultry feed. Tooele County is the leading producer. (See section on limestone and dolomite, p. 188, for nondimensional uses).

For dimensional use the Flagstaff Limestone (Paleocene and Eocene(?)), quarried near Thistle and Hobble Creek in Utah County, has led all other limestone formations and has been used in many buildings throughout the Nation. The Flagstaff Limestone crops out widely along the east flank of the southern Wasatch Mountains, on the tops and flanks of the Wasatch and Gunnison Plateaus, and in adjacent areas (Spieker and Reeside, 1925, p. 448). It takes a high polish and is well adapted to interior use. Concretionary varieties quarried 5 miles south of Thistle and marketed as "Birdseye Marble" and "Golden Travis" are used in wainscots, sills, stair risers, and interior facings. It can be seen in the interiors of the Utah State Capitol and Salt Lake City post office buildings, and in post office buildings in Long Beach, Calif., Montrose, Colo., and Miami, Fla. A highly fossiliferous variety has been similarly used in the old library building on the University of Utah campus.

An oolitic limestone known commercially as "Manti Stone" and "Sanpete White" has been quarried from the Green River Formation (Eocene) at Ephraim, Manti, and Indianola in Sanpete County, chiefly for use as building blocks. It has been used for the exteriors of such buildings as the Mormon Temple at Manti and the Park Building on the University of Utah campus, and has been used in the interiors of the Utah and California State Capitol buildings. Though attractive, it tends to scale on prolonged exposure to the weather. Some oolitic limestone has been quarried in Sanpete County under the name "San Pete Sandstone."

Limestone has been quarried for dimension stone also at Beaver and Greenville in Beaver County, Mantua in Box Elder County, Grayson in San Juan County, and Lehi and Provo in Utah County (Sanford and Stone, 1914, p. 186).

Sandstone.—Between 1900 and 1962, inclusive, Utah produced approximately 15 million short tons of sandstone valued at more than $16 million from quarries in Garfield, Grand, Iron, Kane, Millard, Salt Lake, Sanpete, Sevier, Summit, Uintah, Utah, Wasatch, and Washington Counties. Sandstone is now the most widely used dimension stone in Utah, and the marketable reserves are enormous. It is especially favored for use as ashlar blocks in walls, sills, fireplaces, barbeque pits, and similar structures and as flagstones for walks and patios. Its use as building blocks for structural support has diminished sharply. Large tonnages of crushed sandstone are marketed in Utah for use as refractories and concrete aggregate.

Greatest present sandstone production comes from the red and gray Nugget Sandstone (Lower Jurassic) of central-northern Utah, a stone favored by high quality, pleasing color, and nearness to transportation and markets. Nugget Sandstone has been quarried at Red Butte, Emigration, and Parleys Canyons near Salt Lake City in Salt

Lake County, at numerous localities near Snyderville and Park City in Summit County, near Heber City in Wasatch County, and at Diamond Fork Canyon and Thistle in Utah County. It has been utilized in many buildings and parts of buildings in Salt Lake City such as the Dooley Building, St. Mark's Cathedral, foundation and buttresses of the Tabernacle, and many of the buildings at Fort Douglas.

In the past when building blocks were more widely used, large tonnages of gray sandstone were quarried from the Colton Formation (Tertiary) at Kyune Station near Colton in Utah County for sale both outside and inside the State of Utah (Dixon, 1938). This stone was used in Salt Lake City in constructing the old City and County Building, Cathedral of the Madeleine, and many other buildings.

Other sandstones of good quality and large reserves are quarried from the Moenkopi, Chinle, and Wingate Formations (Triassic) in southern and eastern Utah. Considerable tonnages are shipped from quarries in Washington County to California and Nevada, but exploitation of these formations is discouraged by long haulage distances to markets. Light-gray to yellowish-gray sandstone of good quality is quarried from the Frontier Sandstone (Upper Cretaceous) in the upper Weber Valley, Summit County, and marketed mainly in the Salt Lake City area. Reserves are large.

Marble.—Commercial marble of Utah, including onyx marble, is quarried mostly from rocks known technically as limestone and travertine. The chief requirements are durability, pleasing color, and the capacity to take a high polish. Deposits are widely scattered over the State, especially in Beaver, Box Elder, Millard, Tooele, and Utah Counties. Production from 1900 through 1962 exceeded 72,000 short tons valued at more than $788,000. Utah marble has been quarried for decorative interior uses such as wainscoting, but present production is utilized mostly for terrazzo chips, roofing granules, and small ornamental objects.

Onyx marble or travertine is produced from vein deposits in the Lake Mountains west of Utah Lake in Utah County (Okerlund, 1951, p. 64), the Cedar Mountains 55 miles east of Wendover in Tooele County, and from Fillmore in Millard County. It formerly was quarried near Honeyville in Box Elder County.

A large undeveloped deposit of white magnesian marble crops out on the west slope of the San Francisco Mountains, halfway between Frisco and Newhouse in Beaver County (Lewis and Varley, 1919, p. 52). This deposit seems to have been formed by contact metamorphism of the Grampian limestone (Ordovician and Cambrian(?)) adjacent to a quartz monzonite stock (Butler and others, 1920, p. 515). A large deposit of marble, probably a contact metamorphic deposit also, is reported at Ibapah in Tooele County (Dixon, 1938, p. 20). Other undeveloped deposits occur in Juab, Salt Lake, Sanpete, Summit, Tooele, and Utah Counties. Black marble which takes a high polish has been reported from Pelican Point in Utah County and from a locality in Tooele County 5 miles southwest of Fairfield.

Granite.—Many varieties of igneous and metamorphic crystalline rock are quarried and marketed as commercial granite. From 1900 through 1962 more than 476,000 short tons of commercial granite valued at about $704,000 was produced in Utah. Commercial granite has been quarried from Precambrian gneissic granite at Willard, Box Elder County; from Tertiary quartz monzonite in Little Cottonwood Canyon, Salt Lake County, and Alpine, Utah County; from Tertiary monzonite near Heber, Wasatch County; and from various small Precambrian bodies near Ogden, Weber County. Some of the granite obtained near Ogden was quarried from large field stones.

The largest tonnage of granite has come from the Little Cottonwood stock and its talus slopes in Little Cottonwood Canyon, chiefly for building blocks, monumental stone, and crushed and broken stone. This stone was used for the Mormon and Masonic Temples in Salt Lake City and the State capitol building.

Quartzite.—Early production of quartzite was chiefly from quarries in Millard County, and was used for gannister. More recently lustrous green, white, and light-brown quartzite and quartz schist have been quarried for ornamental use from the Dove Creek formation of Stringham (1963) (Precambrian) of the Raft River and Grouse Creek Ranges, Box Elder County. This attractive stone is used chiefly for decorative effects in rubble walls and veneers; considerable quantities are marketed outside the State. Specimen material is sold for rock gardens and aquariums.

Quartzite has been quarried on a small scale in Salt Lake and Utah Counties for use as crushed stone.

Other building stones.—Sporadic but small production of slate used mostly for roofing granules, and use of various volcanic rocks including basalt, rhyolite, obsidian, and tuff has been reported. The localities are noted on figure 46.

SULFUR

(By Priscilla Mount, Washington, D.C.)

Sulfur is a yellow to yellowish-brown, resinous, brittle element which occurs both in the native state and in combination with other elements. It is widespread in metallic sulfides, calcium sulfates, and hydrogen sulfide gas ("sour" gas) associated with natural gas and petroleum. Sulfur is used in elemental form and in the manufacture of sulfuric and sulfurous acid.

Sulfur in the United States is now mainly produced by the Frasch solution-mining process from salt domes, as a byproduct of sour gas in the petroleum industry, and as a smelter byproduct of sulfide ores. In 1962, 6.84 million long tons in all forms was produced, of which 75 percent was from Frasch process mines.

Utah's first sulfur was produced from hot springs in the late 1860's (Romney, 1963), and in recent years it has been supplied as a smelter byproduct of sulfide ores. During most of the intervening period, however, it has come almost entirely from deposits at Cove Creek and Sulphurdale in Millard and Beaver Counties. The deposits at Cove Creek were discovered in 1869, and the first appreciable production was in 1885. From 1885 to 1952 about 30,000 long tons was produced, having a value of about $700,000. The peak production was 3,125 long tons in 1906. Thereafter, relatively cheap Frasch sulfur from the Gulf Coast and sour gas sulfur supplied most market needs and Utah's output has been sporadic and not more than a few hundred tons per year.

There has been no output from these deposits since 1952, except for experimental purposes.

The only sulfur produced in Utah at present is a byproduct of smelted metallic sulfides. Kennecott Copper Corp.'s Garfield smelter (A, fig. 47) adjacent to the corporation's mill and refinery near the south shore of Great Salt Lake, produces about 1,000 tons of sulfuric acid daily from smelter gases, constituting Utah's entire output. Most of the sulfide concentrates for the smelter come from the Bingham copper mine. The rest of the concentrates are from the United States Smelting, Mining & Refining Co.'s Midvale mill (B, fig. 47). The sulfides from the Midvale mill are pyrite concentrates, a byproduct of lead-zinc ores from the company's Lark mine.

DESCRIPTION OF DEPOSITS

The sulfur resources of Utah that have been exploited are in two quite different kinds of deposits. Current production, as mentioned above, comes entirely from metallic sulfide deposits in the Bingham district which are described in the sections on copper (p. 75), lead, zinc, and silver (p. 96), and economic geology (p. 28). Formerly, production of native sulfur came from deposits associated with springs and fumaroles. These deposits are described below, and their location is shown on figure 47.

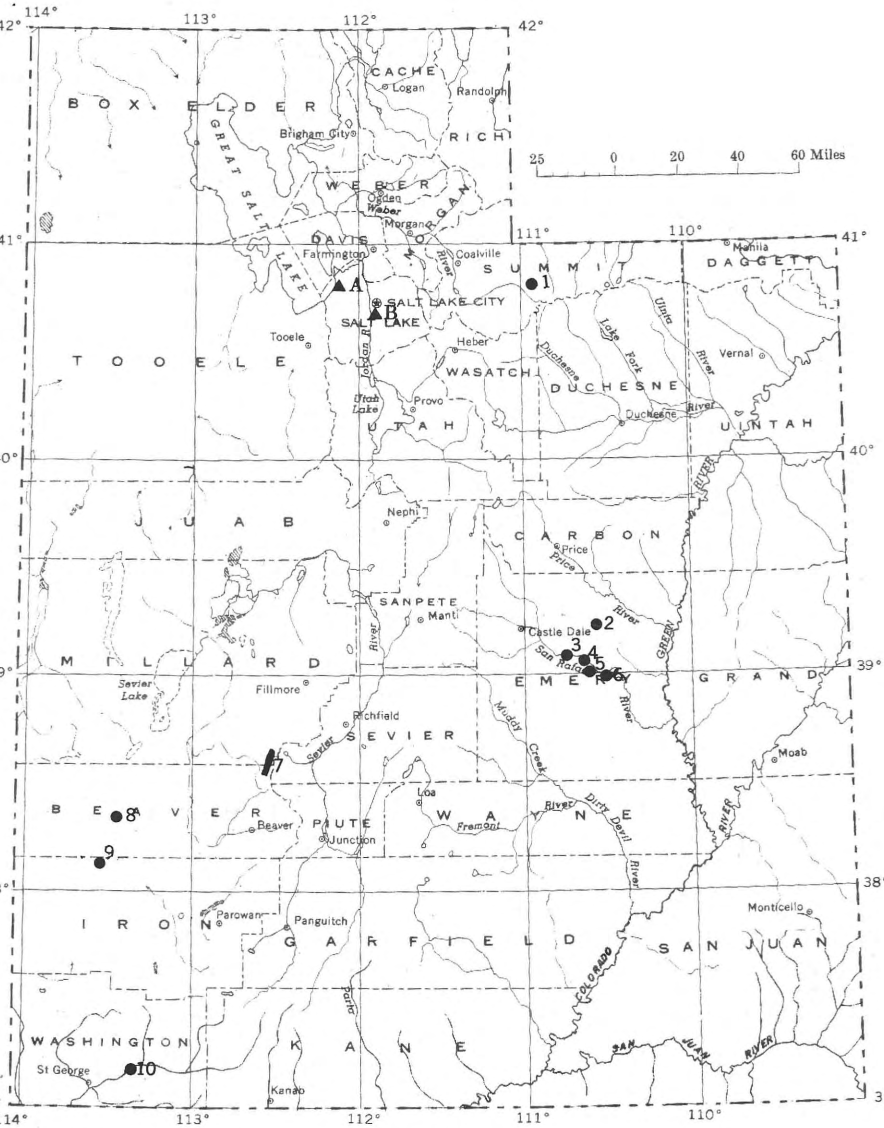
The Summit County sulfur deposit (No. 1) is about 25 miles east of Coalville. Many years ago some sulfur was taken out, probably by hand methods. The deposit was investigated in 1927, but no development work was done.

A sulfur deposit (No. 2) on Cedar Mountain in Emery County, 15 miles north of the San Rafael River deposit (No. 5), is on a wash tributary to the Price River (Hess, 1913, p. 349). Native sulfur is associated with cool springs, and is largely sulfur cementing the soil. The mineralized material is pale yellow to gray in color. Because the deposit is small and low grade, it has not been mined.

At the Mexican Bend sulfur deposit (No. 3) in Emery County, 6 to 8 miles northwest and up river from the deposits at the mouth of Black Dragon Canyon, native sulfur occurs as small crystals and earthy masses cementing soil and rock fragments (Wideman, 1957, p. 32). The sulfur-bearing material, which is pale yellow to gray in color, formed around vents, and is not extensive. The deposit can be reached only by trail and is not developed.

Native sulfur, unassociated with springs, is reported to occur in Emery County along the San Rafael River (No. 4), about 5 to 8 miles above the San Rafael Canyon deposit (Hess, 1913, p. 349). This deposit has not been developed.

The San Rafael Canyon deposit (No. 5) is 18 to 20 miles west of Greenriver, Utah, on the south side of the San Rafael River, and 5 miles from the mouth of the canyon (Hess, 1913, p. 347). Native sulfur occurs in limestone debris which overlies a thin-bedded limestone. The sulfur is deposited by oxidation of hydrogen sulfide gas in hot springs rising through the limestone. Around the springs the ground is impregnated with small crystals of sulfur and amorphous sulfur. The deposit is about 150 feet wide and 750 feet long, and is partly developed by shallow prospect trenches. There has been no production from this deposit.



EXPLANATION

List of deposits

1. Summit County
2. Cedar Mountain
3. Mexican Bend
4. San Rafael River
5. San Rafael Canyon
6. Black Dragon Canyon
7. Cove Creek-Sulphurdale
8. Brim Stone
9. Cina-mine
10. Virgin River

Numbers are mentioned in text

● Sulfur deposit

▬ Area of sulfur deposits

▲ Smelter or mill
A. Garfield smelter
B. Midvale mill

FIGURE 47.—Sulfur in Utah.

The Black Dragon Canyon (No. 6) in Emery County is on the San Rafael River, 14 miles west of Greenriver, Utah. Sulfur occurs on the south bank of the river in an area 900 feet long and 75 feet wide. Mineral springs rise through sandstone and limestone debris, depositing sulfur as a cement in the debris and soil. The sulfur is in the form of yellow crystals, dirty yellow masses, and in high-grade masses stained almost black by hydrocarbons. One of the largest deposits is 50 feet long, 25 feet wide, and 10 feet deep. There is no reported development or production.

The Cove Creek-Sulphurdale deposits (No. 7) are about 20 miles north of the town of Beaver in the Gordon mining district, Millard and Beaver Counties (Lee, 1907, p. 485). They are the largest deposits in Utah, and are in an area that extends from about 4 miles north to about 4 miles south of Old Cove Fort, in a northeast-trending band on the northwest flank of the Tushar Mountains. The sulfur deposits follow a zone of faulting which is marked by recent volcanic cones. Sulfur is being deposited in rhyolite tuffs and andesites by hydrogen sulfide gases rising along the fault zone. The rhyolite tuffs and andesites are overlain by basalt flows and crater cones. Native sulfur is found as cylindrical masses or pipes 10 to 15 feet in diameter that have a rude radial structure; as irregular banded veins of nearly pure yellow sulfur in fissures in beds of tuffaceous material; as flowers or crystals of sulfur in small cavities; and as dark-colored impregnations in rhyolite tuff.

Sulfur impregnations are the most extensive type of deposit; they are circular or elliptical in plan and section, and occupy shallow topographic basins. The deposits are in horizontally stratified, waterworn sand, gravel, and boulders, in water-lain tuff, in breccia, or a mixture of all three. In addition to native sulfur all of the known deposits contain iron sulfide. The latter occurs as intercalated thin strata or lenses with native sulfur and is in the form of a finely disseminated or semicolloidal dispersion in much of the high-grade sulfur or as amorphous or cryptocrystalline ferrous sulfide. Finely crystalline pyrite in erratic disseminations or in pyrite-bearing zones underlies some bodies of native sulfur. The thickness of these pyritic zones is not known.

Of the seven major groups of claims in the Cove Creek-Sulphurdale area, only one, the Sulphurdale group (Beaver County), has had appreciable production. Although idle at present, the Sulphurdale deposits have been worked intermittently since the 1860's. The principal deposits are at the Home mine, within the townsite of Sulphurdale, the Sulphur King mine, and the Victor Conqueror mine.

Native sulfur is found at the south end of a low hill in the southern part of Wah Wah Valley (No. 8), Beaver County, about 29 miles southwest of Milford (Stringham, 1963). Cool springs issue from the base of the knoll, depositing sulfur both in veins and around the central cores of the springs. The deposits have been explored by open cuts, adits, and an inclined winze, to a depth of about 20 feet. The deposits are small, and no production is recorded.

A native sulfur deposit (No. 9) is 11 miles northwest of Lund, Iron County. It is owned by the United Mercury Co., and is undeveloped. Another undeveloped sulfur deposit (No. 10) is located near Virgin River, south of Toquerville, in Washington County.

Principal reserves of currently exploitable sulfur in Utah are those associated with metallic ore deposits. Deposits in the Bingham district appear adequate to maintain the present daily output of 1,000 tons of sulfuric acid for several decades. Sulfide ores mined in other Utah metal mining districts could appreciably augment this production.

Utah's total potential sulfur resources are exceedingly large if a number of sources not now used were to be exploited. Sulfur resources in the native sulfur deposits of the Cove Creek-Sulphurdale area, as compiled by the U.S. Bureau of Mines in 1953, was about 2 million long tons of material that assayed about 20 percent sulfur. Resources at the Home mine are 500,000 long tons of 20 percent sulfur minable by open-pit methods; resources of the Sulphur King mine are 300,000 long tons of 25 percent sulfur; and the resources of the Victor Conqueror mine are 1,250,000 long tons of 20 percent sulfur, with the possibility of a larger tonnage in adjacent ground on three sides of the deposit.

The recovery of sulfur from gypsum and anhydrite is technically feasible, and a number of European plants have begun production. Should the process prove economically feasible in Utah, very large resources of gypsum are available in the bedded deposits described in the section on gypsum (p. 177), together with gypsum associated with Lake Bonneville deposits, and modern Great Salt Lake precipitates. Still further resources may be recoverable from sulfate in brines.

Selected References

Anderson, P. L., 1960, Bloating clays, shales and slates for lightweight aggregate, Salt Lake City, and vicinity, Utah: Univ. of Utah, unpub. M.S. thesis.

Anderson, W. L., 1960, Economic geology of the northern Silver Island Mountains, *in* Utah Geol. Soc. Guidebook 15: p. 159–161.

Anthony, J. W., Dubois, R. L., and Krumlauf, H. E., 1955, Nonmetallic minerals-geology, evaluation, and uses, *of* Mineral resources, Navajo-Hopi Indian reservation, Arizona-Utah: Tucson, Arizona Univ. Press, v. 2, p. 78–83.

Baker, A. A., 1933, Geology and oil possibilities of the Moab district, Grand and San Juan Counties, Utah: U.S. Geol. Survey Bull. 841.

———, 1946, Geology of the Green River Desert-Cataract Canyon region, Emery, Wayne, and Garfield Counties, Utah: U.S. Geol. Survey Bull. 951.

Ball, S. H., 1941, Gem stones: U.S. Bur. Mines Minerals Yearbook, Review of 1940, p. 1399–1410.

———, 1943, Gem stones: U.S. Bur. Mines Minerals Yearbook, 1941, p. 1517–1528.

———, 1945, Gem stones: U.S. Bur. Mines Minerals Yearbook, 1943, p. 1558–1570.

———, 1948, Gem stones: U.S. Bur. Mines Minerals Yearbook, 1946, p. 544–556.

Barr, J. A., 1960, Phosphate rock *in* Industrial minerals and rocks: Am. Inst. Mining, Metall., Petroleum Engineers, p. 649–668.

Bissell, H. J., 1963, Lake Bonneville: Geology of southern Utah Valley, Utah: U.S. Geol. Survey Prof. Paper 257–B, p. 101–130.

Blackwelder, Eliot, 1910, Phosphate deposits east of Ogden, Utah: U.S. Geol. Survey Bull. 430.

Brobst, D. A., 1958, Barite resources of the United States: U.S. Geol. Survey Bull. 1072–B, p. 67–130.

———, 1960, Barium minerals, *in* Industrial Minerals and Rocks, 3d Ed., Amer. Inst. Min. Met. and Petroleum Engineers, New York, p. 55–64.

Bullock, K. C., 1962, Economic geology of north-central Utah, *in* Geology of the southern Wasatch Mountains and vicinity, Utah: Brigham Young Univ. Geology Studies, v. 9, pt. 1, p. 85–94.

Bullock, K. C., Smouse, Deforrest, and Robinson, G. B., Jr., 1960, Minerals and mineral localities of Utah: Dr. K. C. Bullock, Dept. of Geol. Brigham Young Univ., Provo, Utah. 170 p.

Buranek, A. M., 1942a, Initial report on the mineral deposits of Bear Canyon, Davis County, Utah: Utah Dept. Publicity and Ind. Devel. Circ. 1.
———, 1942b, The fluorspar deposits of the Wild Cat Mountains, Tooele County, Utah: Utah Dept. Publicity and Ind. Devel., Circ. 5.
———, 1942c, Initial report on the Utah Mica and Metals property, Morgan County, Utah: Utah Dept. Publicity and Ind. Devel., Circ. 16.
———, 1948, Fluorite in Utah: Utah Dept. Publicity and Ind. Devel., Circ. 36.
Buranek, A. M., and Needham, C. E., 1949, Directory of Utah Mineral resources and consumers guide: Utah Geol. and Mineralog. Survey Bull. 36.
Burchard, E. F., 1933, Fluorspar deposits in western United States: Am. Inst. Mining Metall. Engineers Tech. Pub. 500.
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 Gale, H. S., 1912, Alunite, a newly discovered deposit near Marysvale, Utah: U. S. Geol. Survey Bull. 511.
Butler, B. S., Loughlin, G. F., Heikes, V. C., and others, 1920, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111.
Callaghan, Eugene, 1938, Preliminary report on the alunite deposits of the Marysvale region, Utah: U. S. Geol. Survey Bull. 836–D, p. 91–134.
Callaghan, Eugene, and Parker, R. L., 1961a, Geologic map of part of the Beaver quadrangle, Utah: Mineral Inv. Field Studies Map MF–202.
———, 1961b, Geology of the Monroe quadrangle, Utah: U. S. Geol. Survey Quad. Map GQ–155.
———, 1962a, Geology of the Delano Peak quadrangle, Utah: U.S. Geol. Survey Quad. Map, GQ–153.
———, 1962b, Geology of the Sevier quadrangle, Utah: U.S. Geol. Survey Quad. Map, GQ–156.
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 Invest. Prelim. Map 153..
Cheney, T. M., 1957a, Phosphate in Utah and an analysis of the stratigraphy of the Park City and Phosphoria Formations, Utah, a preliminary report: Utah Geol. Mineralog. Survey Bull. 59.
———, 1957b, Phosphate deposits in the Uinta Mountains, Utah: Guidebook, Eighth Annual Field Conference, Intermountain Assoc. Petroleum Geologists, p. 144–148.
Cheney, T. M., and Sheldon, R. P., 1959, Permian stratigraphy and oil potential, Wyoming and Utah: Guidebook, Tenth Annual Field Conference, Intermountain Assoc. Petroleum Geologists.
Clark, C. B., and McDowell, J. S., 1960, Refractories, *in* Industrial Minerals and Rocks, 3rd ed.: Am. Inst. Mining, Metallurgical and Petroleum Engineers, p. 699–712.
Clarke, F. W., 1924, Data of geochemistry: U. S. Geol. Survey Bull. 770.
Cook, E. F., 1957, Geology of the Pine Valley Mountains, Utah: Utah Geol. and Mineralog. Survey Bull. 58.
Crawford, A. L., 1941, Magnesite, a new economic mineral for Utah: Utah Academy of Sciences, Arts and Letters, Proceedings, vol. 18, p. 18.
———, 1951, Diatomaceous earth near Zion Canyon National Park, Utah: Utah Geol. and Mineralog. Survey Circ. 38.
Crawford, A. L., and Buranek, A. M., 1945, Tungsten deposits of the Mineral Range, Beaver County, Utah: Utah Univ. Bull., v. 35.
———, 1948, Halloysite of agalmatolite type, Bull Valley district, Washington County, Utah: State of Utah Dept. of Publicity and Indust. Development, Bull. 35.
———, 1951, A reconnaissance of the geology and mineral deposits of the Lake Mountains, Utah County, Utah: Utah Geol. and Mineralog. Survey Circ. 35.
Crawford, A. L., Buranek, A. M., and Bell, M. M., 1948, Kyanite schists of Grouse Creek Range, Box Elder County, Utah: Utah Academy of Sciences, Proc., vol. 25, p. 180–181.
Crawford, A .L., and Cowles, H. O., 1932, The fuller's earth deposit near Aurora, Utah: Utah Acad. Sci. Proc., v. 9, p. 55–60.
Currier, L. W., 1960, Geologic appraisal of dimension-stone deposits: U. S. Geol. Survey Bull. 1109.
Dane, C. H., 1935, Geology of the Salt Valley anticline and adjacent areas, Grand County, Utah: U. S. Geol. Survey Bull. 863.

Davis, H. W., 1949, Fluorspar and cryolite; U.S. Bur. Mines Minerals Yearbook, 1947, p. 497–515.

———, 1950, Fluorspar and cryolite: U. S. Bur. Mines Minerals Yearbook, 1948, p. 525–544.

———, 1951, Fluorspar and cryolite: U. S. Bur. Mines Minerals Yearbook, 1949, p. 511–530.

Dennis, P. E., Maxey, G. B., and Thomas, H. E., 1946, Groundwater in Pavant Valley, Millard County, Utah Utah State Eng. Tech. Pub. 3.

Dixon, H. B., 1938, The building and monumental stones of the State of Utah: Brigham Young Univ., thesis.

Dyer, B. W., 1945, Discoveries of potash in eastern Utah: Am. Inst. Mining, Met. Engr. Tech. Pub. 1755.

Eardley, A. J., 1933, Stratigraphy of the southern Wasatch Mountains, Utah: Michigan Acad. Sci. Papers, v. 18, p. 307–344.

———, 1938, Sediments of Great Salt Lake, Utah: Am. Assoc. Petroleum Geologists Bull., v. 22, no. 10, p. 1305–1411.

———, 1962, Glaubers salt bed west of Promontory Point, Great Salt Lake: Utah Geol. and Mineralog. Survey Spec. Studies no. 1.

Eardley, A. J., and Beutner, E. L., 1934, Geomorphology of Marysvale Canyon and vicinity: Utah Acad. Sci. Proc., v. 11, p. 149–159.

Ehlmann, A. J., 1959, Pyrophyllite in shales of north central Utah: Bull. 94, Utah Engineering Experiment Station, University of Utah.

Elston, D. P., and Shoemaker, E. M., 1960, Late Paleozoic and early Mesozoic structural history of the Uncompahgre front, *in* Geology of the Paradox Basin fold and fault belt: Four Corners Geol. Soc. 3rd Field Conf., p. 47–55.

Erickson, M. P., 1963, Volcanic geology of western Juab County, Utah, *in* Beryllium and uranium mineralization in western Juab County, Utah: Utah Geol. Soc. Guidebook to the Geology of Utah no. 17, p. 23–35.

Engineering and Mining Journal, 1958, USS unveils $9-million flourine plant: Eng. Mining Jour., v. 159, no. 1, p. 154.

Everett, F. D., and Wilson, S. R., 1950, Investigation of the J. B. flourite deposit, Beaver County, Utah: U.S. Bur. Mines Rept. Inv. 4726.

———, 1951, Investigation of the Cougar Spar fluorspar deposit, Beaver County, Utah: U.S. Bur. Mines Rept. Inv. 4820.

Fleischer, Arthur, 1944, The Kalunite process: Am. Inst. Mining Met. Engineers Tech. Pub. no. 1713.

Fogarty, C. F., and Tippie, F. E., 1961, Texas Gulf Sulphur Company's new potash project: Mining Cong. Jour., v. 47, no. 12, p. 53–55, 60.

Foshag, W. F., Switzer, George, and Thomson, R. D., 1954, Gem stones: U.S. Bur. Mines Minerals Yearbook, 1951, p. 604–612.

Foster, W. R., 1960, The sillimanite group—kyanite, andalusite, sillimanite, dumortierite, topaz, *in* Industrial Minerals and Rocks, 3rd ed.: Am. Inst. Mining, Metallurgical, and Petroleum Engineers, p. 773–787.

Frey, Eugene, 1947, Blue Bell fluorite deposits, Beaver County, Utah: U.S. Bur. Mines Rept. Inv. 4091.

Gale, H. S., and Richards, R. W., 1910, Preliminary report on the phosphate deposits of Wyoming and Utah: U.S. Geol. Survey Bull. 430, p. 457-535.

Gilbert, G. K., 1890, Lake Bonneville: U.S. Geol. Survey Mon. 1.

Gilliland, W. N., 1951, Geology of the Gunnison quadrangle, Utah: Nebr. Univ. Studies, new series, no. 8.

Gilluly, James, 1929, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U.S. Geol. Survey Bull. 806, p. 69–130.

Gregory, H. E., 1917, Geology of the Navajo country; a reconnaissance of parts of Arizona, New Mexico, and Utah: U.S. Geol. Survey Prof. Paper 93.

———, 1950a, Geology and geography of the Zion Park region, Utah and Arizona: U.S. Geol. Survey Prof. Paper 220, 200 p.

———, 1950b, Geology of eastern Iron County, Utah: Utah Geol. and Mineralog. Survey Bull. 37.

———, 1951, The geology and geography of the Paunsaugunt region, Utah: U.S. Geol. Survey Prof. Paper 226.

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.

Greaves-Walker, A. F., 1911, The commercial clays of Utah: Trans. Am. Ceramic Soc., v. 13, p. 277–300.

Griffitts, W. R., and Rader, L. F., Jr., 1963, Beryllium and fluorine in mineralized tuff, Spor Mountain, Juab County, Utah: U.S. Geol. Survey Prof. Paper 475–B, article 4.

Grim, R. E., 1953, Clay mineralogy: McGraw-Hill, New York.

———, 1962, Applied clay mineralogy: McGraw-Hill, New York.

Grogan, R. M., 1960, Fluorspar and cryolite, *in* Industrial minerals and rocks: New York, Am. Inst. Mining Metall. Petroleum Engineers, p. 363–382.

Gulbrandsen, R. A., 1960, Petrology of the Meade Peak Phosphatic Shale Member of the Phosphoria Formation at Coal Canyon, Wyoming: U. S. Geol. Survey Bull. 1111C.

Hahl, D. C., and Langford, R. H., 1963, Dissolved-mineral inflow to Great Lake and chemical characteristics of the Salt Lake brine, Pt. 2, Technical report: Utah Geol. and Mineralog. Survey Water Resources Bull. 3, Pt. 1.

Hahl, D. C., and Mitchell, C. G., 1963, Dissolved-mineral inflow to Great Salt Lake and chemical characteristics of the Salt Lake brine, Part 1, selected hydrologic data: Utah Geol. and Mineralog. Survey Water Resources Bull. 3, part 1.

Hall, M. B., and Banning, L. H., 1958, Removing and recovering flourine from western phosphate rock and utilizing the deflourinated rock: U. S. Bur. Mines Rept. Inv. 5381.

Hanley, J. B., Heinrich, E. W., and Page, L. R., 1950, Pegmatite investigations in Colorado, Wyoming, and Utah: U. S. Geol. Survey Prof. Paper 227.

Hansen, W. R., 1955, Geology of the Flaming Gorge Quadrangle, Utah-Wyoming: U.S. Geol. Survey Geol. Quad. Map GQ–75.

Hardy, C. T., 1952, Eastern Sevier Valley, Sevier and Sanpete Counties: Utah Geol. and Mineralog. Survey Bull. 43.

Hart, R. A., 1932, The non-metallic mineral resources of Utah: The Utah Engineer, v. 7, no. 1, p. 3.

Hartwell, J .W., and Blankenbaker, E. V., 1958, Gem stones: U. S. Bur. Mines Minerals Yearbook, 1955, v. 1, p. 479–490.

Hartwell, J. W., and Brett, B. A., 1962, Gem stones: U. S. Bur. Mines Minerals Yearbook, 1961, v. 1, p. 585–596.

Hartwell, J. W., and Waters, E. B., 1958, Gem stones: U. S. Bur. Mines Minerals Yearbook, 1956, v. 1, p. 511–523.

Hess, F. L., 1913, A sulphur deposit in the San Rafael Canyon, Utah: U. S. Geol. Survey Bull. 530–0.

Hild, J. H., 1946, Exploration of alunite deposits Marysvale, Piute County, Utah: U. S. Bur. Mines Rept. Invest. 3972.

Hite, R. J., 1961, Potash-bearing evaporite cycles in the salt anticlines of the Paradox Basin, Colorado and Utah, U. S. Geol. Survey Prof. Paper 424–D, article 337.

Howes, M. H., 1962, The mineral industry of Utah: U. S. Bur. Mines Minerals Yearbook 1961, v. 3, p. 1029–1057.

Huddle, J. W., Mapel, W. J., and McCann, F. T., 1951, Geology of the Moon Lake area, Duchesne County, Utah: U. S. Geol. Survey Oil and Gas Inv. Map OM–115.

Hunt, C. B., Varnes, H. D., and Thomas, H. E., 1953, Lake Bonneville: Geology of the northern Utah Valley, Utah: U. S. Geol. Survey Prof. paper 257–A.

Hyatt, E. P., 1956, Clays of Utah County, Utah: Utah Geol. and Mineralog. Survey Bull. 55.

Hyatt, E. P., and Cutler, I. B., 1953, Ceramic value of the Mancos shale of Castle Valley and Book Cliffs, Utah: Utah Acad. Sci., Arts, and Letters Proc., v. 30, p. 117–118.

Ives, R. L., 1948, The Skull Valley area, Utah: Rocks and Minerals, v. 23, p. 193–204.

Jahns, R. H., 1960, Gem stones and allied materials, *in* Industrial minerals and rocks: New York, Am. Inst. Mining Metall. Petroleum Engineers, p. 383–441.

Jones, C. C., 1907, The discovery and opening of a new phosphate field in the United States: Am. Inst. Mining Engineers Bull. 82, p. 2411–2435.

Jones, D. J., 1953, Gypsum-oolite dunes, Great Salt Lake Desert, Utah: Am. Assoc. Petroleum Geologists Bull. v. 37, no. 11, p. 2530–2538.

Kemp, J. F., and Billingsley, Paul, 1918, Notes on Gold Hill and vicinity, Tooele County, Western Utah: Economic Geology, v. 13, p. 247–274.

Kerns, W. H., Kelly, F. J., and Mullen, D. H., 1959, The mineral industry in Utah: U.S. Bur. Mines, Minerals Yearbook, 1958, v. 3, p. 935–965.

Kerr, P. F., and Kulp, J. L., 1949, Reference clay localities, United States: Prelim. Rpt. 2, A.P.I. Proj. 49.

Kerr, P. F., and others, 1957, Marysvale, Utah, uranium area Geol. Soc. America Sp. Paper 64.
Kiersch, G. A., 1955, Mineral resources of the Navajo-Hopi Indian Reservations, Arizona-Utah, vol. 2, Nonmetallic minerals: Arizona Univ. Press, Tucson.
———, Mineral resources of the Navajo-Hopi Indian Reservations, Arizona-Utah, vol. 3, Construction materials—geology, evaluation, and uses: Arizona Univ. Press, Tucson.
Kildale, M. B., and Thomas, R. C., 1957, Geology of the halloysite deposits at the Dragon mine, *in* Utah Geol. Soc. Guidebook to the geology of Utah, no. 12, p. 94–96.
King, C. R., 1953, Cove Creek sulphur: Min. Eng., v. 5, no. 4, p. 375–378.
Kinney, D. M., 1955, Geology of the Uinta River-Brush Creek area, Duchesne and Uintah counties, Utah: U.S. Geol. Survey Bull. 1007.
Kraus, E. H., and Slawson, C. B., 1947, Gems and gem materials: McGraw-Hill Book Co., Inc., New York.
Kunz, G. F., 1893, Precious stones: U.S. Geol. Survey Mineral Resources of U.S., 1892, p. 756–781.
Larsen, E. S., and Shannon, E. V., 1930, The minerals of the phosphate nodules from near Fairfield, Utah: Am. Mineralogist, v. 15, no. 8, p. 307–337.
Lee, W. T., 1907, The Cove Creek sulphur beds, Utah: U.S. Geol. Survey Bull. 315–Q.
Lewis, R. S., and Varley, Thomas, 1919, The mineral industry of Utah: Utah Univ. Bull., v. 10, no. 11 (Utah Engineering Station, Department of Metallurgical Research, Bull. no. 12).
Loughlin, G. F., 1915, Recent alunite developments near Marysvale and Beaver, Utah: U.S. Geol. Survey Bull. 620-K.
Lupton, C. T., 1913, Gypsum along the west flank of the San Rafael Swell, Utah: U.S. Geol. Survey Bull. 530.
Mansfield, G. R., 1927, Geography, geology and mineral resources of part of southeastern Idaho: U.S. Geol. Survey Prof. Paper 152.
McDougal, R. B., 1960, Fluorine, *in* Mineral facts and problems, 1960 edition: U.S. Bur. Mines Bull. 585, p. 305–315.
McDougal, R. B., and Roman, V. M., 1961, Fluorspar and cryolite: U.S. Bur. Mines Minerals Yearbook, 1960, p. 473–492.
McKelvey, V. E., Swanson, R. W., and Sheldon, R. P., 1953, The Permian phosphate deposits of Western United States: Internat. Geol. Cong., 19th, Algiers, 1952, Comptes rendus, sec. 11, pt. 11, p. 45–64.
McKelvey, V. E., Williams, James Steele, Sheldon, R. P., Cressman, E. R., Cheney, T. M., and Swanson, R. W., 1959, The Phosphoria, Park City, and Shedhorn Formations in the western phosphate field: U.S. Geol. Survey Prof. Paper 313–A.
Murphy, T. D., 1960, Silica sand and pebble, *in* Industrial Minerals and Rocks, 3rd ed.: Am. Inst. Mining, Metallurgical and Petroleum Engineers, p. 763–772.
Murray, H. H., 1960, Clays, *in* Industrial Minerals and Rocks (Nonmetallics other than fuels), 3rd ed.: A.I.M.E., New York, p. 259–284.
Nackowski, M. P., and Levy, Enrique, 1959, Mineral resources of the Delta-Milford area: Univ. of Utah, Eng. Expt. Sta. Bull. 101.
Nolan, T. B., 1927, Potash brines in the Great Salt Lake Desert, Utah: U.S Geol. Survey Bull. 795.
———, 1935, The Gold Hill mining district, Utah: U.S. Geol. Survey Prof. Paper 177.
Okerlund, M. D., 1951, Geology of the calcite-aragonite deposits of Lake Mountain, Utah: Compass, v. 29, no. 1, p. 64–72.
Palache, Charles, 1934, Minerals from Topaz Mountain, Utah: Am. Mineralogist, v. 19, no. 1, p. 14–15.
Patterson, C. M., 1960, Lime and calcium, *in* Mineral facts and problems, 1960 ed.: U.S. Bur. Mines Bull. 585, p. 463–472.
Patton, H. B., 1908, Topaz-bearing rhyolite of the Thomas Range, Utah: Geol Soc. America Bull., v. 19, p. 177–192.
Peterson, J. A., 1955, Marine Jurassic rocks, northern and eastern Uinta Mountains and adjacent areas: Wyoming Geol. Assoc. Guidebook 10th Annual Field Conf. 1955.
Pettijohn, F. J., 1957, Sedimentary rocks, 2d ed.: New York, Harper and Bros.
Picard, M. D., 1957, Green River and Lower Uinta Formations—subsurface stratigraphic changes in central and eastern Uinta Basin, Utah: Intermountain Assoc. Petroleum Geologists Guidebook, 8th Ann. Field Conf. p. 116–130.

Pierce, W. G., and Rich, E. I., 1962, Summary of rock salt deposits in the United States as possible storage sites for radioactive waste materials: U.S. Geol. Survey Bull. 1148.

Raburg, W. A., 1886, Salt: U.S. Geol. Survey Min. Resources of the U.S., p. 628–641.

Reeside, J. B., Jr., and Bassler, Harvey, 1922, Stratigraphic section in southwestern Utah and northwestern Arizona: U.S. Geol. Survey Prof. Paper 129–D, p. 53–77.

Richardson, G. B., 1941, Geology and mineral resources of the Randolph Quadrangle, Utah-Wyoming: U.S. Geol. Survey Bull. 923.

Rigby, J. K., 1958, Geology of the Stansbury Mountains, *in* Geology of the Stansbury Mountains, Tooele County, Utah: Utah Geol. Soc., Guidebook to the geology of Utah, no. 13.

Romney, M. P., 1963, Historical review of mining in Utah: Mining Congress Jour. v. 49, no. 5.

Sanford, Samuel, and Stone, R. W., 1914, Useful minerals of the United States: U.S. Geol. Survey Bull. 585.

Schlegel, D. M., 1957, Gem stones of the United States: U.S. Geol. Survey Bull. 1042–G, p. 203–253.

Severy, C. L., Kline, M. H., and Allsman, P. T., 1949, Investigations of the Thompson magnesium well, Grand County, Utah: U.S. Bureau of Mines Rept. Inv. 4496.

Sinkankas, John, 1959, Gem stones of North America: D. Van Nostrand Co., Inc., Princeton, N.J.

———, 1961, Gem stones and minerals: How and where to find them: D. Van Nostrand Co., Inc., Princeton, N.J.

Spieker, E. M., and Reeside, J. B., Jr., 1925, Cretaceous and Tertiary formations of the Wasatch Plateau, Utah: Geol. Soc. America Bull., v. 36, p. 435–454.

Staatz, M. H., and Carr, W. J., (in preparation), Geology and mineral deposits of the Thomas and Dugway ranges, Juab and Tooele Counties, Utah: U.S. Geol. Survey Prof. Paper 415.

Staatz, M. H., and Griffitts, W. R., 1961, Beryllium-bearing tuff in the Thomas Range, Juab County, Utah: Econ. Geology, v. 56, p. 941–950.

Staatz, M. H., and Osterwald, F. W., 1959, Geology of the Thomas Range fluorspar district, Juab County, Utah: U.S. Geol. Survey Bull. 1069.

Sterrett, D. B., 1907, Precious stones: U.S. Geol. Survey Mineral Resources U.S., 1906, p. 1213–1252.

———, 1908, Precious stones: U.S. Geol. Survey Mineral Resources of the U.S., 1907, pt. 2, p. 795–842.

———, 1909, Precious stones: U.S. Geol. Survey Mineral Resources of the U.S., 1908, pt. 2, p. 805–859.

———, 1912, Gems and precious stones: U.S. Geol. Survey Mineral Resources U.S., 1911, pt. 2, p. 1037–1078.

Stokes, W. L., 1963, Geologic map of Utah, northwest quarter: University of Utah.

Stone, R. W., and others, 1920, Gypsum deposits of the United States: U.S. Geol. Survey Bull. 697.

Stringham, Bronson F., 1963, Hydrothermal alteration in the southeast part of the Frisco Quadrangle, Beaver County, Utah: Utah Geological and Mineralogical Survey, Special Studies 4.

Stringham, Bronson, and Cahoon, H. P., 1959, Ceramic red clay near Henefer, Utah, *in* Inter-mountain Assoc. Petroleum Geologists Guidebook, 10th Ann. Field Conf., p. 204–206.

Sverdrup, H. U., Johnson, M. W., and Fleming, R. H., 1942, The oceans—their physics, chemistry and general biology: Prentice-Hall, New York.

Swanson, R. W., McKelvey, V. E., and Sheldon, R. P., 1953, Progress report on investigations of western phosphate deposits: U.S. Geol. Survey Circ. 297.

Thoenen, J. R., 1941, Alunite resources of the United States: U.S. Bur. Mines Rept. Invest. 3561.

Thomas, H. E., and Taylor, G. H., 1946, Geology and ground-water resources of Cedar City and Parowan Valley, Iron County, Utah: U.S. Geol. Survey Water-Supply Paper 993.

Thompson, R. B., 1937, Utah sulphur industries: Compass, v. 17, p. 166–169.

Thomson, R. D., Switzer, George, and Blankenbaker, E. V., 1956, Gem stones: U.S. Bur. Mines Minerals Yearbook, 1953, v. 1, p. 479–493.

Thurston, W. R., Staatz, M. H., Cox, D. C., and others, 1954, Fluorspar deposits of Utah: U.S. Geol. Survey Bull. 1005.

Twenhofel, W. H., 1932, Treatise on sedimentation: The Williams and Wilkins Co., Baltimore, Md.

U.S. Bureau of Mines and U.S. Geological Survey, 1948, Mineral resources of the United States: Washington, D.C., Public Affairs Press.

Utah Mining Association, 1959, Utah's mining industry: Salt Lake City, Utah Mining Assoc.

Van Sant, J. N., Refractory-clay deposits of Utah: U.S. Bur. Mines, Rept. Inv. manuscript in preparation.

Wengerd, S. A., and Matheny, M. L., 1958, Pennsylvania system of Four Corners region: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 9, p. 2048–2106.

Wicken, O. M., 1960, Magnesite and related minerals *in* Industrial Minerals and Rocks, 3rd ed.: Am. Inst. Mining, Metallurgical and Petroleum Engineers, p. 533–543.

Wideman, F. L., 1957, A reconnaissance of sulfur resources in Wyoming, Colorado, Utah, New Mexico, and Arizona: U.S. Bureau of Mines Information Circular No. 7770.

Willard, M. E., and Callaghan, Eugene, 1962, Geology of the Marysvale quadrangle, Utah: U.S. Geol. Survey Quad. Map, GQ–154.

Williams, J. Stewart, 1939, Phosphate in Utah: Utah Agr. Exp. Sta. Bull. 290.

———, 1958, Geologic atlas of Utah—Cache County: Utah Geol. and Mineralog. Survey Bull. 64.

———, 1962, Lake Bonneville, Geology of southern Cache Valley, Utah: U.S. Geol. Survey Prof. Paper 257–C.

Williams, J. Stewart, and Hanson, A. M., 1942, The phosphate reserves of Utah: Utah Agr. Exp. Sta. Bull. 304.

Wilson, LeMoyne, 1959, Soil survey East Millard area, Utah: U.S. Dept. Agriculture, Soil Series 1944, no. 11, 101 p.

Wimbler, Raymond and Crawford, A. L., 1933, The occurrence and possible economic value of diatomaceous earth in Utah: Utah Acad. Sci. Proc., v. 10, p. 61.

Winslow, A. G., and Kister, L. R., 1956, Saline-water resources of Texas: U.S. Geol. Survey Water Supply Paper 1365.

WATER RESOURCES

(By M. T. Wilson, R. H. Langford and Ted Arnow, Salt Lake City, Utah)

INTRODUCTION

Utah's water supply is substantial, but it is small in relation to the large size and potential water demand of the State. Annual precipitation is about 13 inches, and ranges from 5 inches in the Great Salt Lake Desert to 60 inches on the highest peaks. Annual runoff is about 2.0 inches for a total of 7.6 bgd (billions of gallons per day) or 8.5 million acre-feet per year, and ranges from about 0.25 inch in the western deserts and parts of the Colorado Plateaus to about 40 inches in the highest part of the Wasatch Range.

Seasonal, yearly, and cyclic (periods of wet and dry years) runoff are extremely variable and require considerable storage to provide a satisfactory continuing water supply. For example, the runoff of a typical river during the 18-year period 1924–41 was 34 percent lower than during the preceding 18-year period. Surface-reservoir sites are available in both the Great Basin and Colorado River Basin at which seasonal and yearly variations can be regulated, but those in the Great Basin are not adequate to adjust runoff for cyclic changes. Although large capacity surface reservoir sites are not satisfactory in the Great Basin, several large ground-water reservoirs can be used to solve this problem. Accompanying extreme variations in runoff are large variations in the chemical quality of surface water. The high mountainous regions yield water of excellent quality containing less than 100 ppm (parts per million) of dissolved solids, whereas in the lower reaches of some streams the dissolved-solids content exceeds 3,000 ppm. The brine of Great Salt Lake contains about 26.6 percent (by weight) of dissolved solids (4.4 billion tons).

Many streams in Utah transport large amounts of sediment. The Colorado River near the Utah-Arizona State line transports slightly more than 100 million tons of sediment each year; most of this sediment is contributed by the drainage basin below the mouth of the Green River. Yields of sediment in the upper Colorado River Basin of Utah are as great as 2,600 tons per square mile per year.

The State receives water from outside mainly in the Colorado River and its tributaries, the Green, Dolores, and San Juan Rivers. Except for relatively minor outflow in the Virgin and Raft Rivers and Goose Creek, discharge is mainly to the Colorado River and to deserts of the Great Basin.

Principal supplies of ground water are in alluvial fill of valleys in the Great Basin, in similar fill in intermontane basins in the Rocky Mountains and in the Uinta Basin, and in alluvium along a few streams in the Colorado Plateaus. Water is known to be present in sedimentary rocks on flanks of the Uinta Mountains, in the southeastern part of the Colorado Plateaus, and in a few other areas; it is doubtless present in much of the Colorado Plateaus and may be pres-

26 803 O-69 17

ent in scattered areas elsewhere. The chemical quality of ground water varies from place to place and with depth. Wells in alluvial and bedrock aquifers yield water whose quality ranges from excellent to poor. Some springs discharge highly mineralized water that is unsuitable for most uses.

Fresh-water use in 1960 was about 3,900 mgd (million gallons per day) or 4.4 million acre-feet per year: for public supply, 120 mgd of surface water and 100 mgd of ground water; for rural supply, 8.7 mgd of surface water and 11 mgd of ground water; for irrigation, 3,000 mgd of surface water and 350 mgd of ground water; for industry, 227 mgd of surface water (including 77 mgd for public-utility fuel-electric power) and 58 mgd of ground water. Industry also used about 5.5 mgd of saline surface water and 3 mgd of saline ground water. Hydroelectric power use was about 1,800 mgd.

Water problems include potential overpumping of several alluvial basins in the southwest, waterlogging in some areas especially on the eastern shore of Great Salt Lake and in the lower part of Cache Valley, waste of water by evapotranspiration, inadequate surface-water supplies in the latter part of the irrigation season, floods including destructive mudflows from the Wasatch Range and other mountains, poor quality of water in much of the State, high rates of sediment yield of some areas to streams, and deficiencies in quantitative hydrologic data, especially on potentialities for salvage of natural losses in the Great Basin. Nevertheless, future prospects are good because the State recognizes the problems and is active in developing methods for attacking them.

SURFACE WATER

Surface-water supplies for the State are extremely variable, ranging from very deficient in some areas to excessive in others. In general, water supplies are deficient at the lower elevations, whereas an abundance of water is available at the higher elevations, particularly along the Wasatch Range, the Wasatch Plateau, and the Uinta Mountains. Utah's major water supply comes from elevations above 7,000 feet. The pattern of precipitation and, therefore, streamflow is controlled largely by differences in the topography. Moisture-laden masses of air originating in the Pacific Ocean and moving in the general storm path from west to east are elevated as they pass over the mountain ranges. Condensation occurs as the air is cooled at the higher elevations, and thus the heaviest precipitation falls on or near the highest mountains. In the Salt Lake Desert area where the elevation is only slightly above 4,200 feet, the mean annual precipitation is less than 5 inches. Precipitation increases with elevation to a mean annual maximum of about 60 inches at the crest of the Wasatch Range. In northern Utah precipitation is greatest during the winter and early spring months, and moisture that accumulates as snow in the mountains exceeds more than 40 inches of water at some of the highest elevations. Melting of the winter snowpack provides Utah's principal water supply. The highest rates of snowmelt occur during the months of May and June; therefore, considerable storage must be provided to regulate the discharge for a satisfactory late summer irrigation, municipal, and industrial supply.

Additional moisture reaches Utah, principally to the south and southeastern parts of the State, from a second general storm path.

Moisture from the Gulf of Mexico enters Utah from the southeast during the summer months of July, August, and September. Precipitation is generally in the form of high-intensity cloudburst-type storms that produce rapid flood runoff for short periods of time. Average monthly precipitation for this part of the State is greatest during the summer months in contrast to the winter and early spring precipitation in the northern part of the State. Total volume of runoff from summer storms is not large; however, these storms provide considerable moisture for both summer and winter livestock ranges and for livestock drinking water.

The area of Utah, 84,916 square miles, is almost equally divided between the Great Basin and the Colorado River Basin. Only a small area in the extreme northwestern part of the State drains into the Columbia River Basin. Most of the surface-water supply available to Utah from the Great Basin is provided by precipitation within the basin. In contrast, the major part of streamflow in the principal rivers of the Colorado River Basin is derived from areas outside the State. The relative discharge of the principal streams is shown on the schematic map of figure 48. The line width of streams represents the mean discharge. Streamflow in the Colorado River and its principal tributaries coupled with good reservoir and dam sites provides an excellent opportunity for longtime holdover storage and for development of hydroelectric power.

Utah has more than 3 million acres of good arable land; a large part of the best land is in the Great Basin. However, the average water supply in the Great Basin and Utah's allotment from the Colorado River are not sufficient to furnish a full water right for all the arable land. Water is, therefore, the limiting factor in agricultural development.

In addition to the large variations in water supplies from one location to another, streamflow also varies greatly on a seasonal, yearly, and cyclic basis. Monthly streamflow is highest during the snowmelt period of May and June. Water supplies during these 2 months are about 60 percent of the yearly total. Annual streamflow also changes significantly from year to year. (See fig. 49.) Flow of the Logan River near Logan has varied from 186 percent of average for the high-water year of 1907 to 45 percent of average for the drought year of 1934. Likewise, flow of the Beaver River near Beaver in southern Utah has varied from 167 percent of average for the high-water year of 1952 (record not available for 1907) to 43 percent for 1934. Cyclic changes in streamflow also present some unsolved problems in complete utilization of the water resources. For example, discharge of the Logan River during the 18-year period 1924–41 was 34 percent lower than the preceding 18-year period 1906–23. Discharge has recovered somewhat during the 18-year period 1942–59, but it is still 24 percent less than the 1906–23 period. Surface reservoirs assist in equalizing seasonal and yearly variations in streamflow, but in the Great Basin they do not have sufficient capacity to regulate water supplies over long periods of time as would be required to equalize streamflow for cyclic changes. This problem has been partly solved in the Colorado River Basin by the Colorado River storage project, which provides sufficient storage capacity to regulate the flow of the river for periods in excess of 25 years. In the Great Basin several

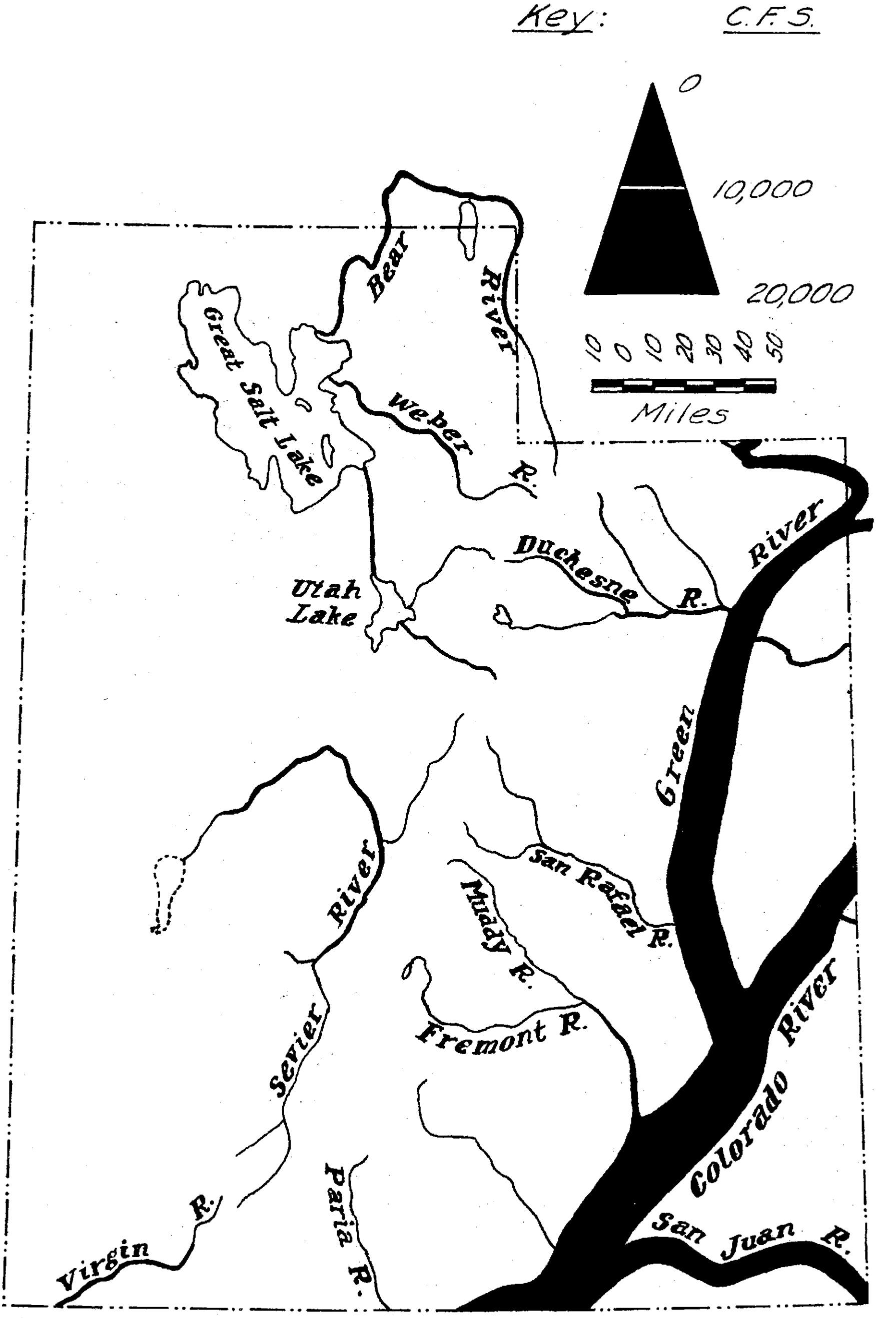


FIGURE 48.—Average discharge, in cubic-feet per second, of the principal rivers of Utah. (Width of river line indicates average discharge.)

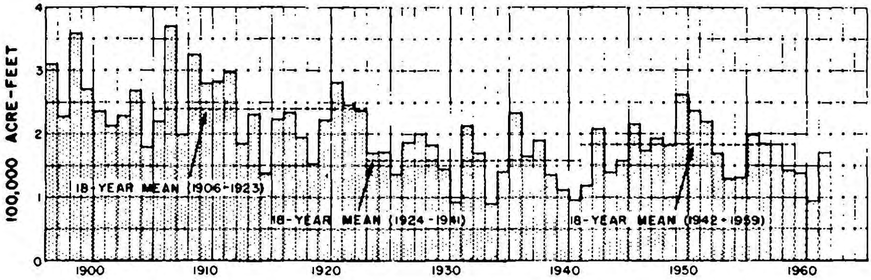


FIGURE 49.—Yearly streamflow (runoff) of Logan River above State dam, near Logan, Utah, showing effects of wet and dry cycles.

large ground-water reservoirs are available to assist in the solution of this problem. Water-development projects should include both surface and ground water if the resource is to be developed to its maximum capacity.

The mean annual surface-water supply for Utah is about 8,500,000 acre-feet (Bagley and others, 1963, p. 9.) Runoff drains to the Pacific Ocean from both the Colorado and Columbia Rivers, to the Great Salt Lake basin from several streams, and a relatively small amount to minor interior basins. Only a small part, slightly more than one-half of 1 percent (about 54,000 acre-feet), drains from the extreme northwestern corner of the State to the Columbia River. More than half of the runoff, about 4,900,000 acre-feet, drains to the Great Basin, while the balance, about 3,600,000 acre-feet, drains to the Colorado River. The total annual surface-water supply represents a depth of 2 inches over the entire State, compared to about 8.5 inches for the whole United States. The average annual runoff varies from approximately 0.25 inch from the western part of the Great Basin and along the main streams in the Colorado River basin to approximately 40 inches from the highest mountains of the Wasatch Range. (See fig. 50.)

Great Basin

The major surface-water resources of the Great Basin part of Utah result from precipitation on the plateaus and mountain ranges that extend from the Markagunt and Paunsagunt Plateaus in south-central Utah to the Wasatch Range and Uinta Mountains in the north.

Great Salt Lake basin.—Great Salt Lake, the largest surface-water area in the Western Hemisphere without drainage to the ocean, is the remnant of ancient Lake Bonneville which covered an area of some 20,000 square miles at its highest level during the Wisconsin glaciation of the Pleistocene period. Although ice was not a direct factor in forming the lake, the cool, moist climate that brought on the glaciers during Pleistocene time also provided water to form Lake Bonneville. The lake reached a depth of 1,000 feet before overflowing the rim of the basin at Red Rock Pass and discharged to the Snake River by way of the Portneuf River. With the return of a warm, dry climate, evaporation from the lake surface exceeded inflow and the lake level began to recede.

When the early pioneers reached the Great Salt Lake basin, the elevation of Great Salt Lake was about 4,200 feet above mean sea level. (See fig. 51.) A series of wet years from 1862 to 1868 raised the stage

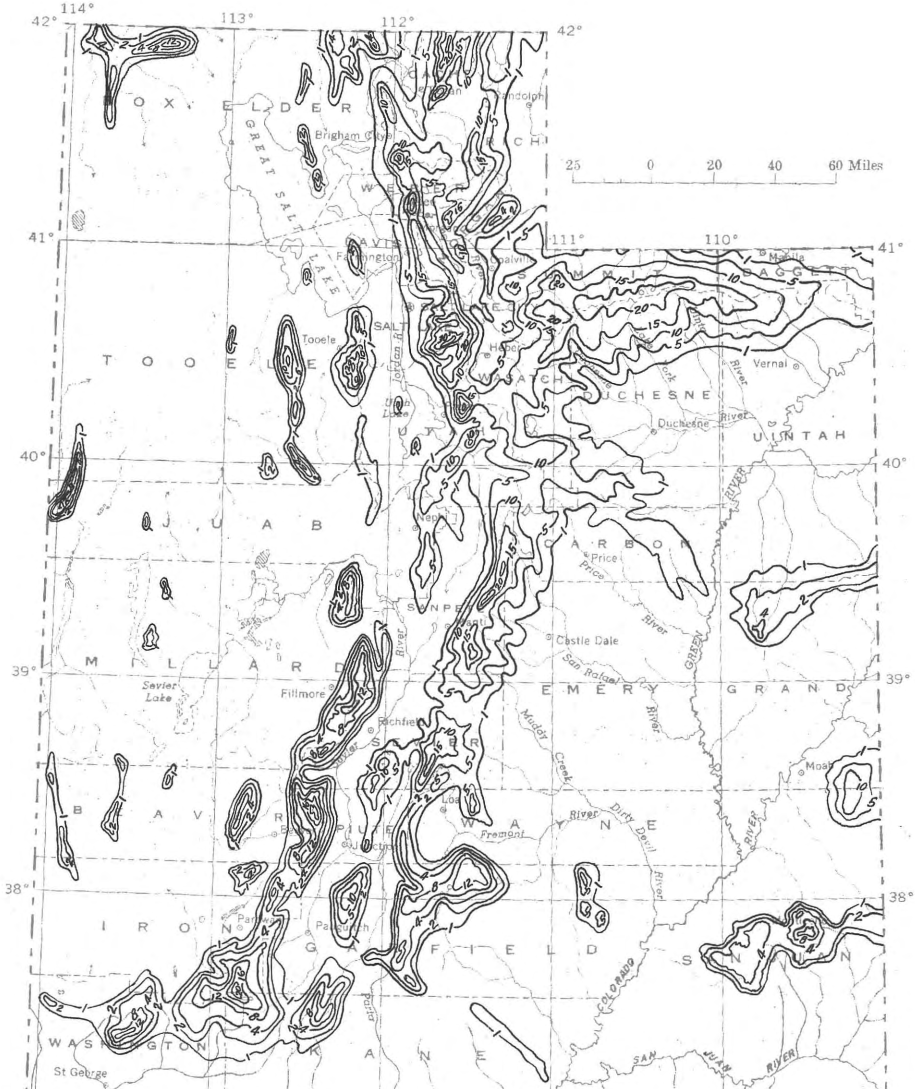


FIGURE 50.—Mean annual runoff in Utah, in inches.

of the lake almost 12 feet; that 6-year period provided a greater water supply to the Great Basin, and in general to the Western United States, than any similar period during the past several hundred years. Evidence from shorelines, vegetation, and other information indicate that the level of the lake had been lower for some centuries preceding 1862. The maximum recorded elevation of the lake was 4,211.6 feet above mean sea level in 1873. A series of dry years from 1873 to 1904 lowered the stage almost 16 feet below the 1873 high. Since 1904 the

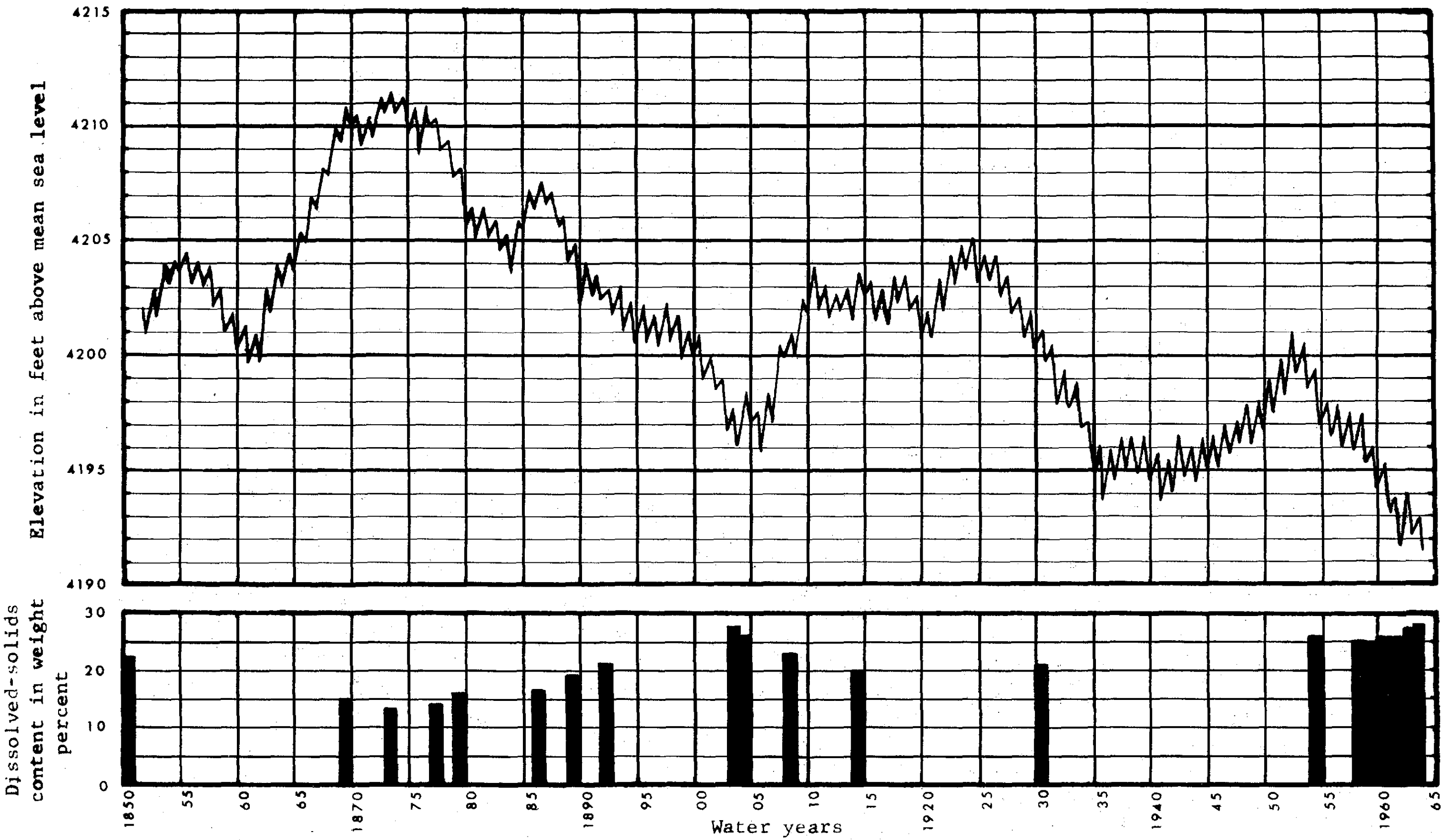


FIGURE 51.—Hydrograph of Great Salt Lake showing yearly maximum and minimum lake-surface elevations, 1851–1963, and the dissolved-solids content of the brine.

lake level fluctuated between about 4,191 and 4,205 feet; the greatest lowering was during the drought period of the late 1920's and early 1930's when the elevation decreased 11 feet. During the past 10 years the stage has decreased 9 feet, and was at the lowest recorded elevation, 4,191.35 feet, on October 15 and November 1, 1963.

Large changes in streamflow are reflected immediately by lake fluctuations. For the high-water year of 1907 the lake stage increased 3 feet, and for 1909, 2 feet. Likewise, for the drought years of 1931, 1934, and 1961 the stage of the lake dropped about 2 feet each year. (See fig. 51.) Although the level of the lake is affected by increased use of water in the basin, the general downward trend since 1873 does not necessarily mean that the lake will completely dry up in the near future. The lake level tends to maintain a balance between the amount of water evaporated from the lake surface and the amount of water contributed to it by surface streams, ground-water inflow, and precipitation on the lake surface. During a period of dry years the level drops and the surface area decreases rapidly, so that the total volume of evaporation is considerably diminished. Thus, less inflow is required to maintain an existing lake level. Likewise, during a period of wet years the level rises and the surface area is materially increased, resulting in a larger volume of evaporation to compensate for the greater inflow. Therefore, these factors are always seeking to stabilize the lake elevation. At the high stage in 1873, the area of the lake was about 2,400 square miles; at the present time it is about 950 square miles.

The dissolved-solids content of the lake brine has ranged from about 15 percent during the high-lake stages of the 1870's to about 28 percent during the low-lake stages of the early 1900's and 1960's (fig. 51). The histograms showing dissolved-solids content in figure 51 were developed from data in Clarke (1924), Talmage (1904, p. 424), Richardson (1906, p. 34), and Hahl and Mitchell (1963, pp. 34–36). They represent single measurements of dissolved-solids content during the indicated water years, except those for the years 1892, 1904, 1960, and 1961 which present averages of several measurements.

In the 1950's a causeway, composed of rock from the Promontory and Lakeside Mountains, was constructed across the lake between Promontory Point and Lakeside. Movement of brine between the two arms of the lake is now restricted by the fill; the southern arm of the lake is fed mainly by relatively fresh water from the major tributaries, but since 1957 the northern arm has been fed mainly by brine discharging through the fill. Because brine on the north side of the fill appears to be more nearly saturated than the brine on the south side, and because inflow northward through the fill is highly mineralized compared to inflow to the remainder of the lake, the dissolved-solids concentration of the northern arm probably will change slowly with time whereas the concentration of the brine to the south could change seasonally. The amount of seasonal change in concentration of the southern part of the lake is determined largely by the amount of inflow from the major tributaries. Years of low runoff will result in a lake of smaller volume which approaches saturation; years of high runoff will produce the reverse effect.

The average volume of brine in Great Salt Lake during the period October 1959 to September 1961 was about 10 million acre-feet. The average dissolved-solids concentration of the brine for the same period was 26.6 percent (by weight) after allowance is made for the slightly higher dissolved-solids concentration of the northern arm. Thus, the brine contained an average of about 4.4 billion tons of dissolved minerals during the period. No great differences in concentration were noted from point to point in the southern arm of the lake, and, on the basis of few data, no mineral stratification of the brine was noted. Because the lake is shallow, the circulation caused by wind, seasonal temperature changes, and evaporation is probably sufficient to produce the uniform chemical characteristics of the brine.

Even though the dissolved-solids concentration of the brine changes with time, the chemical composition of the dissolved solids has remained practically constant over the past hundred years. Despite the differences in analytical methods, in sampling points, and in lake volume and mineralization, the percentage composition of the dissolved solids remained almost constant and was predominantly sodium and chloride with lesser amounts of sulfate, magnesium, and potassium and with even lesser amounts of calcium, bicarbonate, and other constituents. (See table 17.) A comparison of extremes observed during 1959–61 and of average concentrations of individual constituents dissolved in the brine is given in table 18. These data are further compared in table 18 with the discharge-weighted average concentrations of surficial inflow.

TABLE 17.—*Percentage composition (by weight) of the dissolved solids in Great Salt Lake brine*

Constituent	1850 [1]	1869 [2]	August 1892 [1]	October 1913 [3]	March 1930 [3]	April 1960 [3]	November 1961 [3]
Silica (SiO_2)						0.002	0.003
Iron (Fe)						.00002	.00004
Calcium (Ca)		0.17	1.05	0.16	0.17	.12	.10
Magnesium (Mg)	0.27	2.52	1.23	2.76	2.75	2.91	3.49
Sodium (Na)	38.29	33.15	33.22	33.17	32.90	32.70	31.53
Potassium (K)		1.60	1.71	1.66	1.61	1.71	1.95
Bicarbonate as carbonate (CO_3)				.09	.05	.06	.07
Sulfate (SO_4)	5.57	6.57	6.57	6.68	5.47	6.60	8.21
Chloride (Cl)	55.87	55.99	56.22	55.48	57.05	55.86	54.59
Nitrate (NO_3)						.03	.06
Boron (B)						.01	
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Dissolved solids, in percent by weight of the brine	22.28	14.994	22.83	20.349	21.0	24.7	26.9

[1] Computed from data reported by Richardson (1906, p. 34).
[2] Reported by Clarke (1924, p. 157).
[3] From Hahl and Mitchell (1963, p. 34); analyses for samples collected at Promontory Point south of causeway.

TABLE 18.—*Concentrations of dissolved constituents in Great Salt Lake brine and surficial inflow, 1959–61*

[Concentrations in parts per million unless otherwise indicated]

Constituent or property	Great Salt Lake			Surficial inflow
	Maximum [1]	Minimum [1]	Average [2]	Discharge-weighted average [3]
Silica (SiO_2)	7.0	4.2	5.3	18
Aluminum (Al)	2.6	2.5		
Iron (Fe)	.11	.02	.04	
Calcium (Ca)	463	265	319	94
Magnesium (Mg)	9,440	6,920	8,050	49
Sodium (Na)	92,200	77,800	85,700	300
Potassium (K)	5,570	3,810	4,550	20
Lithium (Li)	56	29		
Bicarbonate (HCO_3)	398	266	327	344
Sulfate (SO_4)	22,600	12,100	17,400	188
Chloride (Cl)	158,000	133,000	147,000	475
Fluoride (F)	7.4	5.9		
Iodide (I)	.60	.26	.41	
Nitrate (NO_3)	154	61	82	4.1
Boron (B)	36	21		
Dissolved solids, calculated	285,000	240,000	263,000	1,320
Density, g/ml at 20° C	1.221	1.186	1.208	1.000

[1] Extremes observed from analyses of samples collected in southern arm of lake during June 1959–November 1961.
[2] Average of analyses of samples collected in southern arm of lake in April, July, and October 1960, and January–Feburary 1961.
[3] For water years 1960 and 1961.

Because the dissolved-solids concentration of surficial inflow is only about one two-hundredths of that of the brine, the dissolved-solids concentration of the brine is essentially unaffected by the minerals being delivered to the lake by surficial inflow. The effect of inflow is, however, to change the stage and volume of the lake; thus, inflow acts as a diluent. With increasing lake stage the dissolved-solids concentration of the brine decreases, but the tons of minerals dissolved in the brine increase. This increase in total dissolved minerals results mainly from re-solution of salts that were precipitated on the lake bed and near shore during a previous period when the lake stage was decreasing. Therefore, the chemical characteristics of the brine are mainly controlled by the minerals dissolved in the brine and the soluble salts on the lake bed which are available for solution. Physiographic features of the lake bed, as well as the aquatic life in the brine also affect the dissolved-solids concentration and chemical character of the brine.

Bear River is the largest stream supplying water to Great Salt Lake and likewise the largest stream in the Western Hemisphere without a direct channel to an ocean. It heads from the western end of the Uinta Mountains about 60 miles east of Salt Lake City, flows northward, and enters Wyoming 20 miles south of Evanston, Wyo. After flowing through Wyoming for about 40 miles, the river re-enters Utah east of Woodruff, Utah, for a distance of about 30 miles, and again crosses into Wyoming. From its northward course in Wyoming the river turns to the west crossing the Idaho-Wyoming State line near Border, Wyo., and after a circular course in Idaho for about 110 miles again enters Utah near Preston, Idaho. Following its course through Cache and Box Elder Counties it empties into Great Salt

Lake, a distance of only 90 miles from where it originated. This interstate stream develops water from three States, and the right to use of the supply is largely controlled by the tristate Bear River compact.

The principal regulating reservoir is Bear Lake, an off-stream reservoir with total storage capacity of 1,421,000 acre-feet controlled largely by Rainbow inlet canal and Bear Lake outlet canal.

Streamflow records are available at several locations on the main stem of the Bear River and all the principal tributaries. Selected stations in Utah with long-term records are given below:

Stream	Drainage area (square miles)	Years of record	Average discharge (cfs)	Extremes of discharge (cfs)		Runoff (acre-feet)
				Maximum	Minimum	
Bear River near Utah-Wyoming State line	176	20	183	2,800	16.0	132,500
Mill Creek at Utah-Wyoming State line	59	13	32.0	690	.9	23,170
Bear River near Preston, Idaho	4,500	19	795	4,420	.6	575,600
Little Bear River near Paradise, Utah	203	25	84.3	2,000	4.0	61,030
Logan River near Logan, Utah	218	66	277	2,480	50.0	199,100
Blacksmith Fork near Hyrum, Utah	260	49	124	1,620	29.0	89,770
Bear River near Collinston, Utah	6,000	75	1,604	11,600	0	1,161,000

Most of the discharge of the Bear River near Collinston reaches Great Salt Lake with little or no economic value to the people of Utah. However, because of additional use upstream and less runoff in recent drought years there has not been as much water reaching Great Salt Lake as the table above would indicate. For the past 10-year period runoff of the Bear River near Collinston has averaged 702,000 acre-feet and part of this runoff has been used by Bear River Migratory Bird Refuge. The Bear River project proposed by the Bureau of Reclamation would utilize this undeveloped water supply.

Weber River, the second largest stream flowing to Great Salt Lake, also has its headwaters at the west end of the Uinta Mountains. The river is 125 miles long, traverses Summit and Morgan Counties, forms the boundary for 7 miles between Davis and Weber Counties, and empties into Great Salt Lake about 11 miles southwest of Ogden. The principal tributary is the Ogden River which drains about 400 square miles of mountainous terrain, including parts of the Wasatch and Bear River Ranges. The Uinta Mountains reach an elevation of 11,970 feet and provide a good water supply, some of which is carried by transbasin diversions to the Provo River. Selected records of streamflow, including the major tributaries to the Weber River, are given below.

Stream	Drainage area (square miles)	Years of record	Average discharge (cfs)	Extremes of discharge (cfs)		Runoff (acre-feet)
				Maximum	Minimum	
Weber River near Oakley	163	58	220	4,170	16.0	159,300
Weber River near Coalville	438	31	190	2,190	6.0	137,600
Chalk Creek near Coalville	253	35	56.9	1,540	1.0	41,190
Lost Creek near Croyden	133	23	32.7	770	1.9	23,670
East Canyon Creek near Morgan	155	31	49.1	872	1.1	35,550
Hardscrabble Creek near Porterville	28.1	21	29.8	464	2.7	21,570
Weber River at Gateway	1,610	49	595	7,980	33.0	430,800
South Fork Ogden River near Huntsville	148	41	107	1,890	20.0	77,460
Weber River near Plain City	2,060	58	680	10,100	0	492,300

The Weber Basin project, now in the process of construction, includes plans for complete utilization of the water resources of the Weber River. Runoff from the lower elevations of the basin will be diverted by canal to the Willard Bay Reservoir and made available for irrigation and other needs by means of low-lift pumps. Water reaching Great Salt Lake, as indicated by the record for the Weber River near Plain City, will then be greatly reduced. In fact, during the process of development runoff leaving the basin has changed from the long-time mean of 492,300 to 172,300 acre-feet for the past 5-year mean. Part of the reduced runoff, however, has been caused by recent drought years.

Streamflow from small creeks draining the Wasatch front in Davis County is coordinated with supplies from the Weber Basin project for better utilization. Increased use of runoff from these streams will decrease the amount of water reaching Great Salt Lake. Annual runoff from the area is relatively high ranging from 550 to 1,100 acre-feet per square mile.

The third largest river discharging into Great Salt Lake, the Jordan River, heads at the north end of Utah Lake, flows northward through the Jordan Narrows into Salt Lake County, and empties into the lake about 10 miles northwest of Salt Lake City. The major water supply for the Jordan River comes from Utah Lake, which is fed by more than 30 streams; the largest of which are the Provo River, Spanish Fork, American Fork, Hobble Creek, Payson Creek, Summit Creek, and Currant Creek. Several streams including Little Cottonwood, Big Cottonwood, Mill, Parleys, Emigration, and City Creeks also contribute to the flow of the Jordan River as it passes through Salt Lake County. Records of streamflow for stations on the Jordan River and some selected tributaries are given below.

Stream	Drainage area (square miles)	Years of record	Average discharge (cfs)	Extremes of discharge (cfs)		Runoff (acre-feet)
				Maximum	Minimum	
Spanish Fork at Castilla [1]	670.0	38	214.0	3,610	14.0	154,900
Spanish Fork near Lake Shore	700.0	42	86.2	3,020	0	62,410
Provo River near Kamas	29.6	13	48.9	825	1.7	35,400
Provo River below Deer Creek Dam [2]	560.0	9	325.0	2,190	0	235,200
Provo River at Provo	680.0	27	174.0	2,520	0	126,000
Jordan River, at narrows, near Lehi	3,000.0	49	359.0	1,410	0	259,900
Jordan River at Salt Lake City	----------	19	324.0	1,820	89.0	234,600

[1] Includes water diverted from the Strawberry Reservoir in the Colorado River Basin.
[2] Includes some water diverted from the Duchesne and Weber Rivers.

Deer Creek Reservoir on the Provo River in the canyon west of Heber Valley receives its principal water supply by transbasin diversion from the Duchesne and Weber Rivers. High-water runoff from the Provo River is stored in Utah Lake to satisfy water rights mainly in Salt Lake County. Utah Lake has an area of 96,000 acres at "compromise elevation, 4,489.3 feet above mean sea level at outlet of lake"; the average evaporation loss from the lake, 324,000 acre-feet (Gardner, 1962, p. 18) is greater than that released or pumped each year from the lake, 259,000 acre-feet, to satisfy water rights.

Runoff from the Jordan River at 21st South Street, Salt Lake City (235,000 acre-feet) is return flow from irrigation, ground-water discharge, and discharge from local tributaries. Most of this supply is diverted for irrigation, migatory bird refuges, and duck clubs before reaching Great Salt Lake. Salt Lake City outflow sewer canal (about 40,000 acre-feet per year) and Kennecott outflow canal (about 60,000 acre-feet per year) dump drainage and waste water into Great Salt Lake. Salt Lake City sewage treatment plant, now under construction, will make much of that supply available for additional use. Surface runoff to Great Salt Lake from the southwest, west and northwest, including Tooele, Skull, Curlew, Hansel, and Blue Creek Valleys is small compared to that from the east.

The three major drainage systems of Great Salt Lake head in the western Uinta Mountains which are mantled by quartzite of Precambrian age, carbonate rocks of Paleozoic age, and glacial deposits of Quaternary age. The runoff from these highlands is the bicarbonate type and generally of excellent chemical quality.

The chemical character of water in the Bear River changes from a bicarbonate type in the highland areas to a chloride-bicarbonate type in the lower reaches of the river. Similarly, water in streams draining into Utah Lake is of the bicarbonate type. Analyses of water from Utah Lake (Connor, Mitchell, and others, 1958) indicate that concentrations of chloride and sulfate are about equal to that of bicarbonate. It would be inviting to attribute such changes in chemical character solely to the influence of Bonneville sediments; however, other factors such as discharge of industrial wastes and sewage and return flow from irrigated lands are equally important in determining water types. Water in the Weber River also is bicarbonate in type before leaving the mountains. Almost all the Weber and Ogden River water entering the valley is diverted for irrigation and municipal use between Brigham City and the Davis-Salt Lake County line near Farmington. After use, some of this water returns to the lake area through drainage systems other than the Weber River. Thus, the absence of large amounts of return flow in the lower reach of the Weber River could be one reason why the water remains bicarbonate in type until it enters the lake area.

Inflow of dissolved minerals to Great Salt Lake in 1960 and 1961 water years was determined to be about 1.9 million tons annually (Hahl and Langford, 1963). Although this load delivered by surficial sources does not include the mineral load contributed by subsurface sources, it is believed to represent about 80 percent of the total load of dissolved minerals contributed to the lake area.

Most of the annual inflow of 1.9 million tons was contributed by Bear River and by drains and sewage canals around the lake. The Weber River, Jordan River, and streams draining the intervening mountain front, together contributed about one-fifth of the load. Springs around the lake contributed more than one-sixth of the mineral load.

Information about characteristics and amounts of sediment transported by streams in the Great Salt Lake basin is lacking. Intense storms along the Wasatch Range have caused severe erosion in the mountains and produced mud-rock flows from canyons onto the valley floors. Generally, perennial streams draining the high mountains that have good vegetative cover do not transport great amounts of sediment. However, the lower reaches of streams carry heavy loads of sediment during cloudburst-type storms because vegetative cover is sparse at the lower elevations. Also, lower reaches of major streams, such as the Bear River, transport large quantities of sediment; because stream gradients and velocities are low, the sediment loads in the lower reaches of these streams are usually composed of fine materials. Studies are needed to determine the sediment characteristics of streams in most of the Great Salt Lake basin of Utah.

Sevier Lake basin.—The Sevier Lake basin comprises a little more than 16,000 square miles of high plateaus, narrow valleys, and broad desert areas in the southwestern part of Utah. Water in the basin eventually drains into Sevier Lake, which has no outlet to the sea. Although there is no outward drainage, Sevier Lake has been dry during recent years due to storage and use of water in the upper part of the basin. The Sevier River is the major stream, heading on the high Markagunt Plateau 12 miles east of Cedar City, where the average annual precipitation is more than 30 inches. Its course is to the north for most of its 225-mile length. The lower reach of the river takes a circular course from Gunnison to Leamington and Delta before reaching Sevier Lake. Runoff is not sufficient to supply all irrigation needs in the basin, and storage reservoirs have been constructed for complete regulation of the available water except for unusually high-water years that have occurred at about 25-year intervals when some runoff has reached Sevier Lake. San Pitch River, one of the major tributaries, delivers runoff to the main stem of the Sevier River only during flood years because of irrigation use in the upper part of its basin and storage in Gunnison Reservoir. Streamflow records for selected stations in the Sevier River basin are summarized below.

Stream	Drainage area (square miles)	Years of record	Average discharge (cfs)	Extremes of discharge (cfs)		Runoff (acre-feet)
				Maximum	Minimum	
Sevier River at Hatch	340	40	131.0	1,490	27.0	94,800
Sevier River near Kingston	1,110	48	130.0	3,000	4.2	94,120
East Fork Sevier River near Kingston	1,260	49	82.2	2,030	7.0	59,510
Sevier River below Piute Dam, near Marysville	2,440	50	223.0	2,600	0	161,400
Clear Creek near Sevier	164	5	23.4	301	1.9	16,940
Salina Creek at Salina	290	17	18.5	2,650	0	13,390
Sevier River near Gunnison	4,880	50	226.0	2,620	8.0	163,600
Sevier River near Juab	5,120	51	233.0	2,140	0	168,700
Sevier River near Lynndyl	6,270	25	196.0	2,980	4.5	141,900

Most runoff from other streams in the Sevier Lake basin including Chalk Creek, Beaver River, Center Creek, Coal Creek, Pinto Creek, and Shoal Creek is used in the valley areas near the mouths of canyons draining the adjacent mountains.

Information about the chemical quality of water in the Sevier River has been obtained regularly at only two sites in the basin. Records collected at these sites are summarized below.

Water released at Piute Dam represents runoff from the upper part of the drainage basin and is of excellent chemical quality. Dissolved-solids concentrations range from about 250 to 350 ppm, and the water is of the calcium-bicarbonate type.

Below Piute Reservoir, the water in the Sevier River is extensively diverted for irrigation. Return flow to the river from irrigated lands is impounded and rediverted for irrigation further downstream. Because of repeated use, the water in the Sevier River becomes more highly mineralized downstream (fig. 52) until, near the mouth at Sevier Lake, its dissolved-solids content probably is several thousand parts per million. Accompanying this increase in mineralization is a change in the chemical character of the water. Whereas the water in the upper reaches of the river is of the calcium-bicarbonate type, it is of the sodium-chloride type in the lower reaches. Part of the increase in mineralization and change in character probably is caused by highly mineralized inflow from springs and by runoff from outcrops of highly soluble rocks, such as the Arapien shale.

Stream	Years of record	Annual runoff (acre-feet)	Dissolved solids		
			Weighted-average concentration (ppm)	Discharge	
				Tons per year	Tons per square mile per year
Sevier River below Piute Dam, near Marysvale	2	98,530	289	38,400	16
Sevier River near Lynndyl	11	117,200	1,460	233,000	37

The records obtained near Lynndyl reflect the effects of use and geology in the Sevier Valley on the chemical quality of the water. The water at this site is about five times as mineralized as that at Piute Reservoir, and the principal dissolved constituents are sodium and chloride.

The lack of information about sediment transported by streams in the Sevier Lake basin precludes discussion of this important aspect of surface-water resources. As in the Wasatch Range to the north, cloudburst-type storms along the Wasatch Plateau produce mud-rock flows that debouch onto the valley floors. Following heavy rains sediment is discharged into streams of the basin and much is trapped in reservoirs on the Sevier River and its tributaries.

Minor basins.—Much of western Utah is public domain administered by the Bureau of Land Management. The low annual precipitation and streamflow limit agricultural activities primarily to livestock grazing. With few exceptions, surface water occurs in short, steep, ephemeral streams that flow outward from the mountains only during periods of snowmelt or after heavy rains. Streamflow begins in the early spring when snow starts melting on the lower mountain slopes and ends shortly thereafter when snowmelt ceases at the higher elevations. Basic data on water resources of much of western Utah are sparse. A reconnaissance of the area by Snyder (1963) is currently being supplemented by more detailed studies by the U.S. Geological Survey in cooperation with the State of Utah.

Colorado River Basin

Utah receives considerable water from outside the State, principally from the Colorado River and its tributaries. Discharge of the Colorado River below Dolores River near the Colorado-Utah State line for 1911–62 was 8,006 cfs (cubic feet per second) (5,796,000 acre-feet per year). The Dolores River, with a discharge of 699 cfs

(506,100 acre-feet per year) for the 12-year period 1950–62, enters Utah from Colorado 9 miles above its junction with the Colorado River. The Green River near Linwood, Utah, discharged 1,928 cfs (1,396,000 acre-feet) during the 34-year period 1928–62, principally from Wyoming. Part of the discharge, near Linwood, drains from the north slope of the high Uinta Mountains in Utah and flows to the Green River from Blacks Fork. Henrys Fork of the Green River at Linwood produced 75 cfs (54,400 acre-feet) for the period 1928–62, and likewise a part of this supply comes from the north slope of the Uinta Mountains in Utah. The Green River flows generally eastward from Linwood and after receiving the discharge of tributaries, including Sheep and Carter Creeks (about 100 cfs), enters Colorado. The principal contribution from Colorado and Wyoming to the reach of the Green River in Colorado comes from the Yampa River. Discharge of the principal tributaries of the Green River after it reenters Utah and flows of the Green River are given below in downstream order.

Stream	Drainage area (square miles)	Years of record	Average discharge (cfs)	Extremes of discharge (cfs)		Runoff (acre-feet)
				Maximum	Minimum	
Green River near Greendale	15,100	12	2,107.0	19,600	208.0	1,525,000
Green River near Jensen	25,400	17	4,514.0	36,500	102.0	3,268,000
Brush Creek near Jensen	255	23	19.1	900	0	13,830
Ashley Creek near Jensen	386	15	51.5	1,480	0	37,280
Duchesne River near Randlett	3,920	20	578.0	8,790	2.2	418,500
White River near Watson	4,020	39	719.0	8,160	[1] 53.0	520,500
Green River near Ouray	35,500	14	5,726.0	43,600	[1] 500.0	4,145,000
Price River at Woodside	1,500	16	97.5	8,500	0	70,590
Green River at Green River	40,600	63	6,507.0	68,100	255.0	4,711,000
San Rafael River near Green River	1,690	26	178.0	12,000	0	128,900

[1] Minimum daily.

In addition to the Green and Dolores Rivers, streamflow information for other major tributaries of the Colorado River draining parts of Utah is listed below in downstream order.

Stream	Drainage area (square miles)	Years of record	Average discharge (cfs)	Extremes of discharge (cfs)		Runoff (acre-feet)
				Maximum	Minimum	
Mill Creek near Moab, Utah	74.9	13	14.5	5,110	3.1	10,500
Dirty Devil River near Hite, Utah	4,360.0	14	109.0	35,000	0	78,910
Escalante River near Escalante, Utah	1,770.0	5	85.2	14,600	4.4	61,680
San Juan River near Bluff, Utah	23,000.0	48	2,744.0	70,000	0	1,987,000
Paria River at Lees Ferry, Ariz	1,570.0	39	30.7	19,000	0	22,230
Virgin River at Virgin, Utah	934.0	53	205.0	13,500	22.0	148,400

Utah's major contribution to the Colorado River is from the Uinta Mountains, most of which reaches the Green River near Ouray from the Duchesne River. Several tributaries of the Duchesne River provide a substantial surface-water supply that has not yet been developed. This supply is Utah's principal opportunity for using the water that has been allotted to it by the upper Colorado River compact. The proposed central Utah project would transport by conduits and tunnels a major part of the runoff to the Great Basin. Listed below are summaries of water-supply records for the Duchesne River and its larger tributaries.

Stream	Drainage area (square miles)	Years of record	Average discharge (cfs)	Extremes of discharge (cfs)		Runoff (acre-feet)
				Maximum	Minimum	
Duchesne River near Hanna	78	16	----------	1,500	4.6	----------
West Fork Duchesne River near Hanna	61	18	47.8	666	4.4	34,030
Duchesne River near Tabiona	352	44	201.0	2,500	27.0	145,500
Rock Creek near Mountain Home	149	25	167.0	2,390	7.0	120,900
Duchesne River at Duchesne	660	45	357.0	4,420	15.0	258,500
Strawberry River at Duchesne	1,040	48	152.0	3,490	1.0	110,000
Lake Fork near Mountain Home	110	20	122.0	2,180	0	88,320
Yellowstone Creek near Altonah	131	18	131.0	1,880	26.0	94,840
Duchesne River at Myton	2,750	54	554.0	12,800	1.0	401,100
Uinta River near Neola	181	34	171.0	3,320	24.0	123,800
Whiterocks River near Whiterocks	115	55	124.0	2,750	10.0	89,770
Duchesne River near Randlett	3,920	20	578.0	8,790	2.2	418,500

Runoff of the Colorado River, as it leaves Utah near the Arizona-Utah State line and as measured at the official compact point between the upper and lower basins, averaged 17,760 cfs (12,860,000 acre-feet per year) for the 49-year period 1914–62. Runoff of the Colorado River has been less in recent years compared to the long-time average; for the 10-year period 1953–62 it was 10,000,000 acre-feet per year. The lower runoff is partly due to increased water use but principally to recent drought years. The Colorado River storage project now under construction, with the major storage located in Utah, will have sufficient capacity to regulate the flow of the Colorado River for about a 30-year period. The holdover storage from a series of wet years to a series of dry years will provide for the release of water to the lower basin to satisfy the terms of the 1922 Colorado River compact, and thus allow for development of the water resources in the upper basin.

Accompanying the extreme variations in runoff throughout the Colorado River Basin are large variations in water quality. Although most of the water comes from the mountains and high plateaus, a large percentage of the dissolved solids comes from the lower parts of the basin where precipitation is low. Rocks exposed in the mountains are generally much more resistant to the solvent action of water than are rocks which mantle the lowlands. The dissolved-solids concentration of water in streams generally increases in a downstream direction. The high mountainous regions yield water of excellent quality that, for the most part, contains less than 100 ppm of dissolved solids. At entrances to the valleys, above irrigation diversions, the water generally is of good quality, but below irrigated areas the concentration may range from 400 ppm to several thousand parts per million. These downstream changes in mineralization are illustrated in figure 52.

Average annual concentrations and discharges of dissolved solids in major streams in the Upper Colorado River Basin are summarized in table 19, along with data on sediment characteristics of streams. The data in table 19 represent the long-term average that would have occurred if the water-use developments existing in 1957 had been in place and in operation throughout the water years 1914–57 (W. V. Iorns, personal communication, 1962).

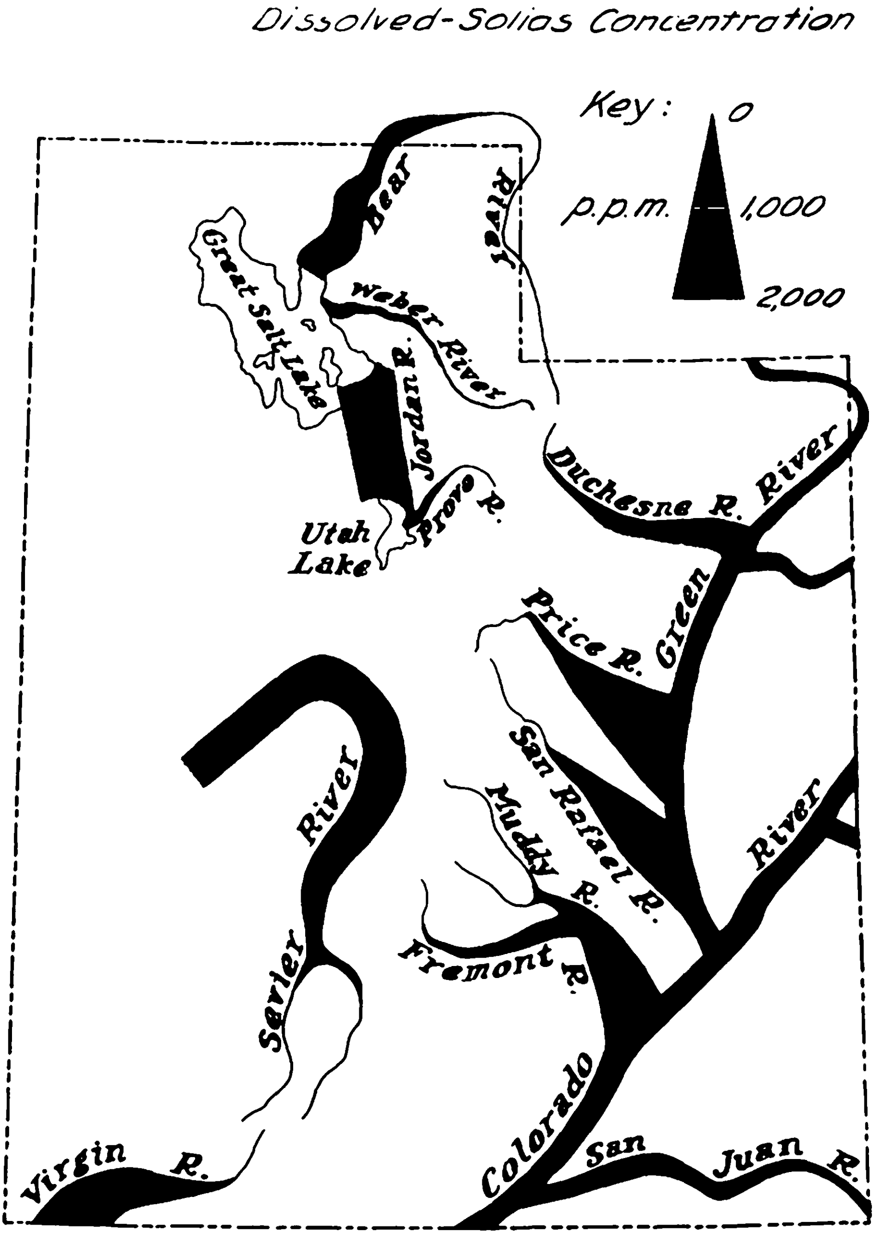


FIGURE 52.—Mineralization of water in the principal rivers of Utah. (Width of river line indicates average concentration in parts per million.)

TABLE 19.—*Concentration and discharge of dissolved solids and suspended sediment for streams in the Upper Colorado River Basin, Utah*

[Data represent annual averages for the water years 1914–57 adjusted to 1957 conditions except as indicated]

Stream	Water discharge (thousands of acre-feet)	Dissolved solids			Suspended sediment		
		Weighted-average concentration (ppm)	Discharge		Weighted-average concentration (ppm)	Discharge	
			Thousands of tons per year	Tons per square mile per year		Thousands of tons per year	Tons per square mile per year
Colorado River near Cisco	5,534	547	4,120	171	[1] 2,050	[1] 14,351	[1] 595
Green River near Greendale	1,645	378	847	56			
Yampa River contribution to Green River [2]	1,603	156	339	49			
Green River near Jensen	3,338	316	1,435	55	1,300	5,902	226
Duchesne River near Randlett	556	608	460	117			
White River near Watson	554	439	331	82			
Price River at Woodside	84	2,110	242	161	33,900	3,879	2,586
Green River at Green River	4,558	427	2,652	65	[3] 3,760	[3] 20,800	[3] 522
San Rafael River near Green River	102	1,370	190	113	6,700	931	551
Dirty Devil River near Hite [4]	74	1,960	198	45	50,200	5,000	1,147
Colorado River at Hite	10,260	527	7,367	96	4,000	55,960	731
Escalante River at mouth near Escalante [5]	62	300	25	13	20,900	1,757	874
San Juan River near Bluff	2,028	361	997	43	13,500	37,100	1,613
Colorado River at Lees Ferry, Ariz	12,710	499	8,642	80	5,800	101,300	939
Paria River at Lees Ferry, Ariz	23	1,090	34	22	84,400	2,655	1,691

[1] For water years 1930–57; average annual water discharge is 5,141,000 acre-feet.

[2] Data represent average annual water, dissolved-solids, and sediment discharge, and weighted-average concentrations of dissolved solids and sediment for Yampa River near Maybell, Colo., and Little Snake River near Lily, Colo.

[3] For water years 1930–57; average annual water discharge is 4,067,000 acre-feet.

[4] For water years 1947–57.

[5] For water years 1951–55.

Of the dissolved-solids load transported by the Colorado River at Lees Ferry, Ariz., about half is contributed by the Colorado River above the mouth of Green River, about one-third by the Green River, and the balance by the San Juan River and other tributaries below the mouth of the Green. The annual average dissolved-solids discharge of the Colorado River at Lees Ferry is 8.6 million tons.

About half of the sediment load of the Colorado River at Lees Ferry is contributed by the drainage area below the mouth of Green River. Only about one-fifth of the sediment load at Lees Ferry is transported by the Colorado River above the mouth of Green River, and less than one-third by the Green River itself. The average annual sediment discharge of the Colorado River at Lees Ferry is 101 million tons.

Variations from year to year in loads of sediments and dissolved solids are illustrated in figures 53 and 54 for the Colorado River near Cisco and the Green River at Green River. Generally, the higher loads are associated with years when water discharge is high. Although the concentration of dissolved solids normally decreases with increasing water discharge, the concentration of suspended sediment normally increases as water discharge increases. Because of this fact and because the load transported by a stream is a product of concentration and water discharge, variations in the sediment load usually parallel variations in water discharge. Dissolved-solids loads fluctuate less widely than sediment loads. For example, the range in annual suspended-sediment loads for Green River (fig. 54) was from about 2 million tons in 1934 to more than 40 million tons in 1937, whereas the range in dissolved-solids load was only from 1 million tons in 1934 to 4.3 million tons in 1952.

The annual suspended-sediment concentration of the Green River at Green River generally was greater during 1930–42 than during 1943–56. This difference may be associated with periods of below normal and above normal precipitation, or, possibly, with differences in the intensity of summer storms. The change seems to be regional in nature as the pattern for Green River is almost identical to that for Colorado River near Cisco.

The yield of sediment and dissolved solids ranges widely in the Upper Colorado River Basin. (See table 19.) The Price River Basin yields about 2,600 tons of sediment each year for each square mile of its drainage area. In contrast, the San Rafael River Basin yields about 550 tons per square mile per year. The difference in sediment discharge is due mostly to differences in the types of rocks in the two basins. The yields of dissolved solids per square mile of drainage area are less than those of sediment, but the percentage differences between basins are almost as great. For example, the Price River Basin yields about 160 tons per square mile per year, whereas the Escalante River Basin yields only 13 tons. Most of the Price River Basin is underlain by rocks of Cretaceous age, including the Mancos shale which yields high amounts of dissolved solids to runoff. The Escalante River contains lower concentrations of dissolved solids near its mouth than near Escalante, which is below irrigated areas. The irrigated lands are underlain mostly by rocks of Cretaceous age. The lower concentrations of dissolved solids near the mouth are due, however, to runoff from the drainage basin of Boulder Creek and the lower

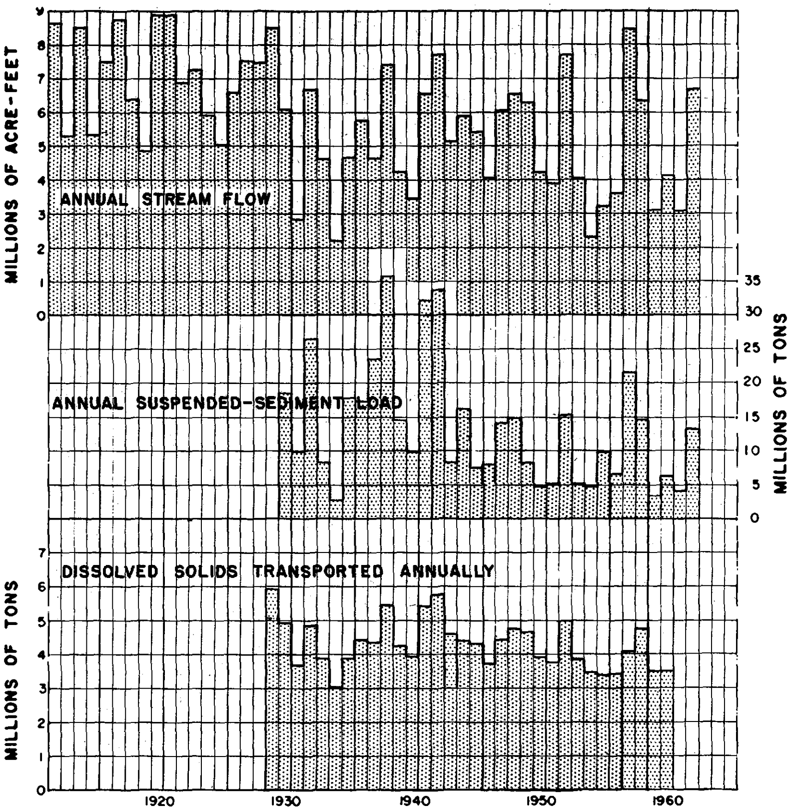


FIGURE 53.—Annual water, sediment, and dissolved-solids discharge, Colorado River near Cisco, Utah.

reaches of the Escalante River, which are underlain mostly by rocks of the San Rafael and Glen Canyon groups. The solubility and erodability of rocks in the drainage basins play an important part in determining the water quality and sediment characteristics of streamflow.

The chemical composition of the dissolved solids in surface waters of the Upper Colorado River Basin not only differs between streams but also differs with water discharge. The dissolved solids in the Dolores River near its mouth are composed principally of sodium and chloride when water discharge is low. In contrast, the dissolved solids in the Escalante River near its mouth are composed principally of calcium and sulfate during low flow. When water discharge is high the dissolved solids in both streams are more nearly alike chemically and are composed principally of calcium and bicarbonate. The differences in chemical composition of runoff are due to differences in the solubility, chemical characteristics, and hydrologic properties of the rocks in the drainage basins, as well as to water use and climatic factors.

Records of water quality are available for several sites in Utah on the Virgin River and its principal tributary, the Santa Clara River,

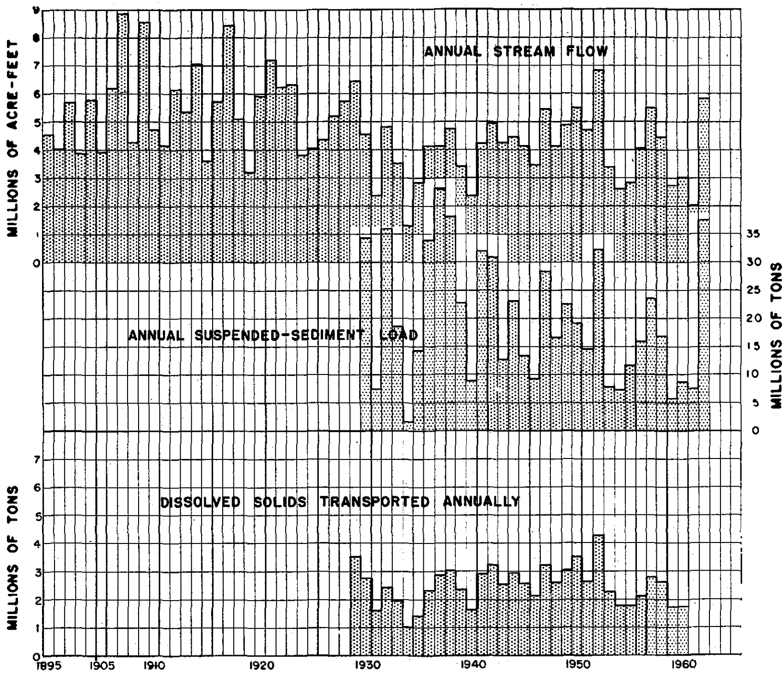


FIGURE 54.—Annual water, sediment, and dissolved-solids discharge, Green River at Green River, Utah.

for the period 1951–56. Similar records for the Virgin River at Littlefield, Ariz., have been obtained since 1949, and data on suspended sediment have been obtained at this site since 1947. These records show that the mean annual dissolved-solids concentrations of the Virgin River increase in a downstream direction from about 500 ppm at Virgin, Utah, to about 2,000 ppm at Littlefield, Ariz. The Santa Clara River near its mouth near St. George contributes water having a weighted-average concentration of dissolved solids of about 1,200 ppm; the load is about 11,000 tons per year. LaVerkin Springs near Hurricane, Utah, contribute about 10 cfs directly to the Virgin River. Water from these springs has a dissolved-solids concentration of about 10,000 ppm; sodium and chloride are the principal dissolved constituents. This spring inflow contributes about 100,000 tons per year of dissolved solids to the Virgin River. At Littlefield the dissolved-solids discharge of the Virgin River is about 365,000 tons per year (1950–62), and the sediment discharge is about 2.5 million tons per year (1948–62). These discharges are equivalent to about 70 and 500 tons per square mile per year, respectively. The dissolved solids are principally calcium, sodium, and sulfate. The particle size of the suspended sediment is about one-third clay, one-third silt, and one-third sand.

GROUND WATER

Ground water is an important resource in Utah because it may be available where or when surface water is scarce or unavailable, or for uses such as domestic supply or small to moderate municipal and industrial supplies, because it may be obtained at a lower cost than surface water. The largest use of water in Utah is for irrigation. The principal supply, surface water, generally is available in adequate quantities at the beginning of the irrigation season; but by the latter part of the season the supply is commonly inadequate, especially in the Great Basin where the surface water available during the late summer is fully appropriated. Under such conditions ground water, if available, forms a valuable supplementary source. Ground water is used also in areas where surface water cannot be obtained feasibly, and it is available but not used in many other such areas.

Alluvial aquifers

The principal ground-water resources of Utah are in alluvial aquifers in the Great Basin and in tracts between mountain ranges or plateaus within the Rocky Mountains and Colorado Plateaus, mostly not far from the east edge of the Great Basin. The principal areas in which there has been at least some development to date are shown in figure 55. The withdrawal of ground water in the Great Basin accounts for nearly all the ground-water withdrawal in Utah.

Drought and heavy pumping during the 1950's combined to lower water levels in some of the areas, especially in the southern part of the State. Despite the lowered water levels in the Parowan and Cedar City Valleys, these areas were considered capable of limited further development as of 1962. In the Milford district the water levels declined appreciably during the drought years of the 1950's, but in years of above-average precipitation the water levels were stable or rose. In the Beryl-Enterprise district, water is being mined, but the rate of decline of water levels is less than two feet a year, as predicted by Lofgren (in Fix and others, 1950, p. 177). The estimated pumpage in the four southwestern basins in 1955 and 1962 was as shown below.

District	1955 pumpage		1962 pumpage	
	Acre-feet	Mgd	Acre-feet	Mgd
Milford	40,000	36	41,500	37
Beryl-Enterprise	51,000	46	61,000	54
Cedar City Valley	16,000	14	18,500	17
Parowan Valley	13,000	12	12,500	11

Water levels in selected wells declined during 1951–62 as much as 21 feet near Milford, 16 feet near Beryl, 17 feet near Cedar City, and 12 feet near Paragonah in Parowan Valley.

Lowering of water levels has not resulted in any significant change in the quality of the water. Seasonal variations are caused by movement of poorer quality water into areas of better quality as a result of pumpage during the irrigation season. However, this movement generally is partly reversed because of the effects of recharge between irrigation seasons.

Additional ground water is physically available (though for legal or economic reasons not necessarily feasibly available) for further development in all or parts of a considerable number of alluvial areas in the State. These areas are shown in figure 55. In addition, at least a

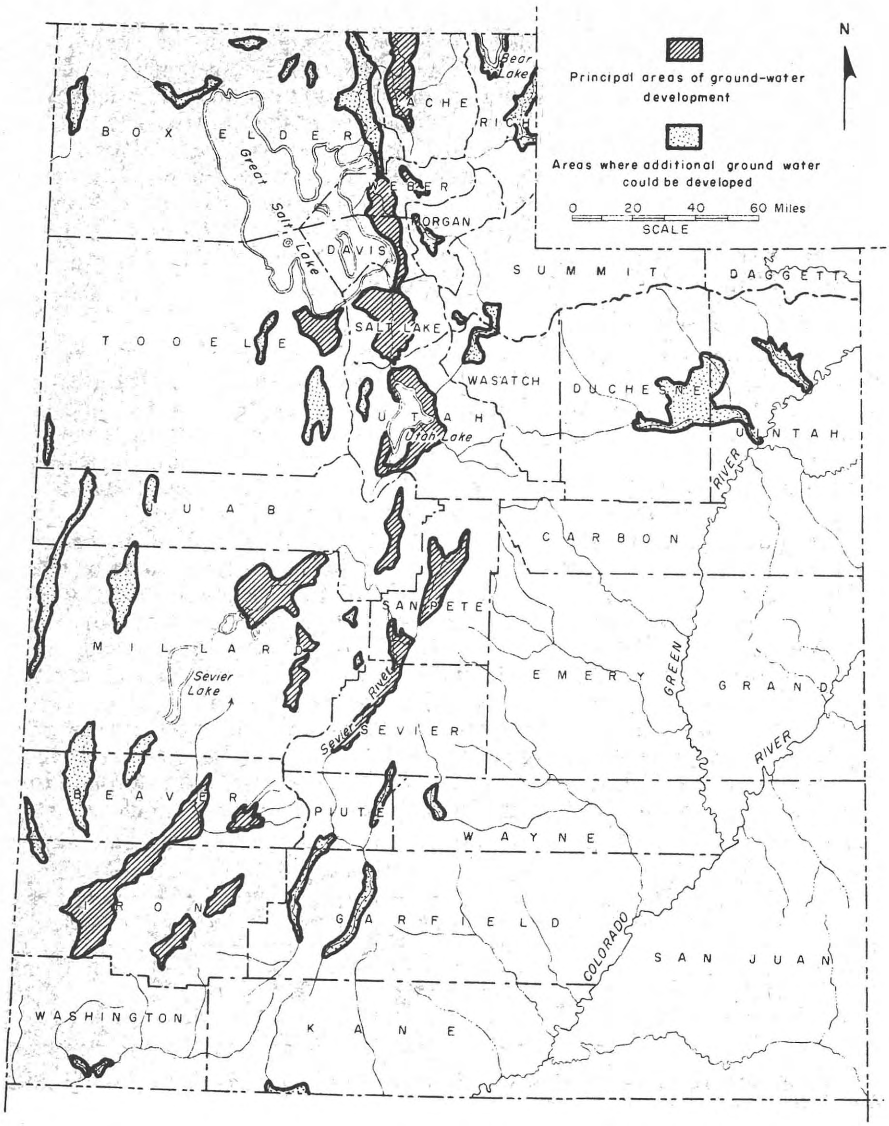


FIGURE 55.—Areas of known or potential ground-water development from alluvial aquifers.

little water is present in many places in alluvium along the major streams and their larger tributaries in the Colorado Plateaus and in small basins in the mountains.

Among the potentially most promising ground-water areas shown in figure 55 are several valleys in the Great Basin which are flanked by mountains 8,000 to 12,000 feet high. The mountains receive rather generous precipitation, 16 to as much as 60 inches, and the annual runoff from them may be as much as 1,500 acre-feet per year per square mile of mountain area, or even more. Among the valleys are the Curlew, Grouse Creek, Cedar, Goshen, Rush, Skull, Juab, White, Deep Creek, Snake, Pine, and Wah Wah Valleys. These valleys are largely unstudied, and virtually nothing is known of the amounts of ground water that might be available, or of the quality of the water and its suitability for various uses.

Also capable of yielding considerable ground water are some of the intermontane valleys in the northeastern part of the State. Among those where some ground water has been developed are the upper Bear River valley and the Ogden, Morgan, Kimball, and Heber Valleys. Of these only the Ogden Valley has been studied in any detail.

In several of the alluvial valleys recharge to the aquifers might be induced from perennial streams by heavy pumping from nearby wells. Such pumping would create storage space in the aquifers which might be filled during the spring snowmelt, and the effect of pumping on late-season streamflow might be small or negligible. Although this procedure would help to maintain the ground-water supply, its effect on surface-water rights would have to be considered; many of the streams that receive ground-water outflow from the alluvium are fully appropriated.

The watercourses where streams and ground water are connected include the upper and lower Bear River valleys; the part of the Cache Valley adjacent to the Bear River; the Green River valley along the southeast edge of the Uinta Basin and the valleys of certain tributaries within the basin including Ashley Creek, the Uinta and Lakefork Rivers, and the Duchesne River as far upstream as Duchesne, and the Strawberry River from there westward; the central Sevier Valley in Sanpete, Sevier, and Piute Counties; the upper Sevier Valley in Piute and Garfield Counties and the valleys of the East Fork and Otter Creek in Piute County and a little of Garfield County; the Fremont River valley from a little below Loa to the vicinity of the Capitol Reef National Monument; and the Virgin River valley downstream from the Hurricane Cliffs.

Bedrock aquifers

Known aquifers in consolidated rocks are much less extensive than those in valley fill, and they have been developed on only a small scale to date. The rocks of the Wasatch and Uinta Ranges and other mountains generally are of low permeability and of little significance as aquifers.

Carbonate rocks of Paleozoic age and sandstones of Mesozoic age in strips on the north and south sides of the Uinta Mountains hold some promise as aquifers, as known from the small amount of information available. The strip on the north is a few tens of miles long and lies in eastern Summit and western Daggett Counties. That on the south is much longer, running from the general vicinity of the West Fork of the Duchesne River in Wasatch County eastward along the north edge of the Uinta Basin past Vernal in Uintah County, then swinging southeastward and eastward south of the Dinosaur National Monument and crossing into Colorado. The meager available data indicate that the water is of good quality in and near areas of recharge but is saline where it lies at depth.

In the Colorado Plateaus, the rocks of Paleozoic and especially those of Mesozoic age include some sandstone and limestone strata that yield water to wells. The plateaus are deeply dissected, however, and in most places the water lies at great depth. Also, recharge conditions are generally unfavorable because the aquifers are covered by rocks of lower permeability through which water can percolate downward only very slowly. The exposures of most of the water-bearing strata are in the walls of canyons and are areas of discharge, not recharge.

Not much detailed information is available for bedrock aquifers; general information is given in reports by Lofgren (1954 a, b), Goode (1958), Goode and Feltis (1962), and Cordova (1963). The southern part of the Colorado Plateaus is more promising than the northern. The principal aquifers, from the top down, in the southern part are the Dakota Sandstone of Cretaceous age; the Bluff and Entrada Sandstones of Jurassic age; the Navajo Sandstone of Jurassic and, possibly in the lower part, Triassic age; the Wingate Sandstone and the Shinarump Member of the Chinle Formation of Triassic age; and the DeChelly Sandstone Member of the Cutler Formation of Permian age (Goode, 1958, fig. 6). The potentially most important are the Entrada and Navajo Sandstones because they underlie the largest areas and, though they lie at depths of more than 1,000 feet in much of their extent, they yield water of good quality under sufficient pressure to rise to moderate depths below the surface and, in some valleys, to flow.

Lofgren (1954b) mentions several areas of particular interest. Flowing wells in the vicinity of Bluff on the San Juan River in southern San Juan County yield water from the Wingate Sandstone and the Shinarump Member of the Chinle Formation. Some of the wells are more than 50 years old. Wells 400 to 600 feet deep in the Montezuma Creek canyon some miles east of Bluff yield flowing water, principally from the Entrada and Navajo Sandstones; yields have been as high as 400 to 500 g.p.m. initially but have dropped off to 100 g.p.m. or less.

In the Sage Plain area east of Monticello in San Juan County, shallow wells obtain water from thin alluvium and the upper part of the underlying Dakota Sandstone. Similar supplies have been developed in the vicinities of La Sal and Blanding in San Juan County and of Moab in Grand County (Lofgren, 1954a, p. 107). A deep oil test about 13 miles east of Monticello is reported to have tapped large quantities of artesian water in several horizons.

An oil test drilled about 12 miles east of Salina in Sevier County yielded flowing water, reportedly from the Blackhawk Formation of Late Cretaceous age, at a depth of less than 560 feet.

Several wells in the northern part of the Wasatch Plateau yield flowing water from the Blackhawk and Price River Formations of Late Cretaceous age and the North Horne Formation of Late Cretaceous and Paleocene age. Wells drilled near Colton in Utah County obtain flowing water from the North Horn and Flagstaff Formations; one well was bottomed at 1,532 feet in the North Horn and flowed about 400 g.p.m.

Wells yield enough water for irrigation from jointed or fragmented basaltic rocks in areas west of Loa in Wayne County and west of Kanosh in Millard County. The wells near Loa, which flow, are near some springs long used by ranchers, and withdrawing water from the wells reduces the flow of the springs proportionately; the total flow of the springs and wells is reported to be about 2,000 g.p.m. The wells near Kanosh yield large quantities of unconfined water from volcanic rocks. The volcanic rocks are interbedded with alluvium, which extends over a large area and apparently has a substantial undeveloped supply.

A few scattered wells in northern Utah obtain moderate quantities of water of good quality from basalt flows interbedded with alluvium. Doubtless many similar supplies will be discovered in the future.

Information needed

Reasonably adequate ground-water studies have been made in only a few areas, principally the alluvial valleys where ground water is heavily pumped. Except for the few valleys that have been studied in detail, little information is available and reconnaissance studies are badly needed, especially in the Great Basin, where there are promising areas for future development.

There is also need for ground-water information in the Colorado Plateaus. The potential for irrigation is relatively low in this area, but there are encouraging prospects for industrial development. Fortunately, the oil "boom" of recent years and test drilling for uranium and potash have yielded and are yielding much valuable information on the occurrence of ground water. Thorough study of the data made available in this way, supplemented by local test drilling and pumping tests in critical areas, will make it possible to assess the ground-water potentialities in broad parts of the area.

Though the withdrawal of ground water in the intermontane basins of the Rocky Mountains is on a generally small scale and the principal problem is the need to consider potential interference between surface-water and ground-water developments, detailed studies of these basins will be needed as development increases.

Additional development

Ground water can meet a substantial share of Utah's increasing water requirements, but only if the requisite hydrologic knowledge is acquired. In most areas additional studies will be needed before substantial additional development can be attempted safely, even though it can be concluded that in many of the areas some additional development is feasible.

In the heavily populated areas along the Wasatch front, appreciably more ground water is available than is now being used, but large additional withdrawals would affect springs and flowing wells now used for water supply. Under court decisions as recent as 1959, it has been held that a prior appropriator is entitled to protection of the flow of his well, and that later appropriators who decrease or stop his flow must pay the attendant costs. Such decisions have the effect of preventing maximum use of the storage capacity of aquifers. In maximum-scale development of ground water, the water level is drawn down in dry periods and allowed to recover in wet periods. If the water must be obtained by natural flow, the aquifers remain full and only a small part of their storage capacity is utilized.

Withdrawing ground water may decrease the flow of streams on which there are senior appropriative rights, and this factor will have to be considered in developing additional ground water from watercourses, as well as from basins which are not watercourses but from which there is subsurface outflow that supports the flow of fully appropriated streams. This problem exists in the basins within the Rocky Mountains in the northern part of the State the upper Bear River Valley and the Ogden, Morgan, Kimball, and Heber Valleys. It exists also in the Sevier River Valley, where there is large ground-water storage but where ground-water outflow helps to support surface flows appropriated downstream for irrigation.

Obviously, therefore, some modification in existing laws, as interpreted in recent decisions, may be needed if there is to be full development where ground water and surface water are interconnected.

In the many "dry" valleys of the Great Basin this problem is not involved to any great extent. Recovery of ground water will simply decrease natural discharge which is now serving no beneficial purpose, and recovery may actually increase replenishment in some valleys when the water table in the recharge areas is lowered, creating storage space that will absorb a greater proportion of the intermittent streamflow than is absorbed under natural conditions.

The Uinta Basin has some promise for ground-water development. The available surface-water and quality-of-water data, though not yet adequate, could serve as a basis for very rough estimates of ground-water potential. Although available data indicate the water to be of generally excellent quality, localized saline water will be a limiting factor, both in shallow aquifiers recharged by irrigation water and in deep aquifers in which circulation of water is slow. The legal problem imposed by interconnection of ground water and surface water exists, but not to the extent that it does in the heavily developed areas along the Wasatch front.

UTILIZATION AND STORAGE

The greatest part of Utah is semiarid, and at present the land serves principally for grazing and as a source of such runoff as originates on it and is captured for productive uses. The following table summarizes the land area by type and the consumptive use of water in each type, in terms of percentage of the total precipitation (U.S. Congress, 1960, pp. 354–355).

Type of land	Percent of total area	Water consumption (percent of total precipitation)
Grazing land and watersheds	81.7	72.1
Arable but uncropped land, used for grazing	2.6	1.9
Dry-farmed land	1.1	1.0
Irrigated land	2.1	4.6
Cities and towns, industrial sites	.5	.2
Wastelands, national parks, and monuments	9.0	6.4
Water area	3.0	9.5
Total	100.0	95.7
Outflow in interstate streams		4.3
Total		100.0

Grazing land and watersheds and uncropped arable land account for 84.3 percent of the area but consume only 74 percent of the precipitation. The remaining precipitation (26 percent) represents runoff that supplies consumptive uses on the other 15.7 percent of the area, and which creates the difference between the surface flow received by the State and that discharged from the State. Irrigated land, which accounts for 2.1 percent of the area but probably receives less than that percentage of the precipitation because it lies at low elevations, consumes water equivalent to 4.6 percent of the precipitation. Water areas, mainly the large lakes, when at "normal" levels account for 3.0 percent of the area (as of 1963 Sevier Lake was dry and Great Salt Lake covered only half the area covered as of 1952) and probably a much smaller percentage of the precipitation, and consume 9.5 percent of the precipitation. To consume, or at least to get more use from, a part of the water now evaporated from the lakes is one of the principal goals of future water development in Utah.

According to the State (U.S. Congress, 1960, p. 350), the irrigated area in 1959 was about 1,165,000 acres. Other sources give different figures, ranging from somewhat less to considerably more. Of the 1,165,000 acres, only 407,000 acres have an adequate water supply at present according to the State. An additional area of 1,429,000 acres would be suitable for irrigation if water could be supplied. Utah by 1980 hopes to irrigate some 57,000 acres of new lands and to provide supplemental water to about 523,000 acres; the total water requirement would be equivalent to that required for 228,000 acres of new lands. By the year 2000 the expected totals are 203,000 acres of new land, 708,000 acres provided supplemental water, and a new-land equivalent of 446,000 acres (U.S. Congress, 1960, p. 360).

As of 1959, the total diversion needs as estimated by the State (U.S. Congress, 1960, p. 357), in millions of acre-feet per year, were 0.2 each for municipal and industrial use and 5.0 for irrigation, a total of 5.4 (4.8 bdg). The expected 1980 figures are 0.5, 1.0, and 5.5, for a total of 7.0 million acre-feet (6.2 bgd). Rural use is not included but is relatively small. These figures assume a full supply for all uses; the actual diversions currently are less.

As of 1960 (MacKichan and Kammerer, 1961; McGuinness, 1963) the total withdrawal use of water was as given below.

In addition to the quantities shown for irrigation, an estimated 750 mgd (840,000 acre-feet), mostly surface water, was accounted for by conveyance losses between points of diversion and points of delivery to irrigated cropland.

Use	Surface water		Ground water		Total	
	Acre-feet per year	Mgd	Acre-feet per year	Mgd	Acre-feet per year	Mgd
	Fresh water					
Public	130,000	120.0	110,000	100.0	240,000	220.0
Rural domestic and stock	9,700	8.7	12,000	11.0	22,000	20.0
Industrial:						
Public-utility fuel electric power	86,000	77.0			86,000	77.0
Other	164,000	150.0	65,000	58.0	230,000	210.0
Irrigation	3,400,000	3,000.0	390,000	350.0	3,800,000	3,400.0
Total	3,800,000	3,400.0	580,000	520.0	4,400,000	3,900.0
	Saline water					
Industrial, total (none for public-utility fuel-electric power)	6,200	5.5	3,400	3.0	9,600	8.5

Streams, lakes, and reservoirs are used extensively for recreation and for fish and wildlife propagation. These uses of the water resources are increasing rapidly; the social and economic values are recognized and given consideration in development plans. Utah's streams, lakes, and marshes were the natural habitat of fish and game before the pioneers arrived. One of the principal migratory bird flyways crosses Utah, and millions of ducks, geese, and other waterfowl not only visit the area during their migration, but thousands stop over during the nesting season. The largest migratory-bird refuge in the world is near the mouth of the Bear River. Several State bird refuges have been developed, and a large number of private duck clubs have developed other marsh areas for migratory birds; it is estimated that the marsh areas exceed 500,000 acres. Fish are taken from streams, reservoirs, and lakes principally for sport or recreation; however, some fish are taken from Utah Lake for the West Coast market.

Production of firm power requires considerable storage to regulate the variations in streamflow. (See section on water power below.) During the snowmelt period of May and June about 60 percent of the yearly streamflow occurs. Discharge of unregulated streams during the winter months is only 10 percent of the May–June discharge.

Early storage reservoirs were based on the concept of single-purpose use of water. The more recent concept of multipurpose development, including benfits outside the borders of the State, has resulted in greatly increased storage capacity during recent years. Flaming Gorge Reservoir and Lake Powell, the two largest reservoirs now being utilized in the Colorado River storage project, have a total capacity of 30,789,000 acre-feet, most of which is in Utah. Exclusive of the Colorado River storage project, the 18 principal reservoirs furnishing water to Utah lands have a total usable capacity of 3,837,000 acre-feet. Two of the reservoirs, Bear Lake and Woodruff Narrows in the Bear River Basin, with a usable capacity of 1,448,000 acre-feet, also supply irrigation water to adjoining States. The principal reservoirs with capacities are as follows:

Reservior:	*Usable capacity*	Reservoir—Continued	*Usable capacity*
Bear Lake	1, 421, 000	Scofield	65, 780
Deer Creek	149, 700	Sevier Bridge	236, 100
East Canyon	28, 730	Steinaker	33, 280
Echo	73, 940	Strawberry	270, 000
Hyrum	15, 280	Utah Lake	1, 149, 000
Moon Lake	35, 800	Woodruff Narrows	26, 500
Otter Creek	52, 500		
Pine View	110, 000	Subtotal	3, 837, 000
Piute	74, 010	Flaming Gorge	[1] 3, 789, 000
Porcupine	11, 300	Lake Powell	[1] 27, 000, 000
Rockport	60, 860		
Rockyford	23, 260	Total	34, 626, 000

[1] Total capacity.

WATERPOWER

(By Arthur Johnson, Washington, D.C., and W. C. Senkpiel, Denver, Colo.)

Utah ranks 12th amongst the States in gross theoretical power available from its developed and potential waterpower sites. Some 1,600

MW (megawatt=1,000 kilowatts), which is 1.3 percent of the national total, might be available ultimately. Utah only ranks 30th, however in actual installed capacity, with its 211 MW at developed sites. The recently completed (October 1963) Flaming Gorge project on the Green River added 108 MW, and slightly more than doubles previous installed capacity.

Power development in Utah was undertaken at an early date, almost entirely in the Great Salt Lake basin. Seven sites had been developed by the end of 1900. During the 1901–10 decade 31 plants were built and during the 1911–20 decade 14 more plants were added. These plants were at scattered locations on small streams (see fig. 56) and served small communities. As explained by Woolley (1947, p. 176), this distribution is related to the physiography of the basin and its numerous small streams, and to the type of settlements. Many of the communities were small because the streams on which they were located were small and because they were separated from other communities by varying amounts of barren areas which served as barriers to communication and transportation as well as to interconnection by transmission lines.

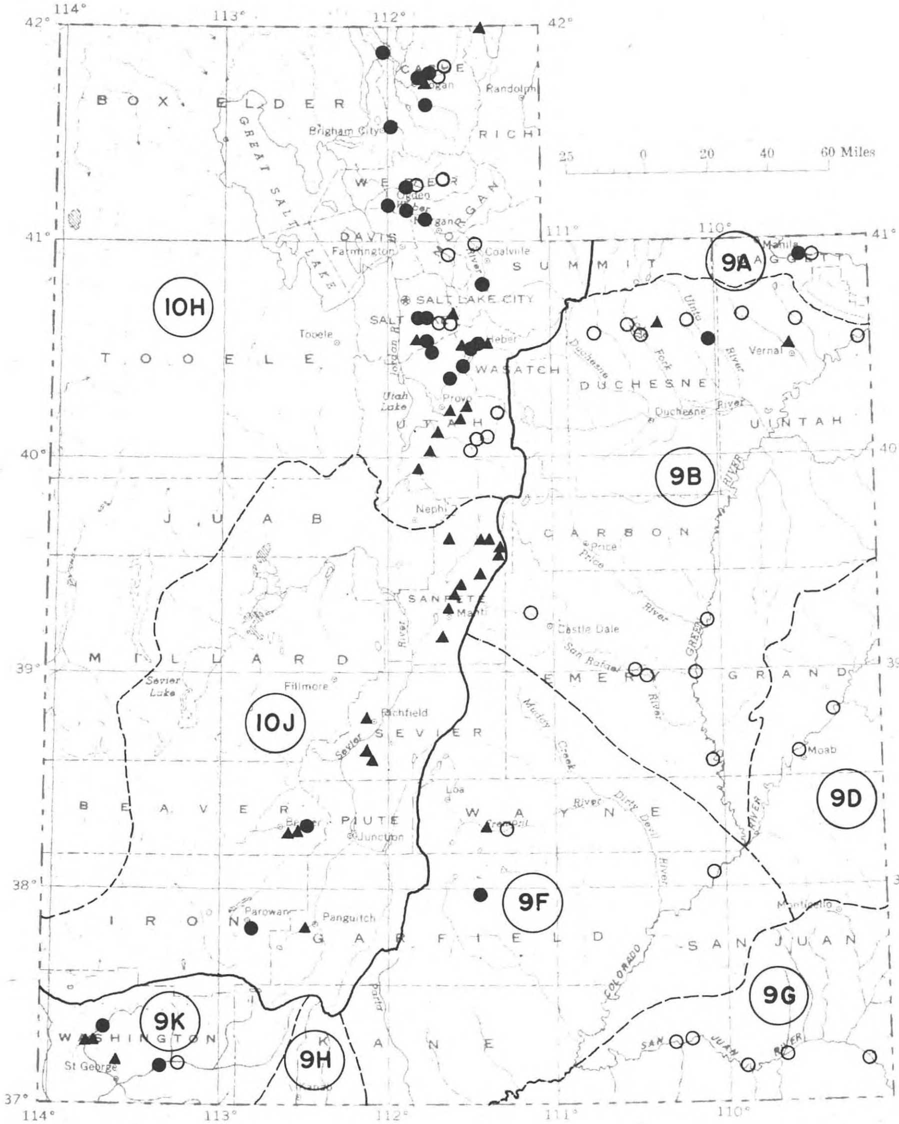
The waterpower resources of Utah are summarized in table 20. The gross theoretical power has been evaluated for the several flow conditions recommended by the World Power Conference, based on 100 percent efficiency and utilization of the full head available at each site. All developed sites have been included regardless of size, but the undeveloped sites include only those having at least 1 MW potential based on the flow available 50 percent of the time (Q50). For these sites, flow available 95 percent of the time (Q95) suggests the firm or continuous power potential on streams lacking storage for equalizing irregular flow. The Q95 evaluation indicates in general the minimum potential power for comparative purposes.

The potential power based on mean flow (Q mean) represents the maximum attainable. To realize this condition sufficient storage must be available to so regulate streamflow that all the water will be utilized through the turbines, a desirable but not always attainable condition on some streams.

Evaluations of potential power based on the flow and fall of a stream tend to give higher values than generally can be realized, either because of the absence of feasible damsites, lack of adequate storage capacity, or the use of water for industrial or agricultural purposes. As previously stated, the estimates are based on 100 percent efficiency in accordance with World Power Conference recommendations. Experience has shown that overall efficiency for a power project will vary between 75 and 85 percent.

The gross theoretical power by drainage basin subdivisions is shown in table 20. The location of the power sites, developed and undeveloped, is shown on figure 56.

There are 50 developed sites in the Great Basin, only two of which have installed capacities greater than 5.0 MW. There are 11 developed sites in the Colorado River Basin, and with the exception of the recently completed Flaming Gorge project on the Green River, the largest installed capacity was 2.8 MW. The distribution of developed



——— Major drainage basin boundary

– – – – Drainage basin subdivision boundary

(1A) Drainage basin subdivision index number

▲ Developed waterpower site, installed capacity less than 1.0 MW

● Developed waterpower site, installed capacity greater than 1.0 MW

○ Undeveloped waterpower site

FIGURE 56.—Waterpower sites in Utah, developed and undeveloped.

sites according to installed capacity is indicated by the following tabulation:

Developed powersites

Installed capacity (MW)	Colorado River Basin		Great Basin	
	Number of sites	Total installed capacity	Number of sites	Total installed capacity
Less than 1.0	7	4.3	32	13.4
1.0 to 2.0	1	1.2	9	13.6
2.0 to 3.0	2	4.8	3	7.4
3.0 to 5.0			4	18.3
5.0 to 10.0				
10.0 to 25.0			1	12.7
25.0 to 50.0			1	30.0
50.0 to 100.0				
Over 100.0	1	[1] 108.0		
Total	11	118.3	50	95.4

[1] Flaming Gorge project.

In considering the developed power in Utah, it should be noted that the reservoir for the Flaming Gorge project, when filled, will extend 60 miles into Wyoming. The Flaming Gorge dam is 32 river-miles from the Wyoming-Utah boundary. The Glen Canyon dam is 13 river-miles below the Utah-Arizona boundary. The reservoir when filled, will extend 173 miles into Utah.

The potential undeveloped power in Utah is predominantly in the Colorado River Basin. As shown in table 20, there are 24 prospective sites in the Colorado River Basin with an estimated gross theoretical power of 1344 MW based on mean flow. The corresponding figures for the Great Basin are 14 sites and 70 MW. Of the 24 sites in the Colorado River Basin, 3 are on the Colorado River with an estimated potential of 602 MW and 5 are on the Green River with an estimated potential of 472 MW. In the Great Basin the two largest undeveloped sites have estimated potentials of 13 and 14 MW, followed by two sites each with 9 MW potential and one with 6 MW. In other words, 51 of the 70 MW of undeveloped power in the Great Basin are in 5 sites. Any significant increase in developed waterpower in Utah, therefore, will be at sites in the Colorado River Basin, primarily on the Colorado and Green Rivers.

Although the tendency is towards the development of large sites, the utilization of small sites has not been entirely discontinued as evidenced by the construction of a 0.3-MW plant in 1955; and plants with 1.4, 2.8, 4.5, and 5.0 MW capacity in 1958.

TABLE 20.—*Developed and undeveloped waterpower in Utah, Dec. 31, 1962*

Principal drainage area and subdivisions	Drainage basin index number	Developed waterpower sites					Undeveloped waterpower sites				Total gross theoretical power (MW), developed and undeveloped sites, based on mean flow
		Number of sites	Gross theoretical power (MW), gross head (100-percent efficiency) flows at—			Installed capacity (MW)	Number of sites	Gross theoretical power (MW), gross head (100-percent efficiency) flows at—			
			Q95	Q50	Q mean			Q95	Q50	Q mean	
Colorado River Basin:											
Green River Basin	9A	1	13.7	43.3	85.5	[1] 108.0	1	1.0	3.1	6.2	91.7
Green River Basin	9B	3	2.9	5.9	11.2	2.4	13	85.8	229.0	528.1	539.3
Colorado River Basin	9D						2	66.0	133.9	288.9	288.9
Colorado River Basin	9F	2	2.1	2.6	3.2	3.0	2	70.4	154.1	322.0	325.2
San Juan River Basin	9G						5	20.4	85.4	194.2	194.2
Virginia River Basin	9K	5	1.6	3.7	6.3	4.9	1	1.6	3.1	4.9	11.2
Total, Colorado River Basin		11	20.3	55.5	106.2	118.3	24	245.2	608.6	1,344.3	1,450.5
Great Basin:											
Great Salt Lake Basin	10H	32	22.1	44.3	75.4	87.6	14	16.5	36.6	69.5	144.9
Southwest Utah basins	10J	18	3.9	5.8	12.3	7.8					12.3
Total, Great Basin		50	26.0	50.1	87.7	95.4	14	16.5	36.6	69.5	157.2
Total for State		61	46.3	105.6	193.9	213.7	38	261.7	645.2	1,413.8	1,607.7

MW = Megawatt = 1,000 kilowatts.

[1] Flaming Gorge project which was placed in operation in October 1963.

According to the Federal Power Commission,[1] there were, at the end of 1962, 83 existing powerplants in Utah which were owned by 24 electric utilities (publicly owned locally, federally owned, and privately owned) with a total installed generating capacity of about 610 MW. Of this total, 102 MW, or 17 percent, were supplied by 58 waterpower plants; 45 MW, or 7 percent, by 16 internal combustion plants; and 463 MW, or 76 percent, by 9 steamplants. Because of the large deposits of coal located in the State, coal-fired steamplants are the principal source of its energy.

Selected References

Detailed records of streamflow, ground-water levels, and quality of water are published in U.S. Geological Survey Water-Supply Papers. Streamflow data are given in a series "Surface Water Supply of the United States." Before 1961 this was an annual series but beginning with 1961–65 a 5-year series will be used. Records for Utah are in Parts 9, 10, and 13. Notable floods are summarized annually in a report "Floods of 19—." Ground-water levels and artesian pressures in observation wells in Utah are given in a 5-year series "Ground-Water Levels in the United States, Northwestern States." Quality-of-water data are given in two annual series (1) "Quality of Surface Waters of the United States"; data for Utah are in Parts 9–14; and (2) "Quality of Surface Water for Irrigation, Western United States."

Bagley, J. M., and others, 1963, Developing a State water plan, Utah's water resources—problems and needs—a challenge: Utah State Univ. and Utah Water and Power Board.

Berwick, V. K., 1962, Floods in Utah, magnitude and frequency: U.S. Geol. Survey Circ. 457.

Clarke, F. W., 1924, The data of geochemistry: U.S. Geol. Survey Bull. 770.

Connor, J. G., Mitchell, C. G., and others, 1958, A compilation of chemical quality data for ground and surface waters in Utah: Utah State Engineer Tech. Pub. 10.

Cordova, R. M., 1963, Hydrogeologic reconnaissance of part of the headwaters area of the Price River, Utah: Utah Geol. and Mineralog. Survey Water-Resources Bull. 4.

Dennis, P. E., Maxey, G. B., and Thomas H. E., 1946, Ground water in Pavant Valley, Millard County, Utah: Utah State Engineer Tech. Pub. 3.

Fix, P. F., and others, 1950, Ground water in the Escalante Valley, Beaver, Iron, and Washington Counties, Utah: Utah State Engineer Tech. Pub. 6, *in* Utah State Engineer 27th Bienn. Rept.

Gardner, D. I., 1962, Utah Lake and Jordan River distribution: Water Commissioner Rept.

Gates, J. S., 1963, Hydrogeology of Middle Canyon, Oquirrh Mountains, Tooele County, Utah: U.S. Geol. Survey Water-Supply Paper 1619–K.

Gilbert, G. K., 1890, Lake Bonneville: U.S. Geol. Survey Mon. 1.

Goode, H. D., 1958, The geology and distribution of aquifers in the southeastern part of San Juan County, Utah: U.S. Geol. Survey open-file rept.

Goode, H. D., and Feltis, R. D., 1962, Water production from oil wells of the Uinta Basin, Uintah and Duchesne Counties, Utah: Utah Geol. and Mineralog. Survey Water-Resources Bull. 1.

Gregory H. E., 1916, The Navajo country—a geographic and hydrologic reconnaissance of parts of Arizona, New Mexico, and Utah: U.S. Geol. Survey Water-Supply Paper 380.

Hahl, D. C., and Langford, R. H., 1963, Dissolved-mineral inflow to Great Salt Lake and chemical characteristics of the salt lake brine; Part II, Technical Report: Utah Geol. and Mineralog. Survey Water-Resources Bull. 3.

Hahl, D. C., and Mitchell, C. G., 1963, Dissolved-mineral inflow to Great Salt Lake and chemical characteristics of the salt lake brine: Part I, Selected hydrologic data: Utah Geol. and Mineralog. Survey Water-Resources Bull. 3.

Hembree, C. H., Iorns, W. V., Oakland, G. S., and Phoenix, D. A., 1959, Chemical quality of water in the lower Duchesne River drainage basin: U.S. Geol. Survey open-file rept.

[1] Federal Power Commission, press release No. 12,506, February 19, 1963, Washington, D.C.

Howard C. S., 1931, Quality of water of the Colorado River in 1928–30: U.S. Geol. Survey Water-Supply Paper 638–D.

———1947, Suspended sediment in the Colorado River, 1925–41: U.S. Geol. Survey Water-Supply Paper 998.

———1955, Quality of Water of the Colorado River, 1925–40: U.S. Geol. Survey open-file rept.

Hunt, C. B., Varnes, H. D., and Thomas, H. E., 1953, Lake Bonneville: Geology of northern Utah Valley, Utah: U.S. Geol. Survey Prof. Paper 257–A.

King, N. J., and Mace, M. M., 1953, Sedimentation in small reservoirs on the San Rafael Swell, Utah: U.S. Geol. Survey Circ. 256.

Langbein, W. B., 1961, Salinity and hydrology of closed lakes: U.S. Geol. Survey Prof. Paper 412.

Lee, W. T. 1908, Water resources of Beaver Valley, Utah: U.S. Geol. Survey Water-Supply Paper 217.

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.

Lofgren, B. E., 1954a, Ground-water possibilities of bedrock aquifers in southeastern Utah, *in* Progress report on selected ground-water basins in Utah: Utah State Engineer Tech. Pub. 9.

———1954b, Ground water developed from bedrock aquifers in Utah: U.S. Geol. Survey open-file rept.

Lohr, E. W., and Love, S. K., 1954, The industrial utility of public water supplies in the United States, 1952, part 2, States west of the Mississippi River: U.S. Geol. Survey Water-Supply Paper 1300.

McGuiness, C. L., 1963, The role of ground-water in the national water situation: U.S. Geol. Survey Water-Supply Paper 1800.

MacKichan, K. A., and Kammerer, J. C., 1961, Estimated use of water in the United States, 1960: U.S. Geol. Survey Circ. 456.

Marine, I. W., 1962, Water-supply possibilities at Capitol Reef National Monument, Utah: U.S. Geol. Survey Water-Supply Paper 1475–G.

———1963, Ground-water resources of the Bryce Canyon National Park area, Utah: U.S. Geol. Survey Water-Supply Paper 1475–M.

Meinzer, O. E., 1911, Ground water in Juab, Millard, and Iron Counties, Utah: U.S. Geol. Survey Water-Supply Paper 277.

Mower, R. W., 1961, Relation of the deep and shallow artesian aquifers near Lynndyl, Utah: U.S. Geol. Survey Prof. Paper 424–C, article No. 185.

Richardson, G. B., 1906, Underground water in the valleys of Utah Lake and Jordan River, Utah: U.S. Geol. Survey Water-Supply Paper 157.

———1907, Underground water in Sanpete and central Sevier Valleys, Utah: U.S. Geol. Survey Water-Supply Paper 199.

Sanberg, G. W., 1962, Ground-water conditions in the Milford and Beryl-Enterprise districts and in Cedar City and Parowan Valleys, Utah, 1954–60: U.S. Geol. Survey open-file rept.

Smith, R. E., and Gates, J. S., Ground-water conditions in the southern and central parts of the East Shore area, Utah, 1953–61: Utah Geol. and Mineralog. Survey Water-Resources Bull. 2.

Snyder, C. T., 1963, Hydrology of stock-water development in the public domain of western Utah: U.S. Geol. Survey Water-Supply Paper 1475–N.

Talmage, J. E., Scottish Geographic Mag., vol. 20, p. 424.

Taylor, G. H., and Leggette, R. M., 1949, Ground water in the Jordan Valley, Utah: U.S. Geol. Survey Water-Supply Paper 1029.

Taylor, G. H., and Thomas, H. E., 1939, Artesian-water levels and interference between artesian wells in the vicinity of Lehi, Utah: U.S. Geol. Survey Water-Supply Paper 836–C.

Thomas, H. E., 1946, Ground water in Tooele Valley, Tooele County, Utah: Utah State Engineer Tech. Pub. 4, *in* Utah State Engineer 25th Bienn. Rept.

———1952, Hydrologic reconnaissance of the Green River in Utah and Colorado; U.S. Geol. Survey Circ. 129.

———1955, Water rights in areas of ground-water mining: U.S. Geol. Survey Circ. 347.

Thomas, H. E., and Nelson, W. B., 1948, Ground water in the East Shore area, Utah; part 1, Bountiful district, Davis County: Utah State Engineer Tech. Pub 5, *in* State Engineer 26th Bienn. Rept.

Thomas, H. E., and others, 1952, Status of development of selected ground-water basins in Utah: Utah State Engineer Tech. Pub. 7.

Thomas, H. E., and Taylor, G. H., 1946, Geology and ground-water resources of Cedar City and Parowan Valleys, Iron County, Utah: U.S. Geol. Survey Water-Supply Paper 993.
Thomas, H. E., and Wilson, M. T., 1952, Determination of total evapo-transpiration in Ashley Valley, Utah, by the inflow-outflow method: U.S. Geol. Survey open-file rept.
———1960, A case of underground piracy: Internat. Geol. Congr., 21st, Copenhagen 1960.
Thomas, N. O., and Harbeck, G. E., Jr., 1956, Reservoirs in the United States: U.S. Geol. Survey Water-Supply Paper 1360–A.
U.S. Congress, Senate Select Committee on National Water Resources, 1960, Water resources activities in the United States—Views and comments of the States: U.S. 86th Cong., 2d sess., Comm. Print 6.
U.S. Geological Survey, 1954, Compilation of records of surface waters of the United States through September 1950, part 9, Colorado River basin: U.S. Geol. Survey Water-Supply Paper 1313.
———1956a, Compilation of records of surface waters of the United States through September 1950, part 10, the Great Basin: U.S. Geol. Survey Water-Supply Paper 1314.
———1956b, Compilation of records of surface waters of the United States through September 1950, part 13, Snake River basin: U.S. Geol. Survey Water-Supply Paper 1317.
———1957, Floods of April–June 1952 in Utah and Nevada: U.S. Geol. Survey Water-Supply Paper 1260–E.
Waite, H. A., and others, 1954, Progress report on selected ground-water basins in Utah: Utah State Engineer Tech. Pub. 9.
White, W. N., 1932, A method of estimating ground-water supplies based on discharge by plants and evaporation from soil—results of investigation in Escalante Valley, Utah: U.S. Geol. Survey Water-Supply Paper 659–A.
Woolley, R. R., 1924, Water powers of the Great Salt Lake basin: U.S. Geol. Survey Water-Supply Paper 517.
———1930, The Green River and its utilization: U.S. Geol. Survey Water-Supply Paper 618.
———1946, Cloudburst floods in Utah, 1850–1938: U.S. Geol. Survey Water-Supply Paper 994.
———1947, Utilization of surface-water resources of Sevier Lake basin, Utah: U.S. Geol. Survey Water-Supply Paper 920.

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

103 Utah Geological Survey Building
University of Utah
Salt Lake City, Utah 84112

THE UTAH GEOLOGICAL AND MINERALOGICAL SURVEY since 1949 has been affiliated with the College of Mines and Mineral Industries at the University of Utah. It operates under a director with the advice and counsel of an Advisory Board appointed by the Board of Regents of the University of Utah from organizations and categories specified by law.

The survey is enjoined to cooperate with all existing agencies to the end that the geological and mineralogical resources of the state may be most advantageously investigated and publicized for the good of the state. The *Utah Code, Annotated, 1953 Replacement Volume 5, Chapter 36, 53-36-2*, describes the Survey's functions.

Official maps, bulletins, and circulars about Utah's resources are published. (Write to the Utah Geological and Mineralogical Survey for the latest list of publications available).

THE LIBRARY OF SAMPLES FOR GEOLOGIC RESEARCH. A modern library for stratigraphic sections, drill cores, well cuttings, and miscellaneous samples of geologic significance has been established by the Survey at the University of Utah. It was initiated by the Utah Geological and Mineralogical Survey in cooperation with the Departments of Geology of the universities in the state, the Utah Geological Society, and the Intermountain Association of Petroleum Geologists. This library was made possible in 1951 by a grant from the University of Utah Research Fund and by the donation of collections from various oil companies operating in Utah.

The objective is to collect, catalog, and systematically file geologically significant specimens for library reference, comparison, and research, particularly cuttings from all important wells driven in Utah, and from strategic wells in adjacent states, the formations, faunas, and structures of which have a direct bearing on the possibility of finding oil, gas, salines or other economically or geologically significant deposits in this state. For catalogs, facilities, hours, and service fees, contact the office of the Utah Geological and Mineralogical Survey.

THE SURVEY'S BASIC PHILOSOPHY is that of the U. S. Geological Survey, i.e., our employees shall have no interest in Utah lands. For permanent employees this restriction is lifted after a 2-year absence; for consultants employed on special problems, there is a similar time period which can be modified only after publication of the data or after the data have been acted upon. For consultants, there are no restrictions beyond the field of the problem, except where they are working on a broad area of the state and, here, as for all employees, we rely on their inherent integrity.

DIRECTORS:

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