UTAH GEOLOGICAL AND MINERALOGICAL SURVEY
AFFILIATED WITH
THE COLLEGE OF MINES AND MINERAL INDUSTRIES
UNIVERSITY OF UTAH
SALT LAKE CITY, UTAH

GEOLOGIC ATLAS OF UTAH

CACHE COUNTY

By

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Professor of Geology
UTAH STATE UNIVERSITY
LOGAN, UTAH

Bulletin 64 June 1958

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UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

The Utah Geological and Mineralogical Survey was authorized by act of the Utah State Legislature in 1931; however, no funds were made available for its establishment until 1941 when the State Government was reorganized and the Utah Geological and Mineralogical Survey was placed within the new State Department of Publicity and Industrial Development where the Survey functioned until July 1, 1949. Effective as of that date, the Survey was transferred by law to the College of Mines and Mineral Industries, University of Utah.

The *Utah Code Annotated 1943, Vol. 2, Title 34,* as amended by *chapter 46 Laws of Utah 1949,* provides that the Utah Geological and Mineralogical Survey "shall have for its objects":

1. "The collection and distribution of reliable information regarding the mineral resources of the State.

2. "The survey of the geological formations of the State with special reference to their economic contents, values and uses, such as: the ores of the various metals, coal, oil-shale, hydro-carbons, oil, gas, industrial clays, cement materials, mineral waters and other surface and underground water supplies, mineral fertilizers, asphalt, bitumen, structural materials, road-making materials, their kind and availability; and the promotion of the marketing of the mineral products of the State.

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4. "The consideration of such other scientific and economic problems as, in the judgment of the Board of Regents, should come within the field of the Survey.

5. "Cooperation with Utah state bureaus dealing with related subjects, with the United States Geological Survey and with the United States Bureau of Mines, in their respective functions including field investigations, and the preparation, publication, and distribution of reports and bulletins embodying the results of the work of the Survey.

6. "The preparation, publication, distribution and sale of maps, reports and bulletins embodying the results of the work of the Survey. The collection and establishment of exhibits of the mineral resources of Utah.

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The Utah Geological and Mineralogical Survey has published maps, circulars, and bulletins as well as articles in popular and scientific magazines. For a partial list of these, see the closing pages of this publication. For other information concerning the geological and mineralogical resources of Utah address:

ARTHUR L. CRAWFORD, *Director*

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

College of Mines and Mineral Industries
University of Utah
Salt Lake City, Utah

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C O N T E N T S

I L L U S T R A T I O N S

F O R E W O R D

Cache is the second county to have a geologic atlas published in this series. The Utah Geological and Mineralogical Survey owes this circumstance to the willingness, capacity, background, and intense interest of one of its Advisory Board Members, Dr. J. Stewart Williams, Head of the Department of Geology, and Dean of the School of Graduate Studies, Utah State University, Logan, Utah.

Dean Williams has contributed much to the knowledge of Utah geology, in general and to the stratigraphy of the Carboniferous of Cache County in particular. He has made himself the outstanding authority on the general subject about which this atlas is written. It was, therefore, fortunate for the success of the "Geologic Atlas of Utah" project that Dr. Williams could take time from his now heavy executive responsibilities to lend a helping hand to a favorite project which must depend largely upon the gratis services of men like him if it is to succeed in our state.

The field work for similar atlases has been completed for Daggett and Salt Lake Counties. It is expected that the drafting and texts for these will be completed before publication funds are available for them. The Atlases for Washington, Beaver, Sevier, and Uinta Counties are well under way. Most of the other counties in Utah have been allotted to geologists who are the best authorities that could be found on the counties assigned.

This is a unique demonstration in public-spirited cooperation on a state-wide program. There has been no promise of a stipend or of other monetary reward for the generous services of the scientists who have and are authoring these publications.

Dr. William Lee Stokes, Head of the Department of Geology, University of Utah, authored the "Geologic Atlas of Utah--Emery County," Bulletin 52 of the Utah Geological and Mineralogical Survey. The Emery County bulletin was the prototype for the series by which we hope to map in color, on a minimum scale of 1/2 inch to the mile, the areal geology of the state.

In the following pages, Dr. Williams has detailed a worthy sequel to the bulletin on Emery County by Dr. Stokes.

As Director of the Utah Geological and Mineralogical Survey, I wish also to acknowledge the wholehearted teamwork of the staff--largely of part-time workers. Their cooperation has made it possible to process this bulletin in record time for release at the 1958 Annual Convention of the Pacific Division of the Am. Ass. for the Advancement of Sci., to be held this year, June 16-20, at Logan, Utah. It is peculiarly fitting that such a propitious occasion could be found for the release of a geologic atlas of the county in which the convention is to be held.

Mr. Donald Gail Prince has worked night and day during all of his available spare time to complete the drafting, and Miss Rosemary Van Dyke, our junior manuscript typist to whom this bulletin was assigned, has been tireless in her editing of the format and her final typing of the manuscript for offset printing. In this she has been ably assisted by her senior associate, Miss Joann Despain. Others of the staff with less direct responsibilities for this project have contributed cheerfully and well whenever there was occasion for their services on this manuscript. Particularly, I should mention here the over-all care of Miss Elizabeth V. Larson, Office Manager and Editorial Assistant of the Utah Geological and Mineralogical Survey.

The format chosen for this atlas series is unique. It is, frankly, an experiment in an attempt to streamline information which hitherto has been portrayed on cumbersome, unwieldy, and weather-vulnerable media. The reasons for this experiment were adequately covered in the Foreword to the Emery County bulletin. They will not be enlarged upon here.

Bulletin 52 (Emery County) has been well received. Its sales have been even better than was expected. Reviews concerning it have been most complimentary. However, in an attempt to incorporate some of the suggestions growing out of the preliminary use of Bulletin 52, we have here departed somewhat from the Emery County rendition. It will be noted that in this bulletin on Cache County there has been no text written on the back of the colored maps. This was possible owing to the smaller size of Cache County as compared with Emery County, necessitating fewer colored maps to plot the areal geology on the same scale. Because of this saving in map space, it was possible to provide more pages for text and still stay within the limits of the number of pages that could be satisfactorily bound by the inexpensive saddle stitch method. As a result, it will now be possible for those geologists who so desire to "lift" the map pages from the center of the bulletin without interfering with the sequence of the text which can be kept bound intact by bending back the staples after the colored maps have been removed. The "lifted" colored maps can then be trimmed to fit into a pattern and pasted on linen or other suitable cloth backing so as to make a single map mosaic of Cache County. Several geologists who have wanted to see all of Emery County as a single map have suggested this procedure as a means of accomplishing their objective so as not to have to buy a second bulletin to preserve the text

We have gone further in experimenting with innovations for Cache County. We are publishing a single map of Cache County giving all of the composite information shown on the thirteen individual colored maps in this bulletin so that there will be little need for going to the time and expense of constructing a composite map as above outlined. Cache County was chosen for this latter experiment primarily because during successive years there will be attending the Utah State University at Logan a great number of students of geology who might be expected to purchase and use the separate geologic maps for field work in the area.

The number of these separate maps which can be sold by the Utah Geological and Mineralogical Survey will determine whether this particular experiment so persistently advocated by certain geologists will be repeated for other counties. Certainly, if the expense of preparing a separate geologic map cannot be repaid through sales in a county containing a university with students doing graduate research in geology, there is little likelihood that the additional expense of such a venture would be warranted in other counties which do not have such a clientele.

The Utah Geological and Mineralogical Survey will carefully analyz the patronage it receives for separate geologic maps in comparison with its sales of the bound volumes of the atlas with text. The Survey is anxious to serve the needs of the people of Utah, but under its present budgetary restrictions it must conserve its resources if it is to be able to give the greatest service to the greatest number.

We shall welcome comments, suggestions, and criticisms not only from our associates in the geological profession, but also from general readers, high school students, and tourists who have occasion to try to use this bulletin.

Arthur L. Crawford, Director
UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

G E O L O G I C   A T L A S   O F   U T A H

CACHE COUNTY[1]

By J. Stewart Williams[2]

A B S T R A C T

Cache County is essentially Cache Valley and its surrounding drainage area. Structurally the valley is a graben at the eastern margin of the Basin and Range province, between the northernmost element of the Wasatch Range, Wellsville Mountain, and the southern extension of the Malad Range, Clarkston Mountain, on the west, and the Bear River Range on the east.

Wellsville Mountain and the Bear River Range reveal a section of Paleozoic rocks tens of thousands of feet thick. All systems are represented with the possible exception of the Permian. The Cambrian section, with seven formations, has long been known through the studies of Walcott and others; the Ordovician System is well represented, and the sole representative of the Silurian in the Rocky Mountain region, the Laketown dolomite, is well exposed. The Devonian System is thicker and more diversified than in most western areas. The Mississippian is represented by thick deposits accumulated at the margin of the Oquirrh Basin. Over 6,000 feet of Pennsylvanian and perhaps Permain strata follow the Mississippian in this basin. Triassic rocks were probably deposited across the area, but later removed by erosion. In Jurassic time the sea remained generally east of the area, and the growing mountains of the Laramide Orogeny rose across the future site of the valley during the Cretaceous Period.

Early Tertiary rocks of the Wasatch groups are rather widely but not well exposed in the eastern parts of the county. Late Tertiary rocks of the Salt Lake group underlie foothill benches about the valley, and reach a total thickness near 9,000 feet. Pleistocene Lake Bonneville occupied Cache Valley and its deposits control the surface geology at all elevations below 5,135 feet. The total thickness of the Lake Bonneville group, and other valley sediments younger than the Salt Lake group, is not known.

Cache Valley is believed to have been repeatedly deepened by reactivation of its boundary faults. This movement has disturbed the Salt Lake group rocks, and created the foothill benches of the valley. Two erosion surfaces related to the changing base level of the valley are recognized, the Rendezvous Peak and McKensie Flat surfaces.

Cache County geology is notable for its thick and well-exposed section of Paleozoic rocks, and for its interesting geologic structures. Its mountains are only sparingly mineralized, but their sedimentary non-metallic resources will increase in importance. Geomorphic features due to solution have significant development in the area.

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[1]The maps for Cache County used in this bulletin were drawn on a base adapted from outline maps furnished by the Utah State Road Commission. The base, all of the color overlays and the necessary supplementary drafting were financed from a grant from the University of Utah Research Fund. Without this grant or without the cooperation of Utah State University, in permitting Dean Williams to complete the geological research and to write the text, this bulletin would have been impossible. The cooperation of the Utah State Road Commission also greatly facilitated the synthesis of the various projects.

[2]Head, Department of Geology, and Dean of the School of Graduate Studies, Utah State University, Logan, Utah

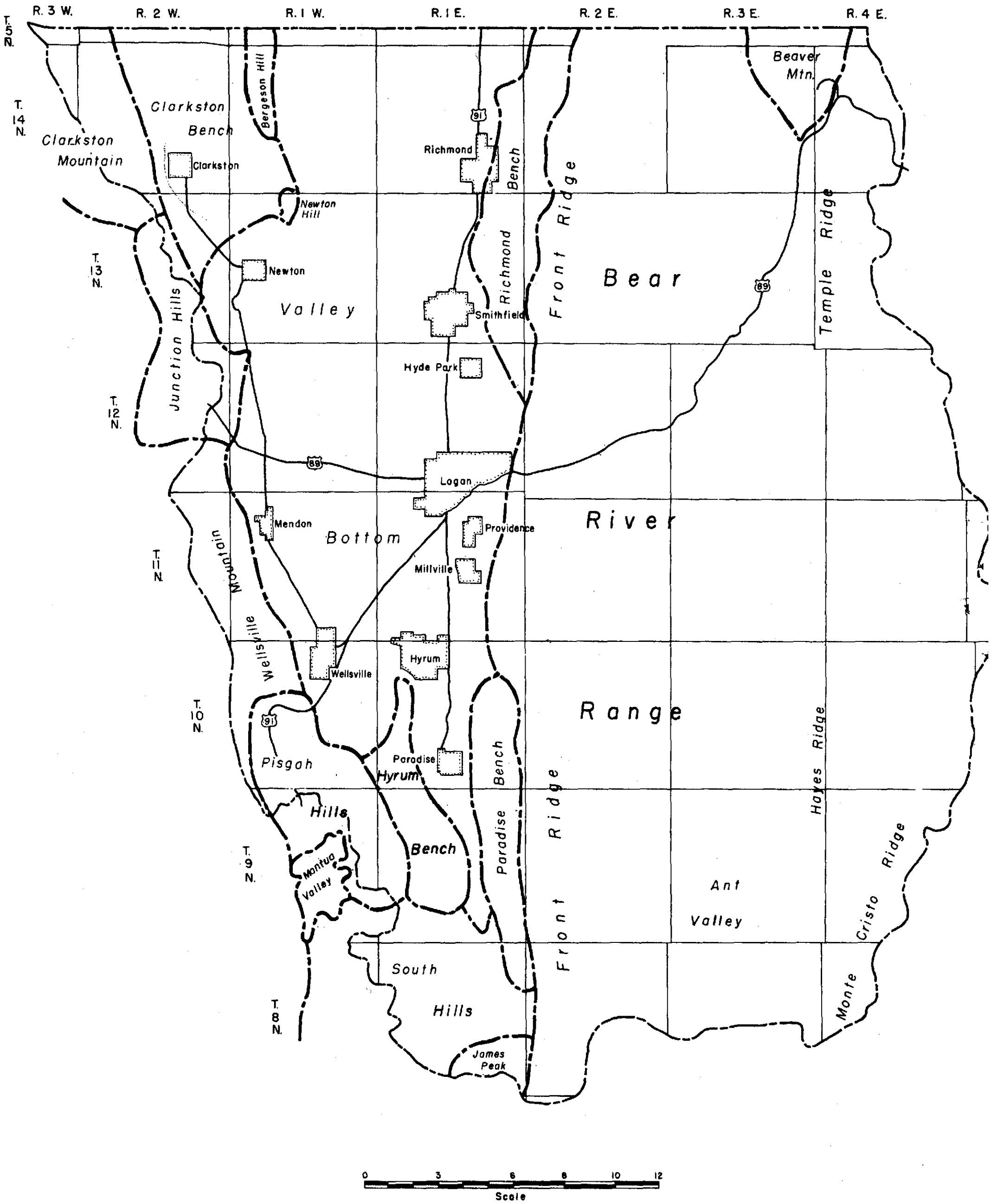


Figure 1. Physiographic divisions of Cache County.

INTRODUCTION

Cache County is one of three Utah counties constituting the northernmost tier and bordering the State of Idaho. It lies between Box Elder County, a much larger county to the west, and Rich County, a smaller county to the east. Cache County's area of 1,175 square miles ranks it 23rd in size among Utah's 29 counties. However, it ranks 5th in population, 8th in assessed valuation, 12th in area of arable land, 2nd in area of irrigated lands harvested, and 3rd in value of farm products.

Cache Valley lies at the eastern edge of the Basin and Range Province (Fenneman, 1917). The boundary between this province and the Middle Rocky Mountains, as drawn by Fenneman, follows the base of the Bear River Range, South and Pisgah Hills, and Wellsville Mountain around Cache Valley, including these in the Middle Rocky Mountains and assigning Cache Valley and Clarkston Mountain to the Basin and Range province. Structurally, all of the mountains surrounding the valley are of the Basin and Range type, and Cache Valley may be considered a Basin and Range type basin. Actually Temple Ridge fault and the fault east of Bear Lake Valley appear to belong to the system of faults that has created typical Basin and Range topography farther west, and mark an incursion of this type of structure into the Middle Rocky Mountains.

GENERAL GEOGRAPHY

Cache Valley is about 60 miles long with approximately 35 miles in Utah and 25 miles in Idaho. It is widest at the state boundary, about 16 miles, and tapers to a point at both ends. Lowest point in the valley, where Bear River leaves through the gorge in Junction Hills, is about 4,400 feet; highest elevation in the county is Mt. Naomi in the Bear River Range, 9,980 feet. Most of Cache Valley's towns are at elevations near 4,500 feet. The valley connects to adjacent valleys north, west, and south through comparatively low passes (4,700 to 6,400 feet), but the major route east through the Bear River Range, U.S. Highway 89, crosses the summit and county line at an elevation near 8,000 feet.

The floor of the valley was smoothed by the deposition of silt and clay from Lake Bonneville. About the lower central portion, between 4,500 and 5,100 feet, the basal slopes of the foothill area are marked with the horizontal land forms of the shore zone of the lake-deltas, bay-bars, and shore embankments. Above these the well-dissected mountain faces display numerous small, steep canyons between the deeper mouths of the major canyons that extend well back into the bordering ranges.

Farming, and the industries related to it, and education, occupy the energies of most of Cache County's 35,000 inhabitants. Practically all land below the Bonneville shoreline, elevation 5,135 feet, is farmed; and in many sections where the foothill benches present reasonably smooth areas of moderate slope, dry-farming is carried high on the valley sides. Processing enterprises associated with the farms include the manufacture of beet sugar, evaporated milk and cheese; the canning of vegetables; and the dressing of turkeys, chickens, and trout for the market.

Utah State University, founded at Logan in 1888, is Utah's land-grant university. From a faculty of 7 and a student body of 139, it has grown to occupy an important position among the leading colleges and universities of the country. Its present faculty of several hundred, and its student body of 5,000, play an important part in the economic as well as cultural life of Cache County.

Bear River crosses Cache Valley from northeast to southwest, carrying the drainage of a basin that extends into Idaho and Wyoming. High Creek and Summit Creek drain the Bear River Range south of the Idaho line, directly to Bear River. Farther south, Logan River, Blacksmith Fork River, and Little Bear River combine west of Logan before emptying into the Bear just before it enters the exit gorge through Junction Hills. Only small streams such as Wellsville, Mendon, and Clarkston Creeks flow from the mountains along the west side of the valley.

H I S T O R Y O F E X P L O R A T I O N

Cache Valley emerges in history as the hunting ground of bands of Shoshoni Indians. When first seen by trappers in the early decades of the last century, herds of buffalo and antelope grazed the valley floor. Weber, Ogden, Bridger, Ferris, and other famous trappers frequented the valley after 1824, when Captain Weber and his party of the Rocky Mountain Fur Company first caught beaver in its streams. These trappers not only gave the valley (and county) its name, when they cached furs in the banks of the Little Bear River, but they named the principal streams of the valley--the Bear River, Logan River, Blacksmith Fork River, and Little Bear River. The history of Cache Valley is interestingly and authentically related in a recent book, History of a Valley by Dr. Joel E. Ricks, from which this and the paragraphs immediately following are abstracted.

The first emigrant train crossed the valley in 1841 when the party of Col. John Bartleson left the Oregon Trail at Soda Springs and followed the Bear River southward enroute to California (pl. V). They followed the west bank of the river to the vicinity of Newton, crossing Junction Hills to the site of Fielding and then continuing westward. Captain Fremont in 1843 viewed the valley from the north end, after travelling through Gem Valley from Soda Springs. In 1849, Captain Stansbury made a reconnaissance survey of the valley as a possible site for a military post. Stansbury was impressed with the resources of the area in soil, grass, timber, and water; and his report probably directed Brigham Young's attention to this northern valley some 80 miles north of Salt Lake City, where Young and his original band of settlers had entered the Great Basin through the Wasatch Mountains on July 24, 1847.

In 1855 the Utah Territorial Legislature granted Cache Valley to Brighan Young as a grazing area, and that summer a group of herdsmen brought 3,000 head of horses and cattle to the valley, establishing the Elkhorn Ranch. But the winter was severe, and before it was over, the herdsmen had driven the stronger cattle back over the Sardine Canyon trail to the Ogden area, and most of the herd had perished. The following summer permanent settlers sent by Brigham Young and led by Peter Maughan entered the valley (pl. VII) and camped on the site of Wellsville, September 15, 1857. Before snow came, Maughan's Fort had been constructed and permanent settlement begun. In 1859, Logan, Providence, Richmond, and Smithfield were settled. The following year Hyrum, Millville, Paradise, and Hyde Park were founded as was Franklin, Idaho. The census of 1860 enumerated 527 dwellings, 510 families, and a total population of 2,605 persons.

Within this and the following decade, the first geological explorations were made in and about Cache Valley. The southern half of the county was visited by Hague and Emmons of the Fortieth Parallel Survey. During their reconnaissance they climbed Mt. Pisgah and Wellsville Mountain, and traversed Logan, Blacksmith Fork, and East Canyons and worked southward into Ogden Valley. The northern half of the area was territory of the Green River Division of the Hayden Survey and was described (1879, pp. 598-608) by Peale, who worked northward from Logan Canyon in 1877. Several years earlier parties of this survey had traversed parts of the area and made brief reports, such as that of 1872 (pp. 18-21) describing a journey through Cache Valley enroute to Yellowstone Park and that of 1873 (pp. 199-200) reporting Bradley's examination of the "Gates of the Bear River" through Junction Hills, as he travelled from Ogden to Malad. Between 1872 and 1890, while he gathered information on ancient Lake Bonneville, G. K. Gilbert visited Cache Valley several times; and his completed report on this lake published as the first monograph of the U. S. Geological Survey makes numerous references to Cache Bay, an important component of this Pleistocene water body which received the lake's largest tributary, Bear River, and also discharged the mighty Bonneville River that drained it at its higher levels northwestward to the Snake River (pls. XI, XII, and XIII).

The second round of geological study, more detailed and particular than these early reconnaissance surveys began in 1906 when C. D. Walcott camped in Blacksmith Fork Canyon, measured and described the Cambrian formations and gave them names (1908). Most of the other Paleozoic formations of the area were named by Richardson in 1913 in his study of the Rich County area to the east. Mansfield's study of the Western Phosphate Field (1927) expanded and systematized much regional geological information. In 1948 the writer completed a geologic map of the Logan quadrangle, which covers most of Cache County. The accompanying report is largely devoted to the stratigraphy and structure of the Paleozoic rocks, and names one new formation and recognized several new members in the previously recognized units. Subsequently, students encouraged and partly directed by the writer, such as Hansen, Ezell, Bues, and Gelnett, have completed mapping of the whole county. Others, such as Ross, Denison, Adamson, and Haynie have contributed new stratigraphic information. The writer has also mapped the Tertiary and Quaternary units in Cache Valley in a manuscript yet to be published. This report, then, summarized some 85 years of geological study in one of Utah's smaller but more notable counties.

P H Y S I O G R A P H Y

GENERAL

The Utah portion of Cache Valley is essentially Cache County and the inward drainage area surrounding it. Thus, the eastern boundary of the county follows the water parting at the crest of the Bear River Range southward from the Idaho line, separating the drainage of Logan River, Blacksmith Fork River, and East Canyon

Creek from the eastward drainage to Bear Lake. The boundary follows Temple Ridge, Hayes Ridge, and Monte Cristo Ridge to a point opposite the parting between the East Canyon Creek and Ogden River drainages; thence it descends the western side of the summit on this parting, and follows it westward across James Peak to the north rim of Ogden Valley.

Along the west side of Cache valley, the county boundary follows the crest of Clarkston Mountain from the Idaho line to Junction Hills, which it crosses on the water parting, and then ascends Wellsville Mountain, to follow its crest to a point opposite Mt. Pisgah. Here it descends on the water parting between Dry Lake Valley and Mantua Valley and follows the crest of the Pisgah Hills southward into South Hills, following the ridges that separate Mantua Valley and Cache Valley drainage. It continues thus to the rim of Ogden Valley.

PHYSIOGRAPHIC DIVISIONS

The physiographic divisions of Cache Valley are shown on Figure 1. They may be summarized as in the following paragraphs.

Bear River Range: This includes James Peak as its southern terminus. Subdivisions are Front Ridge, between Cache Valley and the principal north-south tributaries of Logan River and Blacksmith Fork River; Beaver Mountain, Temple Ridge, Hayes Ridge, and Monte Cristo Ridge. The wide area between Monte Cristo Ridge and Front Ridge is Ant Valley.

Richmond Bench: The foothill area developed on Tertiary rocks along the front of the Bear River Range from the Idaho line to Green Canyon. Crow Mountain is a high mass of Paleozoic rocks protruding through the Tertiary rocks of the bench.

Paradise Bench: The foothill area developed on Tertiary rocks along the front of the Bear River Range from Blacksmith Fork to Southeast Canyon. Its surface is considered part of the McKensie Flat surface (pl. III).

South Hills: The area of lower mountains between Ogden and Cache Valleys and between James Peak and Willard Mountain (pls. I, II, and IV). It includes South Mountain, north of James Peak, and joins the Pisgah Hills at Clay Valley. Its higher parts are remnants of the Rendezvous Peak erosion surface.

Pisgah Hills: An area of lower mountains east and north of Mantua Valley (pls. II and VII). These hills join South Hills at Clay Valley, and Wellsville Mountain between Mantua Valley and Rattlesnake Hollow. They surround Dry Lake Valley on three sides. Their higher parts are considered part of the Rendezvous Peak erosion surface.

Wellsville Mountain: The northernmost extension of the Wasatch Range (pl. VI). At the Bonneville shoreline on the north it joins Junction Hills.

Junction Hills: The low ridge joining Wellsville Mountain to Clarkston Mountain. The ridge was largely covered by Lake Bonneville at its highest levels. Bear River crosses the ridge through "The Gate of Bear River" or the Wheelon Narrows. Cache Butte is part of the ridge.

Clarkston Mountain: The southern extension of the Malad Range, rising substantially above the lower middle part of the range south of the Idaho line.

Clarkston Bench: The bench-like area between Newton Hill, Bergeson Hill, and Clarkston Mountain. Developed largely on Tertiary rocks partly covered by Lake Bonneville sediments.

Newton Hill: A small hill of Paleozoic rocks veneered with Tertiary sediments, elevated adjacent the Dayton fault. It lies at the southeastern corner of Clarkston Bench.

Bergeson Hill: An elongate hill of Paleozoic rocks veneered with Tertiary sediments, elevated along the Dayton fault from the vicinity of Newton to the Idaho line (pl. V).

Valley Bottom: The lowest parts of the valley inside the foothill benches. Largely covered by lake bottom sediments of the Lake Bonneville group (pl. VIII).

E R O S I O N   S U R F A C E S

Although Cache Valley is thought to be a fault-valley or graben, created by down-faulting of a valley block between mountain blocks that remained high or rose, it none-the-less contains evidence of having evolved at least partly through erosion. This evidence is in the form of remnants of graded surfaces, partly covered with alluvium, and now well above the valley floor, which, when under active formation, were graded to the then-existing base-level of the valley. Two such surfaces are observed in Cache Valley. They were named by Williams (1948, p. 1160) from localities in the south end of the valley, but examples have been discovered by other workers farther north, both in Utah and Idaho.

RENDEZVOUS PEAK SURFACE

Several of the higher peaks in South Hills are capped by gravel containing larger boulders of Precambrian quartzite (pl. I). These gravel caps are mapped by Ezell (1953). They appear to represent a pediment that sloped eastward from the crest of the Wasatch Range in the vicinity of Willard Peak, toward an earlier and shallower Cache Valley. The west-east profile of Rendezvous Peak (Axel Beard Mountain on new topographic map series) appears to show the slope of this old surface, and hence the name. Remnants of the old surface in South Hills lie between 6,000 and 7,000 feet. A sloping gravel cap at the north end of Wellsville Mountain in the area mapped by Bues and Gelnett (1958) seems by position and altitude to represent this same surface. Similarly, Hansen (1949, p. 91), working on Clarkston Mountain, mapped patches of boulder gravel on high shoulders of the mountain sloping from its crest eastward toward the valley. In altitude and topographic position these are similar to those in South Hills and are thought to represent the Rendezvous Peak surface.

McKENSIE FLAT SURFACE

At the south end of the valley, from the mouth of East Canyon

Plate I. View southwestward across South Hills, showing Rendezvous Peak and around the base of South Hills and Pisgah Hills to Sardine Canyon, a lower and younger erosion surface seems to be discernible above the features of Lake Bonneville and below the tops of the Hills which are conceived to retain remnants of the Rendezvous Peak surface (pls. III and IV). This has been called the McKensie Flat surface. It is essentially coextensive with Hyrum Bench. It lies mostly between 5,500 and 6,000 feet. In this area, it seems more terrace-like than pediment-like and might have been shaped partly by the major streams of the south end of the valley working against the base of South and Pisgah Hills. The valleys that intersect these hills including Clay Valley, Sink Valley, Devils Gate Valley, and Dry Lake Valley, appear to be part of this cycle of erosion that has dissected the Rendezvous Peak surface to late maturity (pls. I and II). Wind-gaps north and south of Box Elder Canyon might well belong to this cycle, which was interrupted when Cache Valley was deepened to its present base-level, and Mantua Valley was created in its McKensie cycle predecessor by the rejuvenation of Box Elder Creek (pl. II).

Along the east side of Cache Valley the pediments developed on foot-hill blocks of Salt Lake group rocks are considered part of the McKensie flat surface. Plate III shows this surface from Blacksmith Fork southward. While McKensie Flat itself is the work of Southeast Creek, the pediment appears graded to the level of the flat. No such pediment is present between Blacksmith Fork and Green Canyons, but, north of the latter, it again appears and may be followed into Idaho where Keller (1952, p. 33) has recognized the McKensie surface in the vicinity of Mink Creek, and northwestward across the Oneida Narrows. The pediments along the Bear River Range have been dissected to the base-level of the existing valley.

In mapping north of the Idaho line, adjacent Hansen's area on lower parts of the Malad Range, Prammani (1957, p. 38) discovered patches of boulder gravel, apparently a continuation of those to the south and west, and presumably deposited on a surface similar to the Rendezvous Peak surface.

AGE AND CORRELATION OF THE SURFACES

The age of these surfaces, and their correlation with surfaces recognized in adjoining areas, present interesting problems. In southern Cache Valley the gravels of the Rendezvous Peak surface do not reach the areas of Salt Lake group rocks, and the writer projected the surface to the gently sloping area north of James Peak, on which lie patches of Salt Lake group. Hence, he believed the surface to be older than the Salt Lake group, and thus the essential equivalent of Mansfield's Tygee erosion surface (1927, p. 15). Subsequent work on the west side of the valley farther north, by Bues and Gelnett, Hansen, and Prammani, has shown that a high-level surface or surfaces similar in altitude and topographic position and covered with boulder gravel, bevel outcrops of the Salt Lake group. This casts grave doubt on the original interpretation and requires a post-Salt Lake group age for the surface in the vicinity of rendezvous Peak, if it is the product of the same period of erosion as the more northerly occurrences. If this surface is post-Salt Lake group in age, it probably correlates best with Mansfield's Gannet surface.

There is little reason to doubt that Eardley's Herd Mountain surface extended over at least the southeastern part of Cache

Plate II. View of Clay and Mantua Valleys, looking southwestward.

County (Eardley, 1944, pl. 9, fig. 1). The Rendezvous Peak surface, however, it appears to be too low to be a part of that surface, and hence is probably younger and contemporaneous with the Weber Valley surface. Both the Rendezvous Peak surface and the McKensie Flat surface were probably developed while the Weber Valley surface was forming, their distinctness as surfaces being due to a different diastrophic history in the area of Cache Valley.

Those parts of the Salt Lake group in Cache Valley that have yielded fossils apparently are of Pliocene age. However, parts may be as old as Oligocene or late Eocene, the age of the Norwood tuff (Adamson, 1955, p. 39). If the rocks beveled by the Rendezvous Peak surface on the Malad Range are Pliocene, this surface is probably early Pleistocene in age. If the oldest and highest erosion surface in the area is Miocene in age (Eardley, 1944, p. 864), a late Pliocene or early Pleistocene age for the Rendezvous Peak surface is appropriate since it is in part contemporaneous with the Weber Valley surface.

GENERAL STRATIGRAPHIC FEATURES

The geologic column in Cache County has not been completely measured. The thick Precambrian section in James Peak, presumably part of the Big Cottonwood Canyon Series, is yet to be studied. It probably will total thousands of feet of quartzite, phyllite, and related metamorphic rocks. The Paleozoic section, including formations from Cambrian through Pennsylvanian and possibly into the Permian, totals about 25,000 feet, mostly carbonate rocks with considerable sandstone, but only minor shale. Almost all of this sequence is marine. Mesozoic rocks do not crop out in the county, but the Cenozoic is represented by at least 15,000 feet of terrestrial sediments, most of which have been deposited since Cache Valley was formed. The sediments of Lake Bonneville cap the valley fill and are on the top of the column.

The thick Paleozoic section in Wellsville Mountain and the Bear River Range is due to the location of the area in the miogeosyncline of Kay (1951, p. 9), though close to the margin adjacent to the Wyoming Shelf. The Cambrian section is well developed with 7 well-known formations. Ordovician, Silurian, and Devonian formations, thin or absent farther east, are well represented; and the Mississippi and Pennsylvanian rocks, deposited in the persistently sinking Oquirrh Basin, are extraordinarily thick. Perhaps even some Permian rocks are present. The recent work of Adamson and Keller has shown the Tertiary Salt Lake group to be surprisingly thick.

PRECAMBRIAN ROCKS

Rocks older than Cambrian are not widely exposed in Cache County. Largest area of outcrop is at James Peak at the south end of the mapped area. Here, reconnaissance indicates that the contact of these rocks with the basal Cambrian Brigham quartzite is obscure, but that a thick section of quartzite and phyllite is present, presumably a part of the Big Cottonwood Canyon series, such as exposed to the west of Willard Mountain (Eardley and Hatch, 1940). As one approaches the county through Box Elder Canyon, these rocks are visible at roadside in the lower part of the canyon.

Plate III. View of Paradise Bench and the McKensie Flat erosion surface along

Whether the oldest quartzites exposed in the west face of the Bear River Range at the Idaho line are older than Cambrian is not known. Here they are over 4,800 feet thick (Williams, 1948, p. 1132) with no observed lithologic change that would serve to separate the lower beds from the Brigham quartzite. In the Idaho part of Cache Valley Precambrian rocks are much more widely exposed, being present in the Malad and Portneuf Ranges, and in inliers in the valley bottom.

C A M B R I A N   S Y S T E M

A wide belt of Cambrian rocks lies along the east side of the county in Beaver Mountain, Temple, Hayes and Monte Cristo Ridges, and in Ant Valley; and across the south side in South Hills. The belt swings northward outside the county through Mantua Valley to Honeyville and is continued again on the west side of Clarkston Mountain. A great wedge of Cambrian rises from a point at the mouth of Logan Canyon northward in the front of the Bear River Range until at the Idaho line practically the whole face exposes these rocks. Basal formation is the thick Brigham quartzite of Lower Cambrian age, named by Walcott for the conspicuous exposure in the Wasatch Front east of Brigham City. The Brigham appears to be terrestrial, and its gradation into the overlying Langston formation seems to coincide with the beginning of Middle Cambrian time. It also marks the arrival of the shoreline of the transgressing Cambrian sea, which thereafter deposited the shale, limestone, and dolomite of the Middle Cambrian formations, the Langston, Ute, Blacksmith, and Bloomington formations, while the shoreline lay farther east.

Above the transition beds lie the fossiliferous Ptarmigania limestone and Spence shale members of the Langston formation whose faunas are well known through the works of Resser and Maxey. The Spence shale member is absent in Blacksmith Fork Canyon and southward, as is the Ptarmigania limestone. The massive, light-gray, brown-weathering dolomite which constitutes the major member in the formation has been reported from as far southwestward as the Sheeprock Mountains, Tooele County, Utah, and as far northward as Alexander, Idaho, the northernmost tip of the Bear River Range.

The shale and limestone of the Ute formation would be indistinguishable from those of the Bloomington were it not for the intervening massive Blacksmith dolomite. This conspicuous cliff-forming unit is present in Cambrian outcrops throughout the county, particularly at the top of Temple Ridge in Upper Logan Canyon, in Hayes Ridge farther south, and in Wellsville Mountain. The overlying Bloomington formation, with its thin-bedded limestone members, constitutes the base of Beaver Mountain, and lies back of Temple Ridge in "The Sinks," a long strike valley developed by solution in this formation. Logan River largely heads in fissure springs west of Beaver Mountain fed by solution channels in the Bloomington limestone and other carbonate formations in the mountain. Three-Mile Canyon in South Hills is another strike valley, here east-west in direction, in this formation.

The Middle Cambrian - Upper Cambrian boundary is thought to lie in the Nounan dolomite which overlies the Bloomington formation. This dolomite crests the ridge at the county boundary east of "The Sinks" and surrounds Temple Peak. It forms the high part of Rendez-

Plate IV. Hyrum Bench and the McKensie Flat erosion surface View south from Hyrum Resorvoir vous Peak in South Hills, and with the overlying St. Charles formation is conspicuous in Clarkston Mountain.

During the Franconian age of Late Cambrian, the shoreline of the Cambrian sea returned to the vicinity of Cache County, depositing the Worm Creek clastic member, taken by Richardson as the basal member of the uppermost Cambrian formation, the St. Charles. Haynie (1957) has shown that this member has beds that were deposited in the littoral zone and that these quartzitic sandstone units thicken and become arkosic northward, whence lay the land areas. After this short interlude of near-shore environment, limestone and then massive dolomite were deposited, making up most of the St. Charles formation. These are conspicuous at the very mouth of Logan Canyon, in the canyon a mile above Ricks Spring, at the top of Temple Peak and in the southeast ridge of Clarkston Mountain.

This Cambrian section in Cache County is one of the thickest and best known in the United States. Its study was begun by Walcott in 1906, and has been carried forward by Resser, Deiss, Maxey, and Hanson. Most accessible section is that in Blacksmith Fork between the Hyrum City hydroelectric plant and the Hardware Ranch. But better exposed sections lie in the west faces of Wellsville and Clarkston Mountains and the Bear River Range north of Green Canyon.

O R D O V I C I A N   S Y S T E M

In Ordovician time the littoral zone of the Cordilleran geosyncline again approached northern Utah, there depositing in the early part of the period a pair of formations that are readily identified, and whose correlatives stretch far to the southwest from the Logan area, along the shore-zone of the old seaway. These are the Garden City limestone, largely of Canadian age, and the Swan Peak formation of early Chazyan age.

The Garden City formation is generally thin-bedded and shaly, with fragmental fossils, apparently the result of shallow water. The shaly partings between limestone beds, a few inches to a foot thick, enabled the early settlers to quarry a rough building stone which built the Mormon Temple and Tabernacle, and the foundations and walls of numerous other buildings. The principal quarry is in Green Canyon, northeast of Logan, where a dip-slope made operations relatively easy.

Other conspicuous outcrops of the Garden City limestone are at the mouth of Logan Canyon behind the hydroelectric plant of Utah Power and Light Company and at the twin bridge section of Logan Canyon, from Logan Cave to Ricks Spring, a stretch starting and ending with interesting solution features developed in the limestone and climaxed at the long dugway between two bridges, one of the most spectacular parts of the canyon. The narrows of South Canyon at the south end of Cache Valley are formed in Garden City, as is Devils Gate Valley farther southwest. The formation makes great cliffs in Wellsville Mountain east of Honeyville, and is an important element in Clarkston Mountain.

Reuben James Ross, Jr. has made a detailed study of the stratigraphy of the Garden City formation and its trilobite faunas (1951). He has in general distinguished three members; shaly limestone below constituting most of the formation, followed by some 200

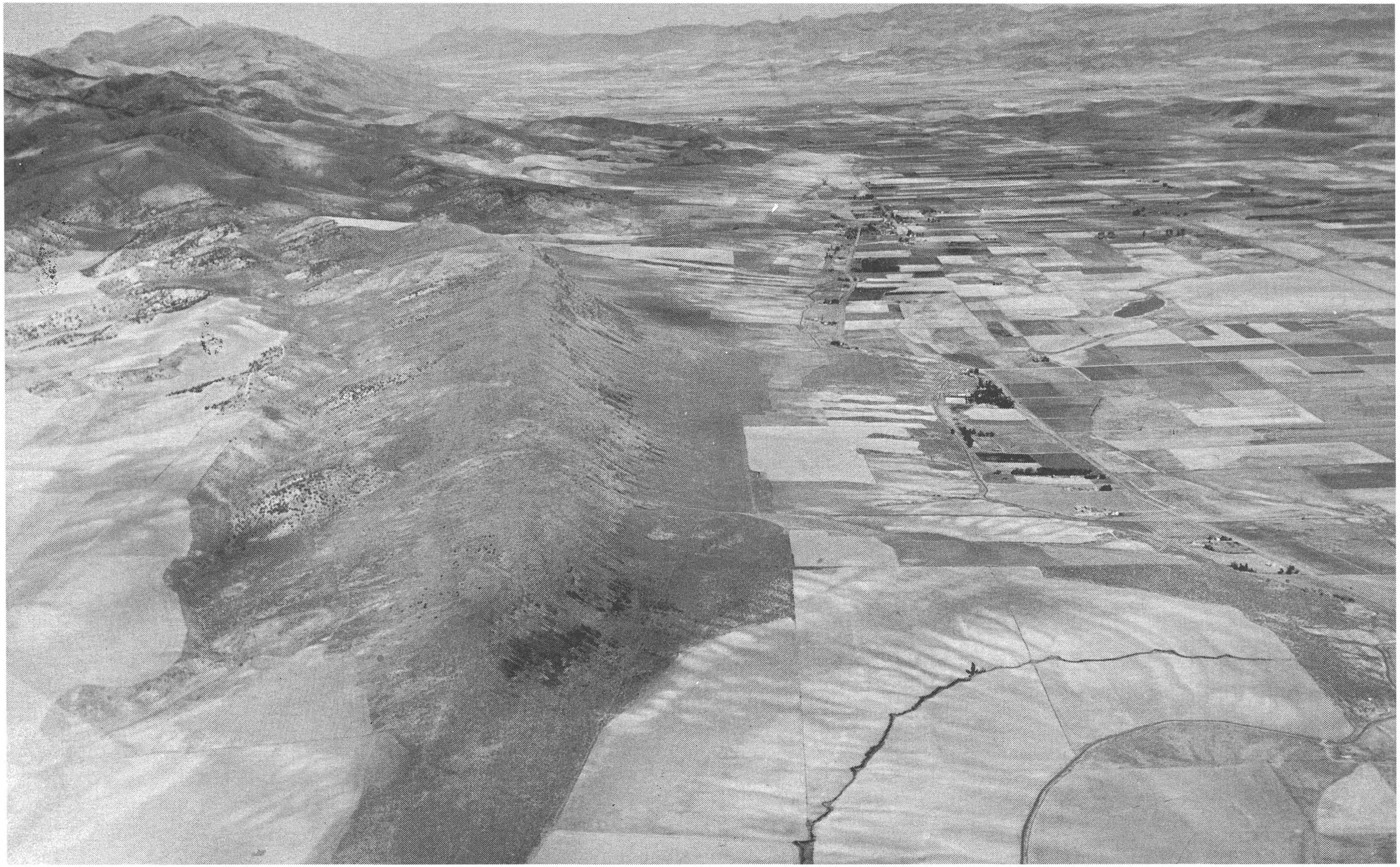


Plate V. North end of Cache Valley, toward the outlet of Lake Bonneville at Red Rock Pass.

feet of cherty limestone, followed by about 100 feet of dolomitic limestone, which grades into the Swan Peak formation above. These distinctive members may be followed throughout the area. Ross recognizes faunal zones A-L, which have found correlatives in the Pogonip limestone of northeastern Nevada.

The Garden City limestone grades upward through sandy limestone into shale and sandstone of the Swan Peak formation, a thin but striking stratigraphic unit. Most notable structure in the few hundred feet of this formation is the fucoidal markings that characterize the undersides of the brown quartzitic sandstone beds in the middle member of the formation, separated by thin partings of greenish-gray shale. These are unique in the section of northern Utah, not being duplicated in any other sandstone unit. These markings are essentially casts of concave impressions in the mud that became the shale beds. While the majority of them are probably of organic origin, several inorganic processes, such as desiccation shrinkage, flowage, and intrusion of fluid sediments, very likely contributed to the total pattern.

At the forks in Logan Canyon a large slab of fucoidal quartzite is displayed beside the road. Coulter (1955) has offered what is probably a partial explanation of these structures, and Hardy (1956) has pointed out some of its inadequacies.

The tripartite Swan Peak formation with a shale member below, the fucoidally-marked brown sandstone in the middle, and massive buff quartzitic sandstone above, is the most readily identified formation in the region. It greatly aids the interpretation of structure in South Hills and Pisgah Hills, where a well-known outcrop occurs directly east of Mantua. Northward from Mantua valley, it marks off the numerous transverse faults of the Dry Lake area and appears near the crest of the ridge northwest of Dry Lake, clearly offset by additional dip faults in that area. It may be traced across the west face of Wellsville Mountain, terminating at a transverse fault east of Honeyville. It crops out at the east end of Wheelon Narrows in Junction Hills, and appears again near the top of Clarkston Mountain. In the Bear River Range from Providence Canyon north, it follows around the plunging Logan Peak syncline, making conspicuous outcrops in the glaciated canyons from Tony Grove Canyon north (pl. IX), and following down the east side of the syncline to Logan Canyon, where the large slab of fucoidal quartzite mentioned above is on display adjacent to the highway. In Blacksmith Fork, the unconformity above the formation reaches low in the shale member so that only a small part of the same remains in the section. In South Canyon the shale member has normal thickness, but the quartzite beds have been removed by erosion. A notable outcrop in Green Canyon, on a dip slope, exposes a large area of ripple-marked beach. Here the brown quartzite was quarried to provide a building stone of contrasting color used as a trim for the temple and tabernacle.

The uppermost Ordovician formation, the Fish Haven dolomite, lying above the unconformity representing most of Middle Ordovician time, is in marked contrast to the two formations below. Its dark gray carbonate rock contains only a few percent of clastic material. It is massive without noticeable bedding planes. It appears everywhere in the county above the Swan Peak formation, and its correlatives extend northeastward to the Black Hills and southwestward far into Nevada. Best known outcrop of the Fish Haven is at the forks in Logan Canyon where it forms a great cliff above the river.

Plate VI. Wellsville Mountain from south of Mendon, showing Lake Bonneville

The Ordovician formations, as elsewhere in the world, are the oldest to present fossils in a great variety. Ross has zoned the Garden City formation with trilobites as has been related, and Rousseau Flower is studying the cephalopods. The abundant graptolites demand study at the earliest opportunity.

S I L U R I A N   S Y S T E M

The Silurian System in northern Utah is represented by 1500-1800 feet of massive, light and dark gray dolomite, named by Richardson the Laketown dolomite from its occurrence in Laketown Canyon southeast of Bear Lake. There is little variation in the composition of the formation, which is over 90% carbonate. Dolomitization appears to have destroyed most of the large number of fossils expectable in such a unit, except corals and stromatoporoids, which are silicified. The fossils that have been collected indicate a Middle Silurian age, and it is not known whether Lower and/or Upper Silurian are represented. Probably not, since no rocks of these series are certainly known in the western states (Duncan, 1956). If they are not, disconformities lie under and over the formation.

Dolomitization has created a "vugginess" in this formation which has attracted petroleum geologists to its potentiality as a reservoir rock. The widespread development of bioherms and biostromes in the Silurian dolomites of the Eastern United States has brought a search for such features in the Laketown. Both are well developed in the formation in the Card Canyon area. A bioherm from the formation across the Idaho line is reported to have preserved a varied fauna.

In Logan Canyon the Laketown makes picturesque cliffs on both sides of the syncline. In the lower canyon the formation is beautifully exposed from the American Legion home to the Logan City hydroelectric plant; in the upper canyon tributary Card Canyon in cut is Laketown cliffs, and the ranger station stands in their shadow. Farther north the dolomite constitutes the walls of cirques in the glaciated upper parts of Tony Grove, White Pine, and Steam Mill Canyons; and Mt. Naomi, high point in the county, is supported by these rocks. In Blacksmith Fork the Laketown cliffs lie just above the forks in the main canyon. In Wellsville Mountain this formation is not conspicuous among the continuous cliffs of the steep Wasatch Front. Clay Valley, east of Mantua, is a solution feature in this formation.

The Laketown dolomite forms the sheer walls of the gorge through which Bear River escapes from Cache Valley. It probably underlies a considerable part of Junction Hills south of the gorge, and it is thought to constitute the sheer face of Cache Butte. It forms the eastern part of the crest of Clarkston Mountain (Hanson, 1949, p. 49).

D E V O N I A N   S Y S T E M

The Devonian System is represented in northern Utah by two formations, the thin terrestrial Water Canyon, and the thick marine Jefferson. Both exhibit interesting stratigraphic features. A

Plate VII. North end of Pisgah Hills, Wellsville Canyon, and Dry Lake Valley. View to southwest profound disconformity overlies the Devonian here, and as a result the Jefferson formation shows marked variation in thickness between Wellsville Mountain, South Hills, and Logan Canyon.

WATER CANYON FORMATION

Several hundred feet of silty, compact, white- and buff-weathering dolomite and dolomitic sandstone between the Laketown beds below and the disconformity beneath the Jefferson formation above, has been called the Water Canyon formation (Williams, 1948) p. 1139). It is named from the left-hand fork of Green Canyon, northeast of Logan. It has long been known as a source of fish fossils, which were first described by Branson and Mehl (1931), and have subsequently been studied by Bryant (1933 and 1934) and Denison (1952 and 1953). All students have concurred in a Lower Devonian age for these fossils. The fish fauna in the Water Canyon formation appears to be the same as that in the Beartooth Butte formation of Wyoming, and both have similar lithologies. Fish collecting localities are listed by Denison.

The Water Canyon formation appears to represent a lithofacies of the Devonian that increases in thickness southwesterly into east-central Nevada where the "white weathering" Sevy dolomite, characterized by the same lithotope as the Water Canyon, reaches a thickness of 1500 feet (Osmond, 1954). Probably deposition of this lithotope began in Silurian time in central Nevada and transgressed eastward into Utah by Lower Devonian time.

The Water Canyon formation is conspicuous in Wellsville Mountain from east of Honeyville southward into the Pisgah Hills. North of Dry Lake, the compact tan- and white-weathering dolomites of this formation are readily distinguished; east of Mantua Valley, the Madison limestone appears to rest directly on the Laketown dolomite. In South Hills, east of Clay Valley, the Devonian rocks reappear and thicken rapidly. The Water Canyon in this area is reported to be 350 feet thick (Ezell, 1953, p. 19).

In Logan and Blacksmith Fork canyons outcrops of the formation are readily accessible; just above the forks in the left-hand fork in the latter, and about two miles below the forks, in the former. On the west side of the syncline in Logan Canyon, the Water Canyon crosses the river at the Logan City hydroelectric plant. Cottonwood Canyon, tributary to Logan Canyon, is in its upper part a strike valley on the Water Canyon formation. Another excellent exposure is at the turn in Green Canyon northeast of Logan, several miles below the type area in Water Canyon.

JEFFERSON FORMATION

In the Logan Peak syncline, the basal bed above the Water Canyon - Jefferson unconformity is a massive limestone intraformational breccia that weathers to a rounded contour, and overhangs the weak sandy beds of the Water Canyon below. Thus, the disconformity and base of the Jefferson is conspicuously marked. Above this breccia in Logan, Green, and Cottonwood Canyons, a fauna including *Tenticospirifer Utahensis*, *Atrypa* cf. *A. Missouriensis* and *Favosites limitaris* marks this horizon as the *Spirifer Argentarius* zone of the Devils Gate formation of Nevada (Merriam, 1940, pp. 67-68; Cooper, 1942, pp. 1768-1769) and of Upper Devonian age.

Plate VIII. Central Cache Valley, looking north along Bear River.

In the Jefferson formation of the Bear River Range are some 1700 to 2000 feet of interbedded dolomite and sandstone, with minor limestone beds. In the lower half of this unit, dolomite, mostly dark gray, is dominant, producing the Hyrum dolomite member; in the upper half gray and tawny sandstone is predominant, creating the Beirdneau sandstone member. The Hyrum dolomite is impressively exposed in lower Blacksmith Fork Canyon; in Logan Canyon it forms a conspicuous ridge northeast of the Logan City hydroelectric plant. In both canyons the buff, comparatively thin-bedded sandstone of the Beirdneau member makes the canyon walls at road level at the middle of the syncline, where, because of the gentler canyon gradient, a reservoir is present. Near the top in both these sections, casts of halite crystals are common in the thin sandstones, suggesting littoral conditions at the time deposition of the unit was completed.

In Wellsville Mountain there is no Beirdneau member. Southeast of Deweyville, the Jefferson is represented entirely by dolomite and limestone, 700 feet thick, with a few thin beds of quartzitic sandstone. The Water Canyon is recognizable at the west side of the Wheelon Narrows, where the section passes under younger materials, but no rocks as young as Devonian occur in Clarkston Mountain. Southward the unconformity lowers to the Water Canyon at Dry Lake and to the Laketown east of Mantua, eliminated all Devonian. In South Hills the Jefferson reaches a maximum thickness of 950 feet, both members being present near Sink Valley (Ezell, 1953, p. 19).

M I S S I S S I P P I A N S Y S T E M

Rocks of this system are thick and particularly well exposed in Cache County. Both the Bear River Range and Wellsville Mountain have notable exposures at Lower and Upper Mississippian. No rocks this young are exposed in Clarkston Mountain. Near the axis of the syncline in Logan and Blacksmith Fork Canyons, the continuous sheer cliff of the lower third of the Lodgepole limestone of the Madison group is noted by everyone. Beneath this "Chinese Wall" Holland (1952) has distinguished the Leatham formation of lowest Mississippian, which, however, is not present in Wellsville Mountain (Beus and Gelnett, 1958). At Dry Lake in the Pisgah Hills a thick and easily accessible exposure of the Brazer formation (Upper Mississippian) has received considerable study (Williams and Yolton, 1945; Sadlick, 1955). Deposited in the edge of the Oquirrh Basin, it reflects the subdivisions of the Oquirrh Mountain section and perhaps may to advantage be subdivided accordingly. A major unconformity at the top of the Brazer formation halves the thickness of the Brazer formation at the north end of Wellsville Mountain and in the Bear River Range.

LEATHAM FORMATION

In 1952, Holland separated about 75 feet of shales, sandy shales and nodular limestones near the base of what had been called the Madison limestone, as the Leatham formation with the type section in Leatham Hollow, a tributary to the Left Fork of Blacksmith Fork. The "Contact Ledge" (Williams, 1948, p. 1141) heretofore considered the basal Mississippian unit, is, according to Holland, Devonian in age. The base of the Leatham is a thin bed of conglomeratic limestone with abundant chert fragments, just above the "Contact Ledge,"

Plate IX. Tony Grove Lake, Front Ridge. View to north.

and the top is the base of some 30 feet of arenaceous shale below the "Chinese Wall." Holland considers the Leatham formation the exact correlative of the Sappington sandstone of Montana, and expects it to be rather widespread in the Rocky Mountain region. However, Bues and Gelnett did not discover it in the Wellsville Mountain section.

LODGEPOLE LIMESTONE

The "Chinese Wall" in the Bear River Range is the lower third of about 850 feet of thin-bedded, cherty, fossiliferous limestone long recognized as simply the Madison limestone, but better now called the Lodgepole limestone of the Madison group (Strickland, 1956). Abundant fossils prove its correlation with the widespread and well-known equivalents in the Rocky Mountain region of the "Madison limestone" of Montana, more particularly with the Lodgepole limestone of the Madison group.

Exposures in the western part of the county repeat the characteristics of the Bear River Range exposures. The Lodgepole limestone may be traced continuously from the Bonneville shoreline east of Deweyville southeastwardly across the high part of Wellsville Mountain down to the north side of Dry Lake; from the lower west flank of Mt. Pisgah it caps the valley wall northeast of Mantua and is exposed in Sink Valley in the South Hills.

The limestones of the Lodgepole are the most fossiliferous in the county. Abundant fossils may be found at most any outcrop, and these are indicative of the Kinderhookian Series of the Mississippian System. Some beds are coquinoid, consisting entirely of fossil fragments. Zeller (1957) has recently zoned the Mississippian rocks in Blacksmith Fork Canyon using endothyroid foraminifera. He finds the Madison or Lodgepole characterized by a lower Granuliferella zone and an upper Plectogyra tumula zone.

BRAZER FORMATION

The Brazer formation was named by Richardson (1913, p. 413) for Upper Mississippian rocks in Brazer Canyon, Crawford Mountains, Rich County, Utah. The name was extended to Cache County by Williams (1943, p. 610) for all Mississippian rocks above the Madison limestone. While part of the Brazer formation, so defined, is well exposed about the deeper parts of the Logan Peak syncline in the Bear River Range, the thickest and most accessible section was soon discovered to be in the Pisgah Hills, especially east of Dry Lake. This section, 3700 feet thick, was measured and divided into 5 members by Williams and Yolton (1945, p. 1145). Distribution of fossils indicated that the Lower Mississippian - Upper Mississippian boundary lay close to the base of the formation. If the term Madison group is adopted for rocks up through the Meramecian series, as suggested by Strickland (1956), the type Brazer, apparently equivalent to Unit No. 1 of the Dry Lake section, becomes part of the Madison group, along with Units No. 2 and 3. The sections at the north end of Wellsville Mountain and in the Logan Peak syncline could properly be called Brazer by this definition, but the upper part of the section at Dry Lake, Units 4 and 5, would require new names.

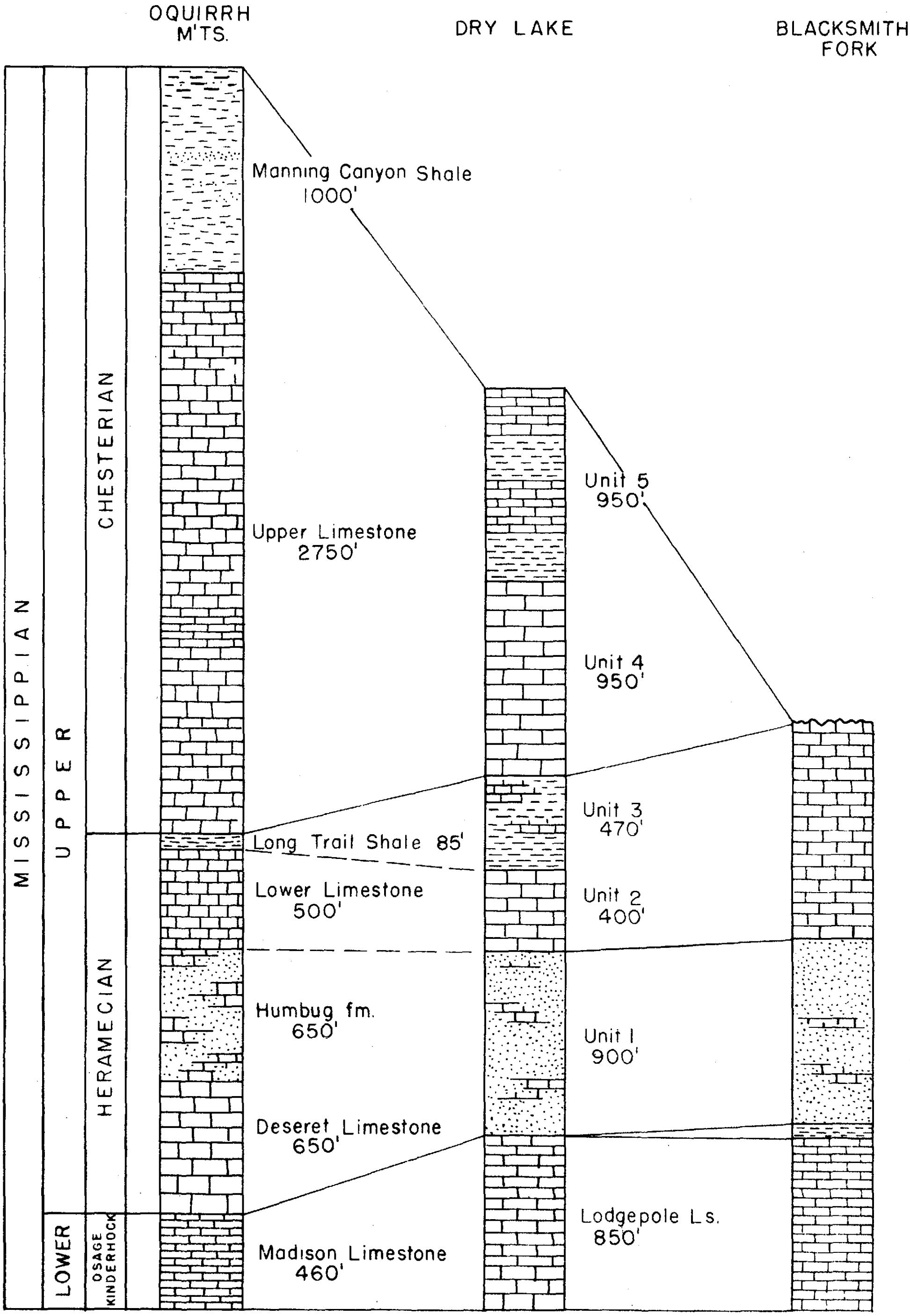


Figure 2. Mississippian rocks of Cache County and their correlation.

The formations recognized by Gilluly (1932) in the rocks above the Madison limestone in the Oquirrh Range appear to be reflected in the Dry Lake section to the extent that these units might be given Oquirrh Range names. Unit No. 1 appears to be the equivalent of the Humbug formation, and there is no Deseret limestone equivalent unless it be the black phosphatic shale member. Unit No. 2 may well be the equivalent of the lower Great Blue, with shaly Unit No. 3 the equivalent of the Long Trail shale. Unit No. 4 is apparently equal to the upper Great Blue limestone, and Unit No. 5 is largely equivalent to the Manning Canyon shale.

The basal unit of the Brazer formation as earlier defined and as mapped for this report, in the Bear River Range, is a black shale and mudstone member with thin beds of oolitic phosphorite, which has been sampled both for vanadium and uranium, as well as phosphorus. It has not been recognized in Wellsville Mountain or Pisgah Hills. Best exposures of this member are in Providence and Millville Canyons, and the most recent and complete sampling for phosphorus has been reported by Cheney (1957, p. 36). An exposure of this member in Laketown Canyon, Rich County, has the distinction of being the richest uranium-bearing black shale sampled by the U. S. Geological Survey (Mapel, 1956, p. 230).

The calcareous sandstone member above the black shale and the basal member (Unit No. 1) of the Dry Lake section forms the west slope of Mt. Pisgah clear to its crest. It may be followed northwestward across Wellsville Mountain and makes conspicuous brown-weathering taluses at the mountain base east of Deweyville. Weaker than the limestones above and below, it has a smooth outcrop area. There is a notable exposure of these rocks in Spring Hollow, Logan Canyon, east of the synclinal axis where slippage on the basal shale member down the $6^{\circ} - 7^{\circ}$ dip into the hollow has filled it with great masses of calcareous sandstone rubble. At the toe of these the big spring emerges. This member is well developed in Laketown Canyon, together with the black shale member.

Units 2 and 3 are mostly represented in the thinner Brazer sections in Blacksmith Fork (Parks, 1951, p. 174) and northern Wellsville Mountain (Bues and Gelnett, 1958) but the unconformity has elimated Units 4 and 5 from these sections.

The basal shale member acts as an aquiclude about the Logan Peak syncline, and thus is the locus of contact springs in many canyons of the Bear River Range, notably Spring Hollow, Providence Canyon, Millville Canyon, and Leatham Hollow.

The upper Brazer limestones form magnificent cliffs as viewed from the forks on Blacksmith Fork (pl. X). They support a high level rock terrace or bench about the central part of the Logan Peak syncline, from which the highest peaks, Logan, Providence, and Little Baldy, composed of Pennsylvanian rocks, rise. They form the highest parts of Wellsville Mountain, and in them most of the cirques have been cut (pl. VI). They may be readily distinguishedat a distance from the weaker calcareous sandstones of the Oquirrh formation above. They form the crest of the Pisgah Hills east of Dry Lake, and the east flank of the same from Mt. Pisgah south.

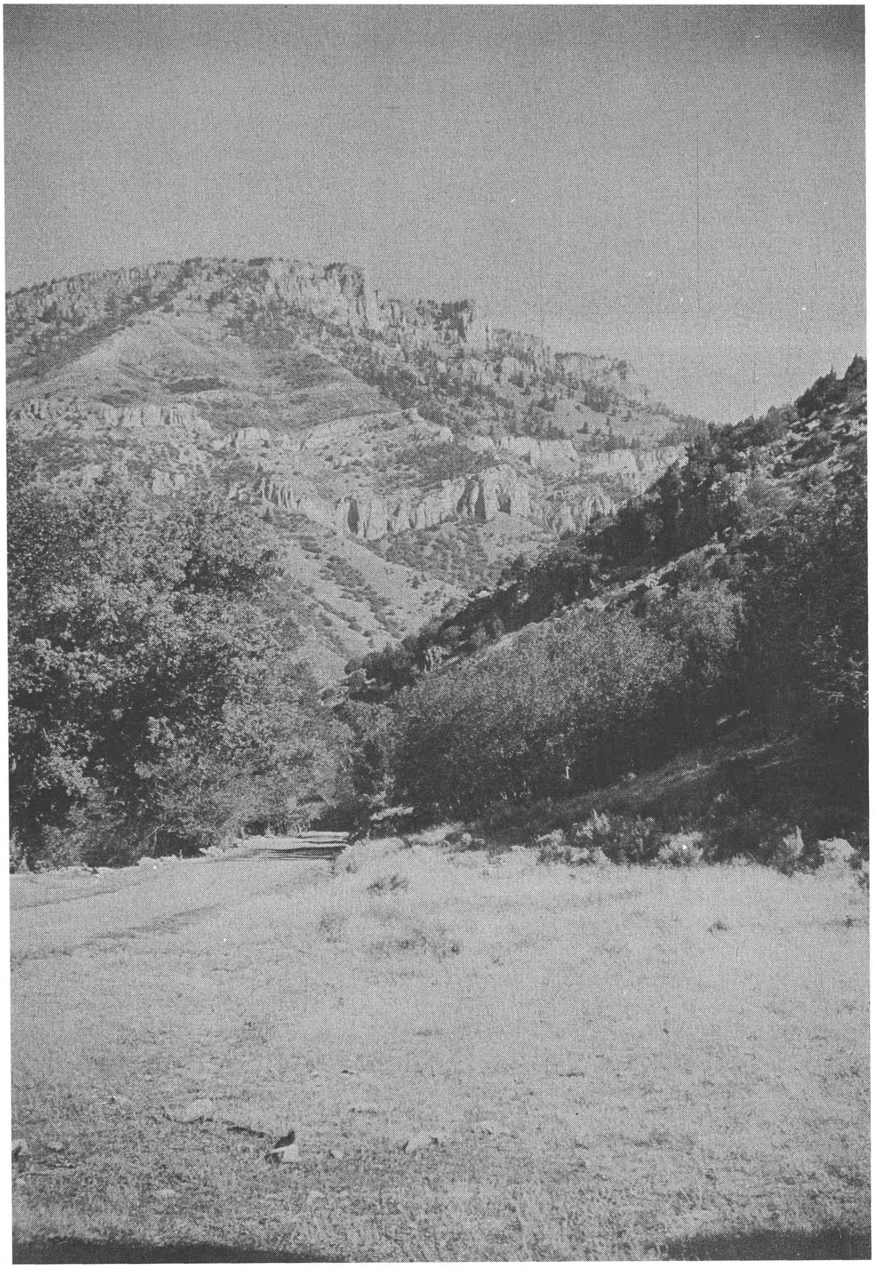


Plate X. Lodgepole limestone and Brazer formation in left fork, Blacksmith Fork Canyon. View to north.

PENNSYLVANIAN SYSTEM

This system is represented in Cache County by more than 6,000 feet of limestone and calcareous sandstone of the Oquirrh formation. It occurs in a wide outcrop belt along the east side of the Pisgah Hills and Wellsville Mountain (pl. VI); the Mississippian - Pennsylvanian boundary crossing the north end of Pisgah Hills near their crest, and ascending Wellsville Mountain in Rattlesnake Hollow. North of the highest peak, it passes to the west side and descends to the Bonneville shoreline east of Deweyville. Thus, the whole mountain crest at the north end is Oquirrh formation, as well as the whole of the valley-side face north of Wellsville Peak. In general, the calcareous sandstone of the Pennsylvanian is weaker than the limestone of the Brazer formation below, and weathers to notably smoother slopes.

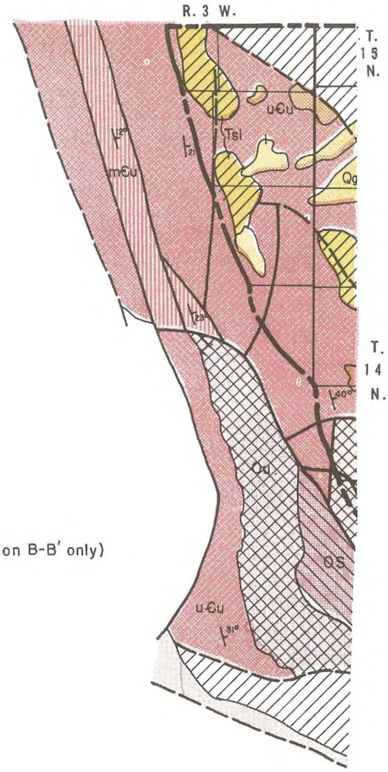
One other area preserves Pennsylvanian rocks, the low part of the Logan Peak syncline between Logan and Blacksmith Fork Canyons. Here the highest peaks, Logan, Providence, Little Baldy and Millville, are comprised of an unknown thickness of these rocks resting upon the much wider platform created by the Brazer limestone.

Cache County lies at the margin of the Oquirrh Basin where the Pennsylvanian rocks change rapidly between a basin and shelf facies (Williams, 1953, p. 38). The rocks of Wellsville Mountain are clearly deposits of the Oquirrh Basin and belong to that formation, although in earlier reports they have been called the Wells formation, a shelf facies named by Mansfield in southeastern Idaho. The nature of the rocks in the Bear River Range outcrops is not known, but eastward in Laketown Canyon, Rich County, the shelf facies, the Weber quartzite is present.

Which series of the Pennsylvanian System are represented in the Oquirrh formation in Cache County is not definitely known, although much progress has been made on the problem. Certainly the Des Moinesian Series is well represented in the basal part of the section. The macrofossils identified by Williams and Yolton (1945, p. 1152) and the microfossils identified by Chalmer L. Cooper (idem) from the beds below the Des Moinesian beds at Sardine Canyon, indicate a Morrowan age, but Nygreen (1955) reports a Des Moinesian fusulinid, *Wedelkindellina* from below these beds, casting doubt upon the validity of the earlier evaluation.

Fusulinids recovered higher in the section have been reported as late Missourian (Williams, 1943, p. 617) or Virgilian (Bues and Gelnett, 1958). Actually, Bues and Gelnett are the first students to systematically search the entire section for fusulinids, and their failure to find Missourian forms suggests the possibility of a disconformity in the section. It is interesting to note that Bostwick, studying the type localities of the Wood River formation, likewise found only Des Moinesian and Virgilian forms (1955, p. 941). Perhaps, likewise the top of the Oquirrh formation in Cache County may be Permian. No Atokan rocks appear to be present, a feature this section has in common with those along the Uinta Mountains.

Plate XI. Red Rock Pass, view toward Cache Valley. Landslide partly blocking channel from right.



Quaternary
- Qg — High level gravels
- Qs — Slope wash & alluvium
- Qb — Lake Bonneville group

Tertiary
- Tsl — Salt Lake group
- Tw — Wasatch group

- Paleozoic undifferentated (Section B-B′ only)

Pennsylvanian
- Po — Oquirrh formation

Mississippian
- Mu — Missippian undifferentated
- Mb — Brazer formation
- Ml — Lodgepole limestone

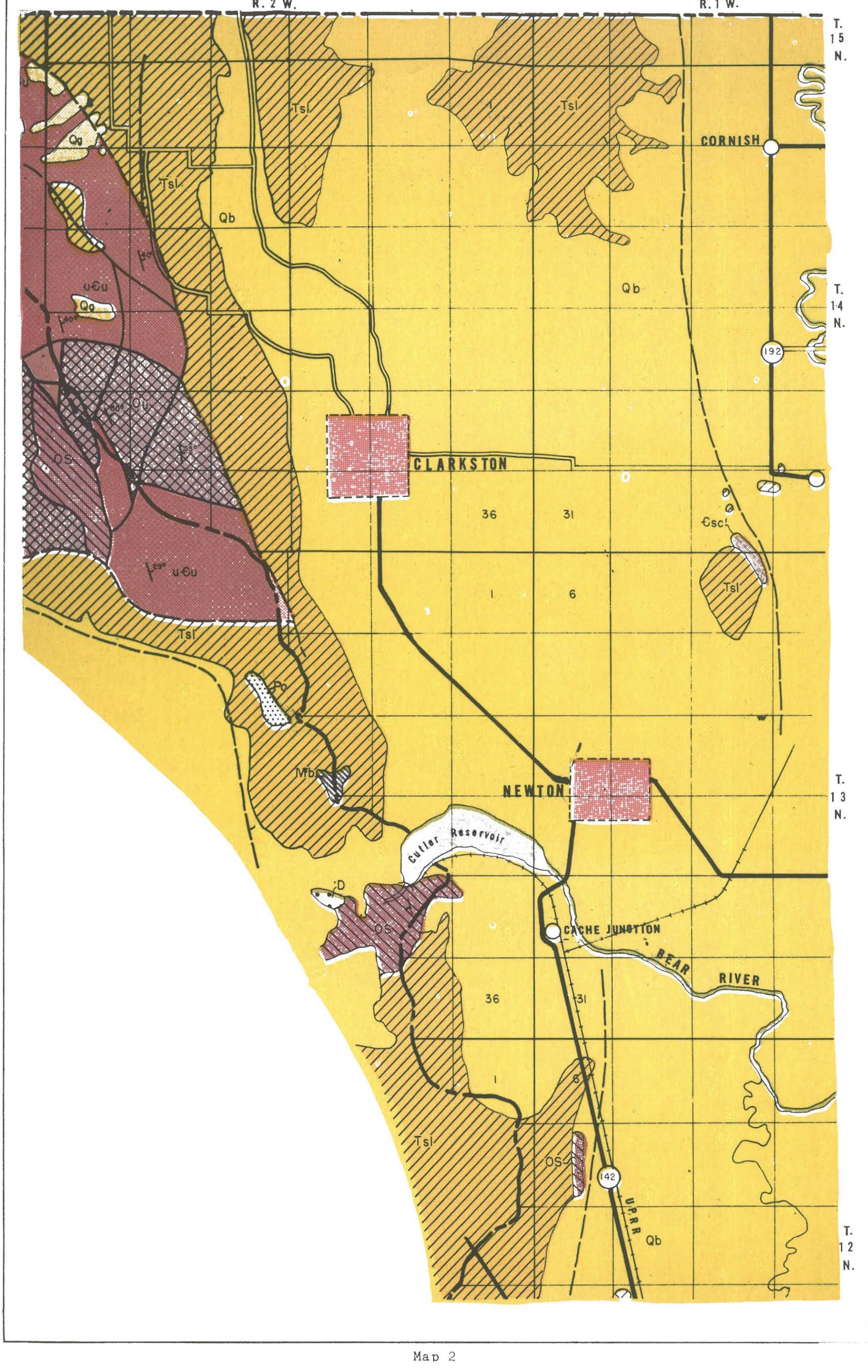
Devonian
- D — Jefferson fm. (middle (?) & upper Dev.) Water Canyon fm. (lower Dev.)

Ordovician & Silurian
- OS — Laketown dolomite (upper Ord. Fish Haven dolomite at base)

Ordovician
- Ou — Ordovician undifferentated
- Osp — Swan Peak Quartzite
- Ogc — Garden City limestone

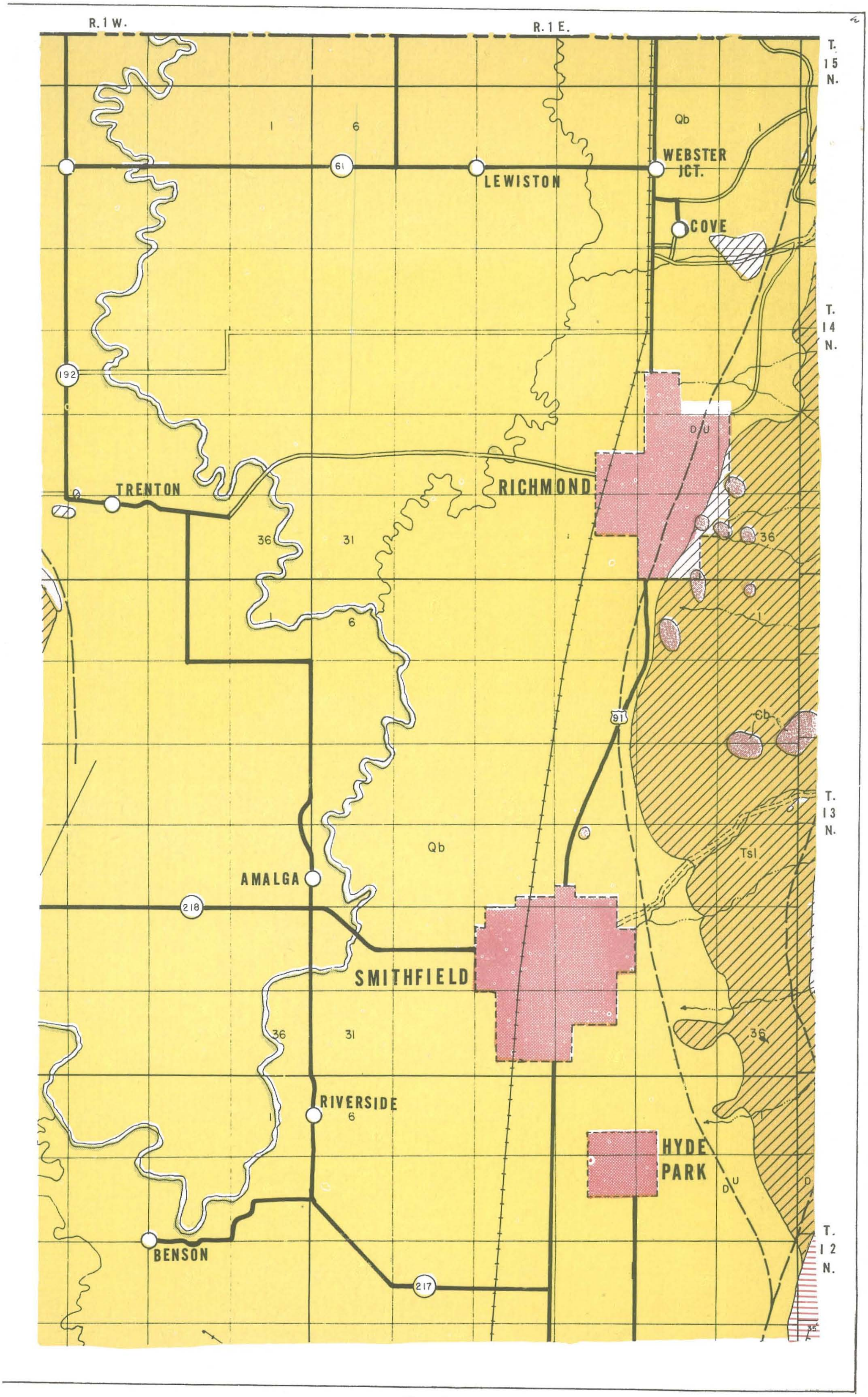
Upper Cambrian
- u€u — Upper Cambrian undifferentated
- €sc — St. Charles formation
- €n — Nounan formation

Legend continued on Map 10.

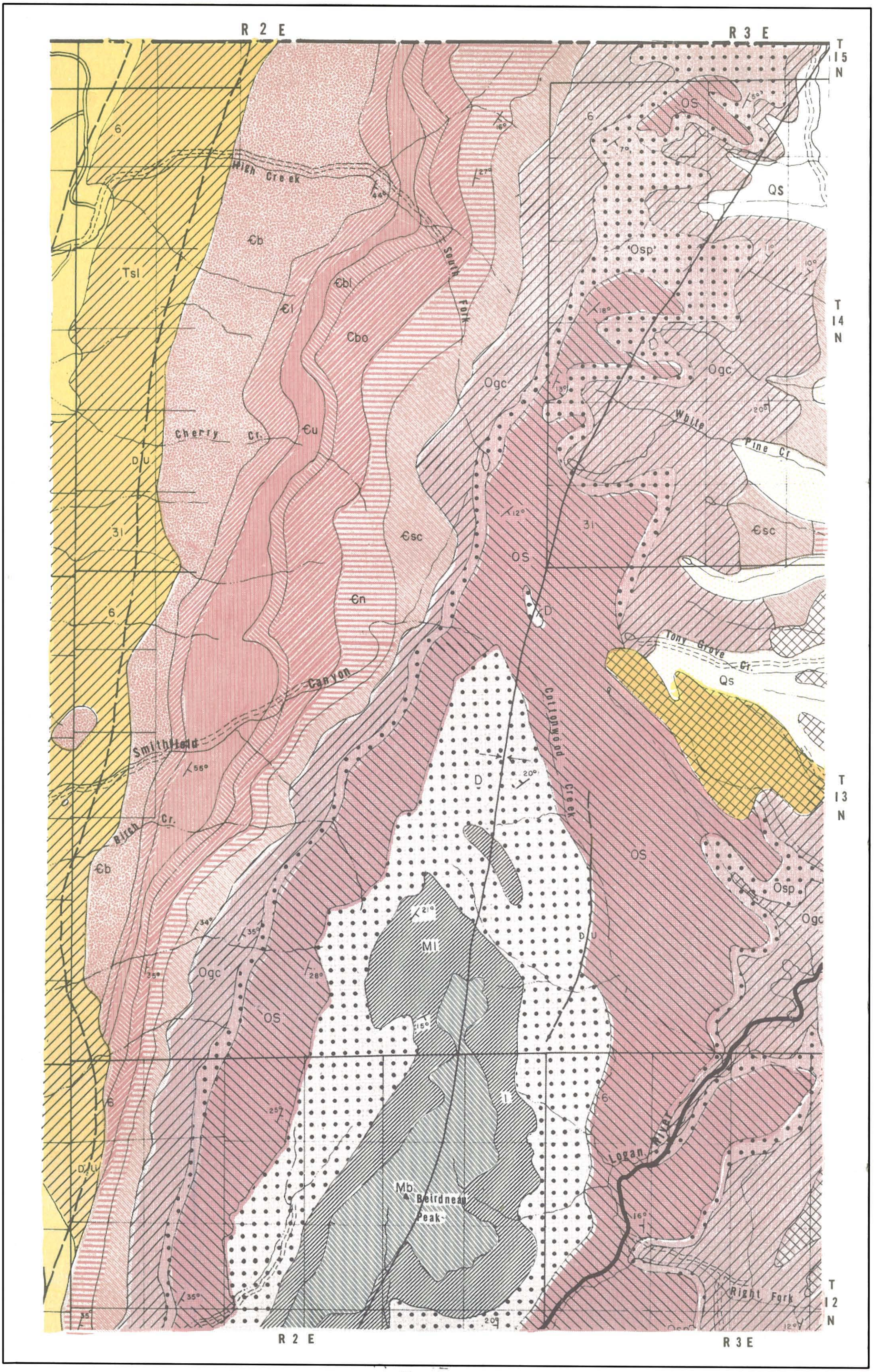


R. 2 W.
R. 1 W.
T. 15 N.
T. 14 N.
T. 13 N.
T. 12 N.
CORNISH
CLARKSTON
NEWTON
CACHE JUNCTION
BEAR RIVER
Cutler Reservoir
U.P.R.R.
192
142
Tsl
Qb
Qg
u€u
OS
Po
Mb
D
€sc
36
31
1
6

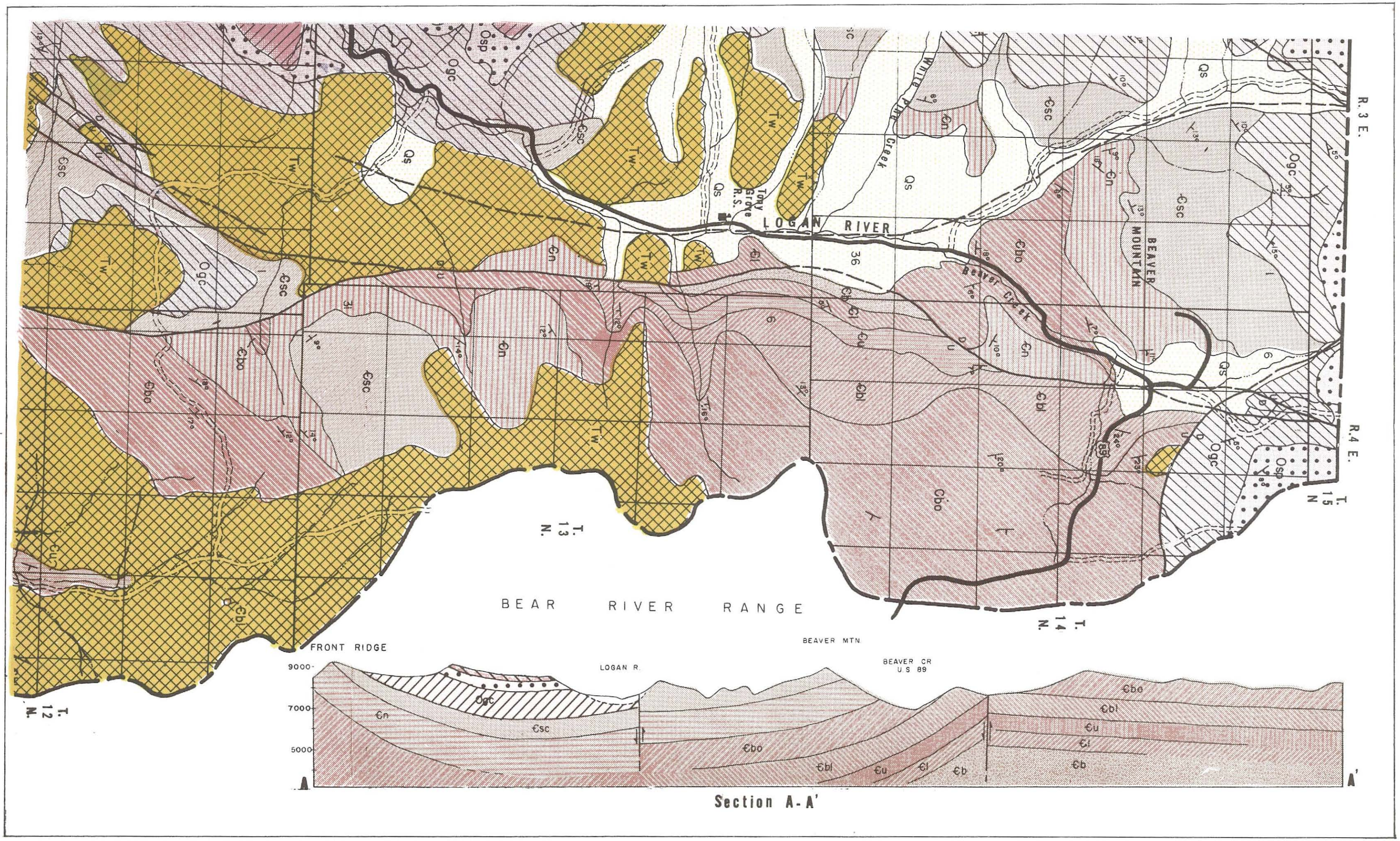
Map 2


R.1W.
R.1E.
T. 15 N.
T. 14 N.
T. 13 N.
T. 12 N.
Qb
WEBSTER JCT.
LEWISTON
COVE
61
192
RICHMOND
TRENTON
36
31
1
6
D U
91
Cb
Tsl
AMALGA
218
SMITHFIELD
RIVERSIDE
HYDE PARK
BENSON
217
35

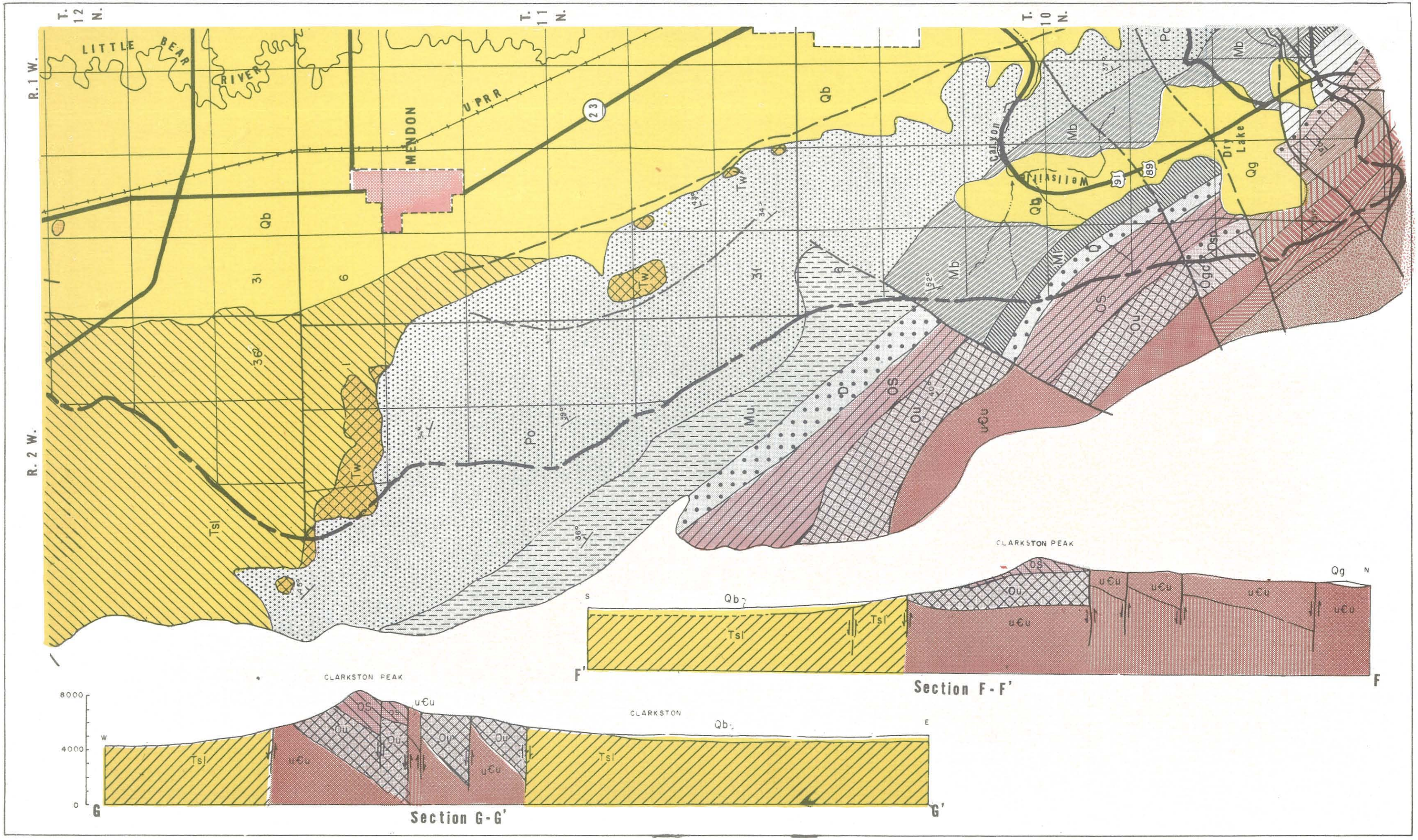
Map 3

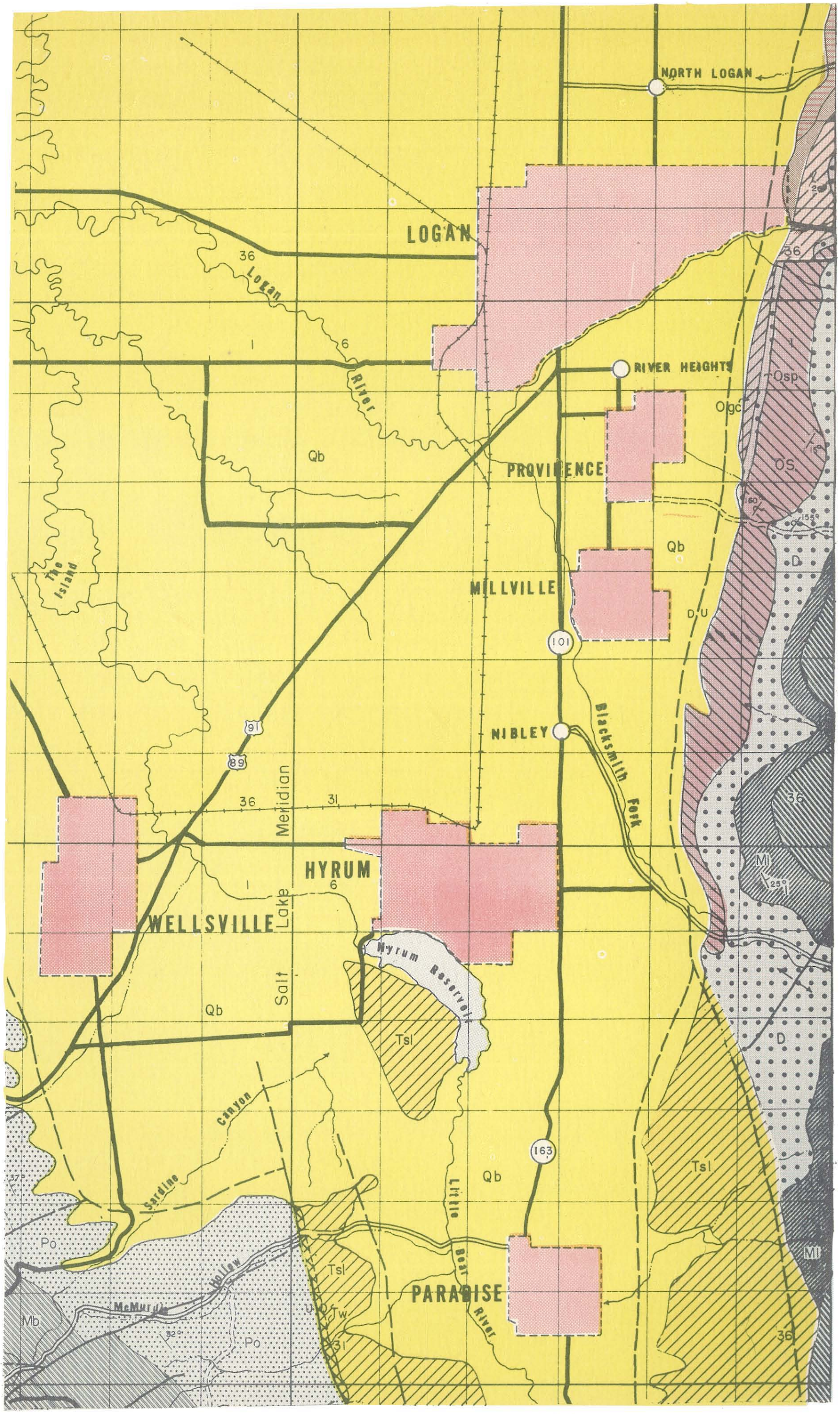

R 2 E
R 3 E
T 15 N
T 14 N
T 13 N
T 12 N
R 2 E
R 3 E
High Creek
South Fork
Cherry Cr.
Smithfield Canyon
Birch Cr.
Cottonwood Creek
White Pine Cr
Tony Grove Cr.
Logan River
Right Fork
Beirdneau Peak
Tsl
Cb
Cl
Cbl
Cbo
Cu
Csc
Cn
Ogc
OS
Osp
QS
Qs
D
Ml
Mb
D U
31
6

Map 4

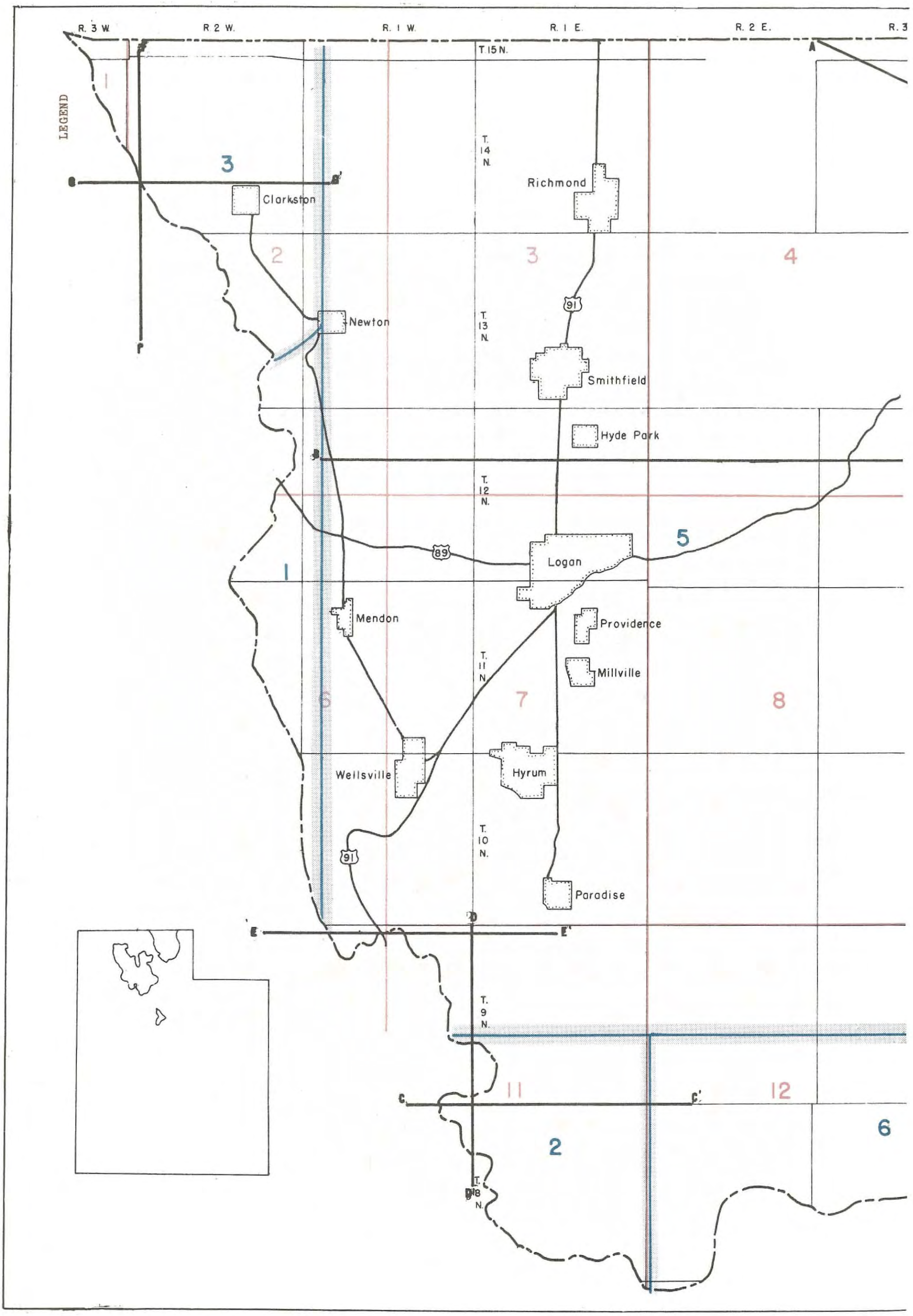

LOGAN RIVER
White Pine Creek
Tony Grove R.S.
BEAVER MOUNTAIN
Beaver Creek
BEAR RIVER RANGE
R. 3 E.
R. 4 E.
T. 15 N.
T. 14 N.
T. 13 N.
T. 12 N.
FRONT RIDGE
LOGAN R.
BEAVER MTN
BEAVER CR
U.S. 89
9000
7000
5000
A
A'
Section A-A'

Map 5

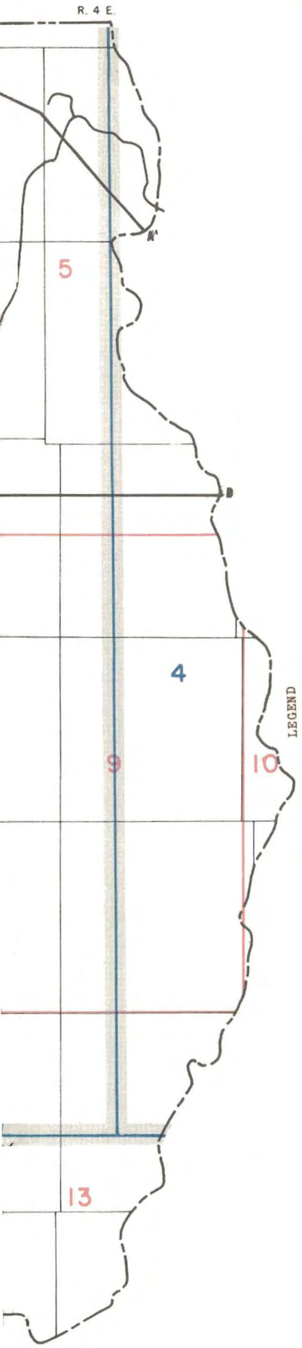

T. 12 N.
T. 11 N.
T. 10 N.
R. 1 W.
R. 2 W.
LITTLE BEAR RIVER
U P R R
MENDON
23
Qb
Tw
Tsl
Po
Mu
Mb
Ml
OS
Ou
u€u
Ogc
Osp
Pc
Qg
Canyon
Wellsville
91
89
Dry Lake
CLARKSTON PEAK
S
N
Qb
Qg
Tsl
u€u
Ou
OS
F'
F
Section F - F'
CLARKSTON PEAK
CLARKSTON
8000
4000
0
W
E
Tsl
u€u
Ou
OS
Qb
G
G'
Section G - G'


T. 12 N.
NORTH LOGAN
LOGAN
36
Logan
River
6
1
RIVER HEIGHTS
Osp
Olgc
OS
PROVIDENCE
Qb
MILLVILLE
D
U
T. 11 N.
The Island
101
NIBLEY
Blacksmith
Fork
91
89
36
31
Meridian
Lake
Salt
HYRUM
WELLSVILLE
Hyrum Reservoir
Tsl
Ml
Canyon
Sardine
163
Little
Bear
River
T. 10 N.
Po
Mb
McMurdie
Hollow
Jw
PARADISE
R. 1 W.
R. 1 E.

Map 7



LEGEND
R. 3 W.
R 2 W.
R. I W.
R. I E.
R. 2 E.
T 15 N.
T. 14 N.
T. 13 N.
T. 12 N.
T. 11 N.
T. 10 N.
T. 9 N.
T. 8 N.
Richmond
Clarkston
Newton
Smithfield
Hyde Park
Logan
Providence
Millville
Mendon
Wellsville
Hyrum
Paradise



INDEX TO

GEOLOGIC ATLAS OF UTAH
CACHE COUNTY

Scale of plates: 1/2 inch = 1 mile

1 0 1 2 3 4 5 Miles

Scale of index: 1 inch = 6 miles

0 2 4 6 8 10 12 14 16 Miles

SOURCES OF INFORMATION

1. Bues, Stanley S., and Gelnett, Ronald H., Geology of Wellsville Mountain, Cache and Box Elder Counties Utah: Unpublished Masters thesis, Utah State University, 1958.
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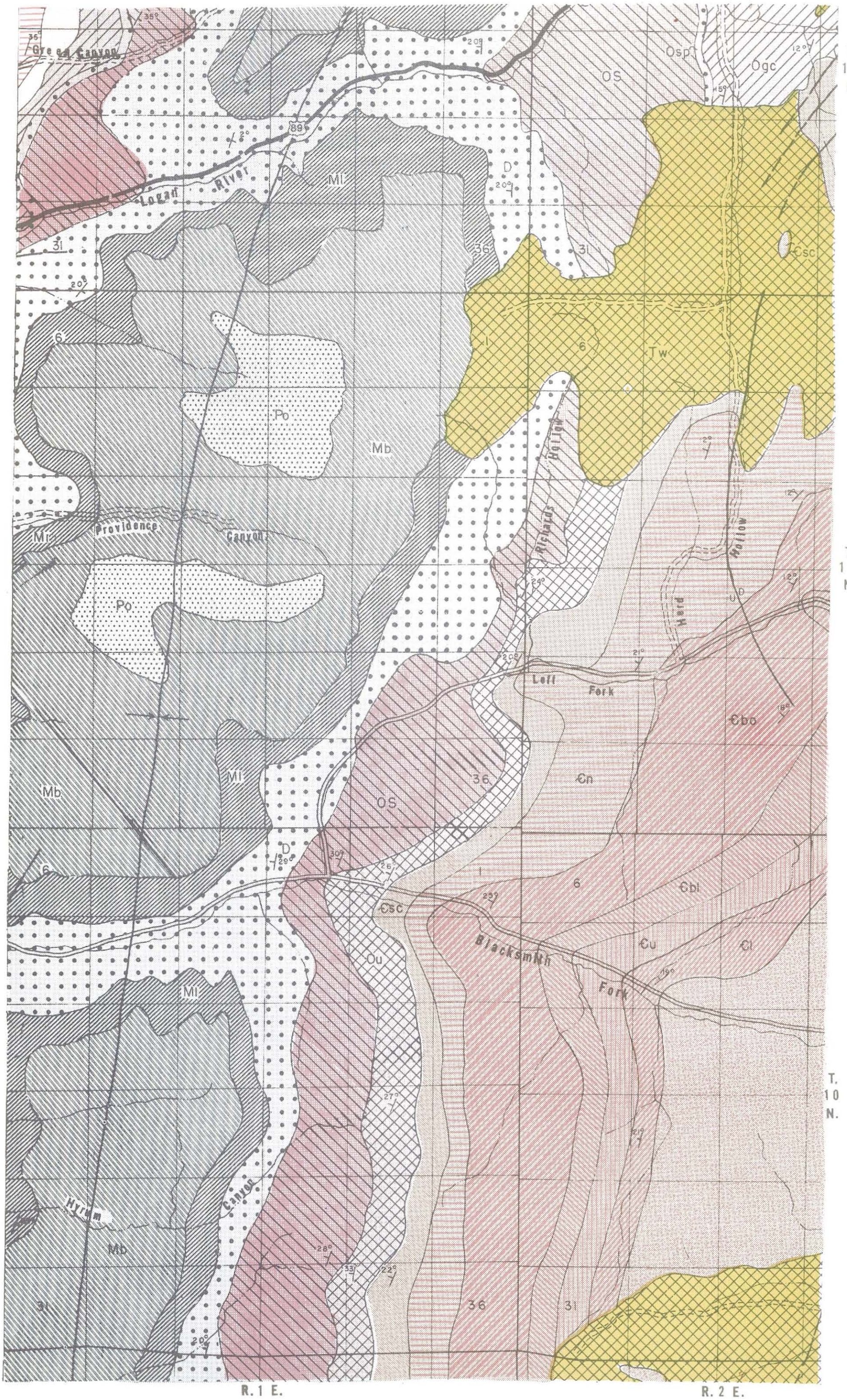
3. Hansen, Alvin M., Geology of the Southern Malad Range and vicinity in northern Utah: Docter's thesis, University of Wisconsin, 1949.
4. Richardson, G. B., Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., Vol. 36, pp. 406-416, 1913.
5. Williams, J. Stewart, Geology of the Paleozoic rocks, Logan quadrangle, Utah: Geol. Soc. of America Bull. Vol. 59, pp. 1121-1164, 1948.
6. Williams, J. Stewart, This bulletin.

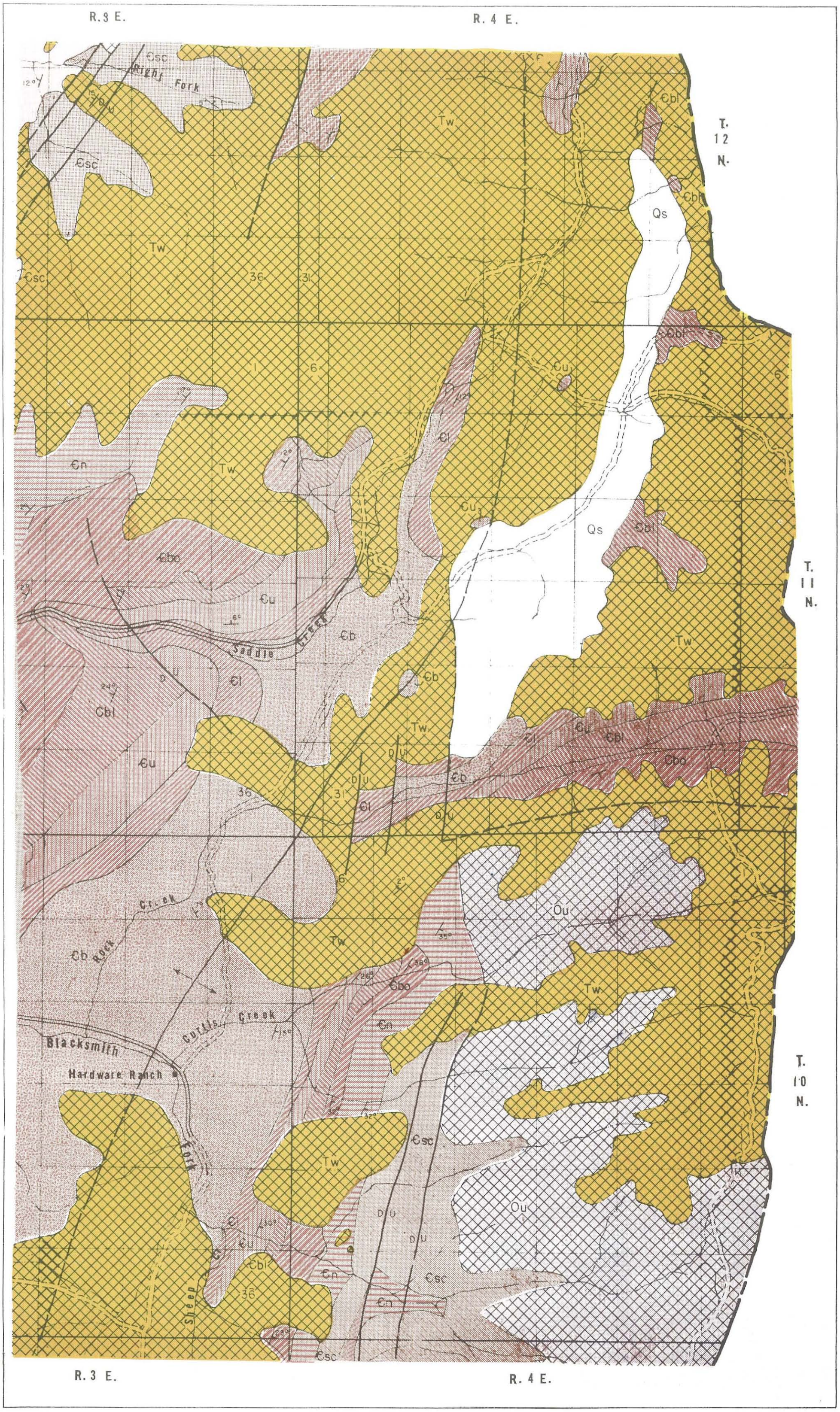
Red numbers correspond to plate numbers.

Blue numbers correspond to sources of information.



Green Canyon
Logan River
89
Ml
D
OS
Osp
Ogc
T. 12 N.
Tw
€sc
Po
Mb
Mr
Providence
Canyon
Richards Hollow
Hollow
Herd
T. 11 N.
Left
Fork
€bo
€n
36
Ou
Blacksmith
Fork
€bl
€u
€l
T. 10 N.
Hyrum
Canyon
31
6
R. 1 E.
R. 2 E.

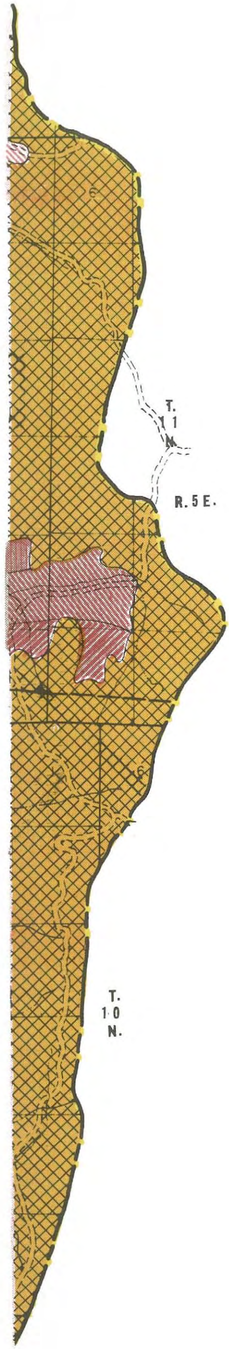
Map 8



R. 3 E.
R. 4 E.
T. 12 N.
T. 11 N.
T. 10 N.
Right Fork
Saddle Creek
Rock Creek
Curtis Creek
Blacksmith Fork
Hardware Ranch
Sheep Creek
Tw
Qs
Ou
Csc
Cn
Cbo
Cu
Cbl
Cl
Cb
R. 3 E.
R. 4 E.

Map 9

Legend continued from Map 1.



Middle Cambrian
- mCu — Middle Cambrian undifferentated
- Ꞓbo — Bloomington formation
- Ꞓbl — Blacksmith dolomite
- Ꞓu — Ute formation
- Ꞓl — Langston formation

Lower Cambrian
- Ꞓb — Brigham quartzite

Pre-Cambrian
- p-Ꞓbc — Big Cottonwood series

D / U Fault

Axis of Anticline

Axis of Syncline

Strike and dip of strata.

Horizontal strata

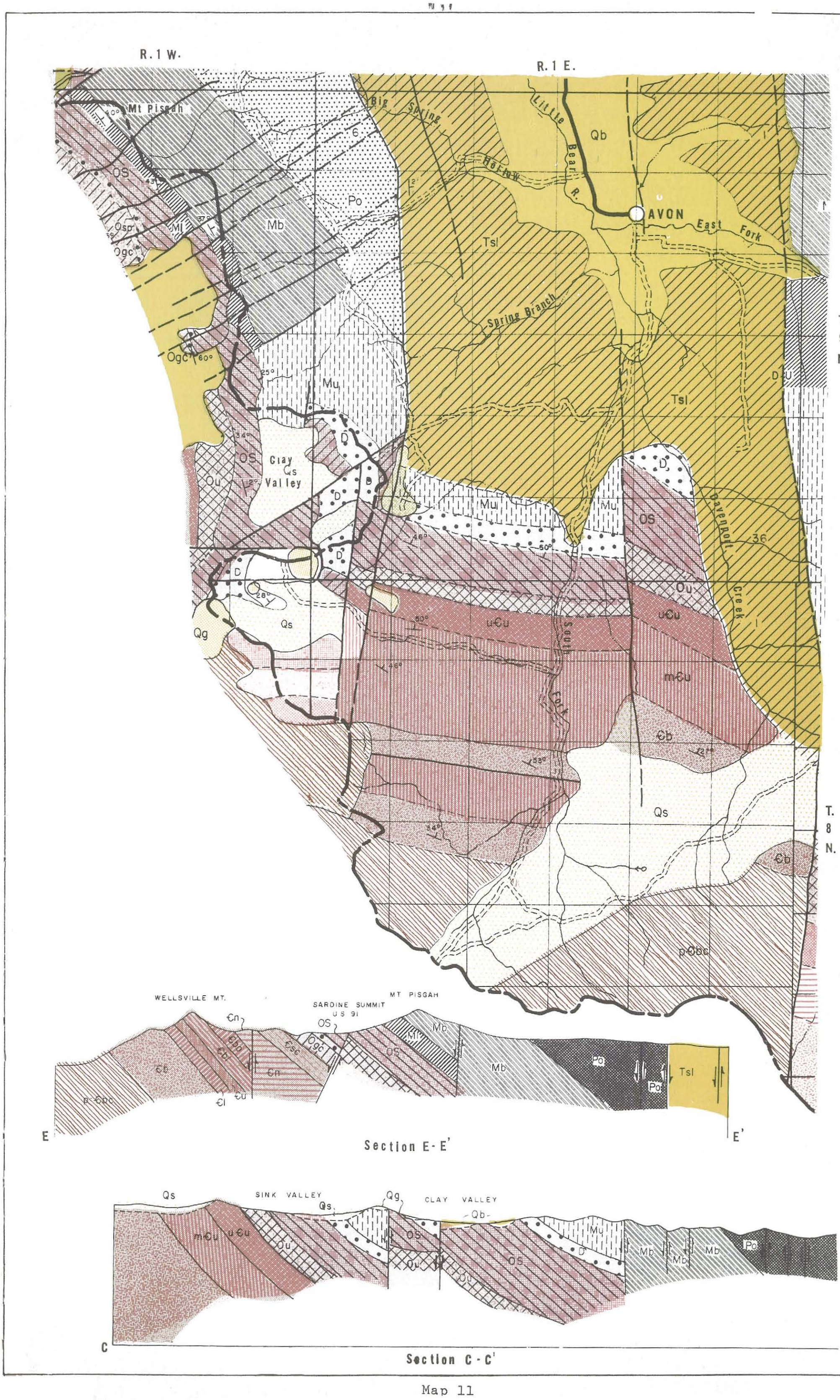
Overturned strata

Formation boundary

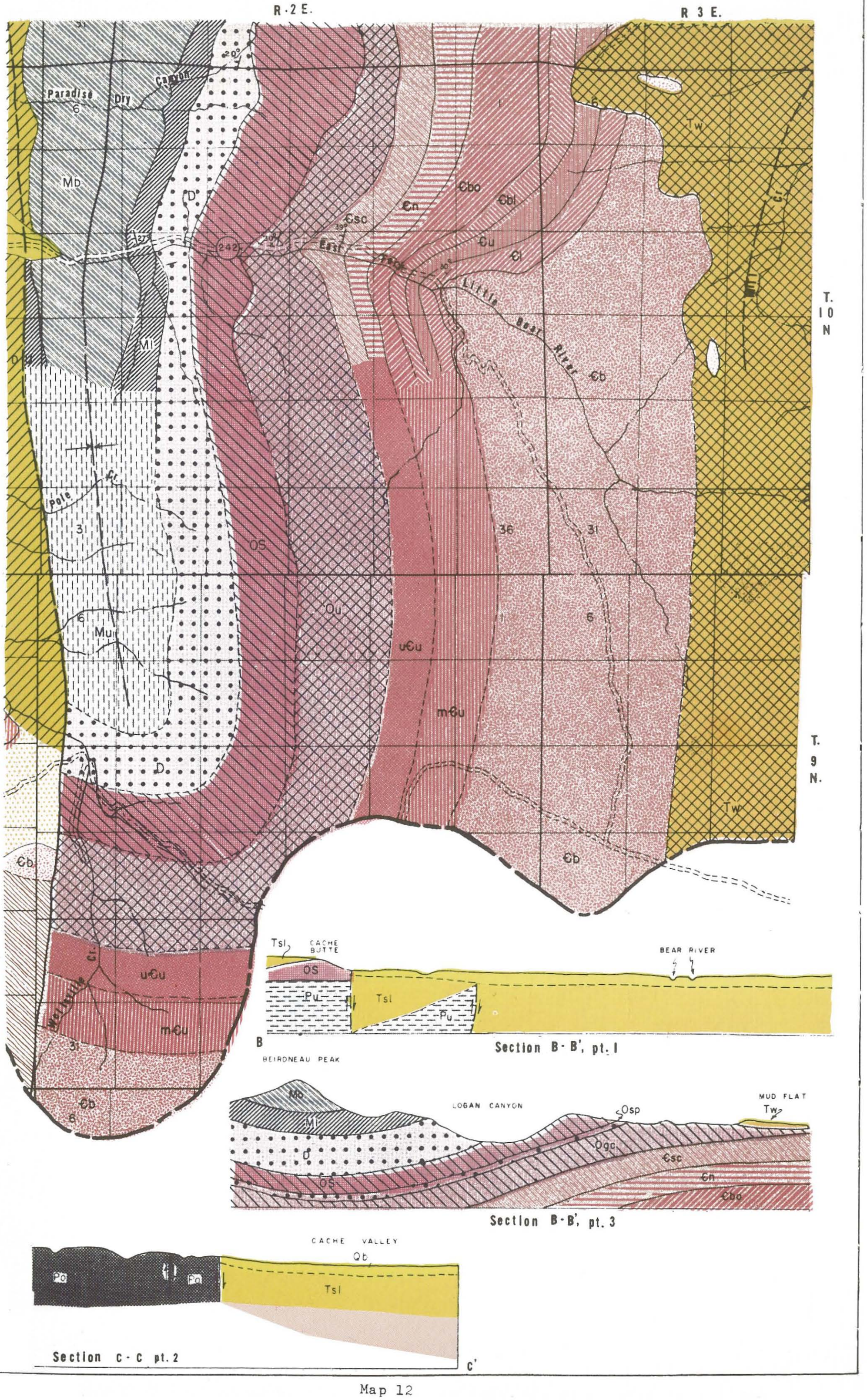
91 U.S. Highways

23 Utah Highways

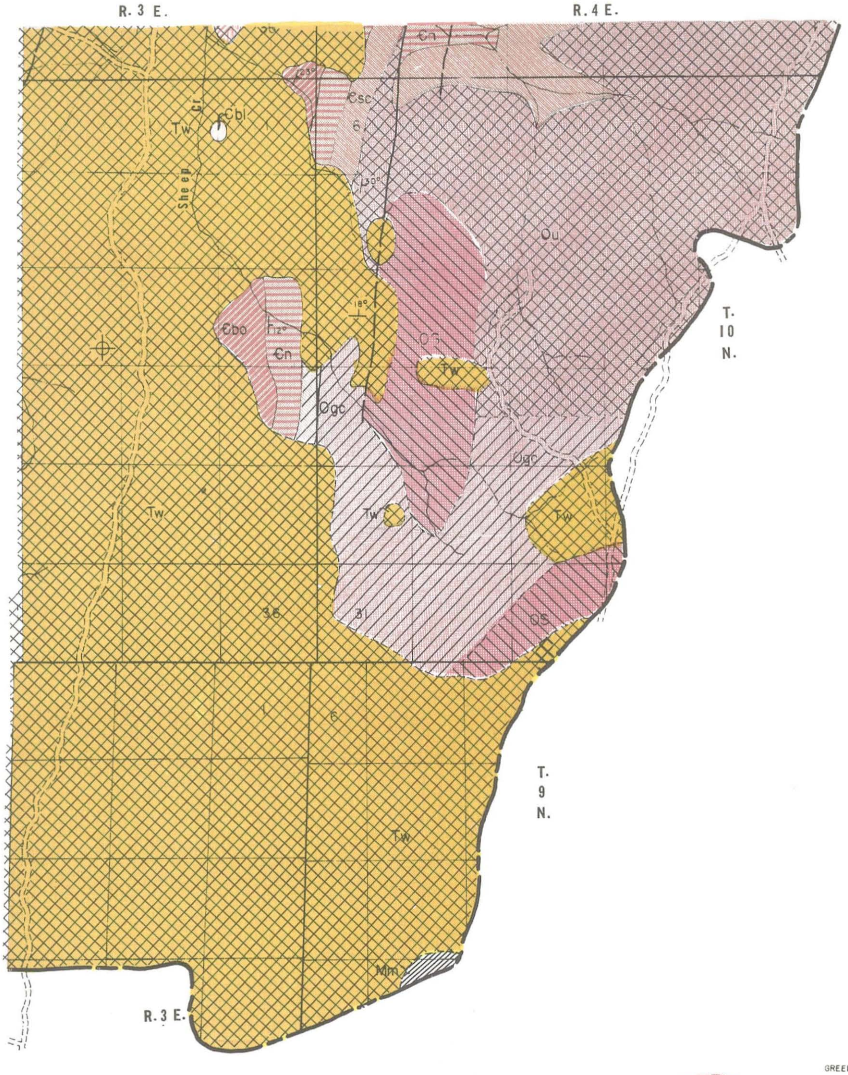
Paved
Improved
Unimproved
Roads

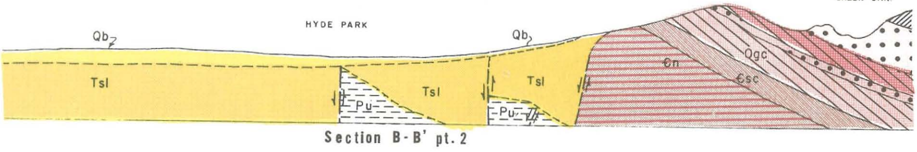

R.1 W.
R.1 E.
Mt Pisgah
Big Spring Hollow
Little Bear R.
AVON
East Fork
Spring Branch
Clay Valley
South Fork
Davenport Creek
T. 9 N.
T. 8 N.
WELLSVILLE MT.
SARDINE SUMMIT
U S 91
MT PISGAH
Section E-E'
SINK VALLEY
CLAY VALLEY
Section C-C'

Map 11

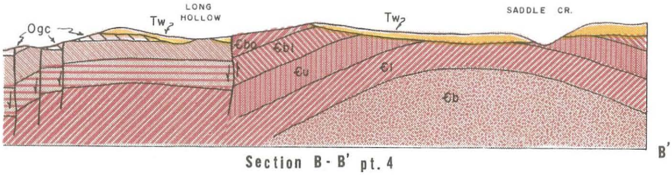

R 2 E.
R 3 E.
T. 10 N
T. 9 N.
Paradise
Dry
Canyon
East
Fork
Little
Bear
River
Pole
Cr.
Wellsville
Cr.
242
Mb
Ml
Mu
D
OS
Ou
u€u
m€u
€b
€sc
€n
€bo
€bl
€u
€l
Tw
Section B-B', pt. 1
CACHE BUTTE
BEAR RIVER
Tsl
OS
Pu
B
Section B-B', pt. 3
BEIRDNEAU PEAK
LOGAN CANYON
MUD FLAT
Osp
Ogc
€sc
€n
€bo
Section C-C pt. 2
CACHE VALLEY
Qb
Tsl
Pa
C'

Map 12





Section B - B' pt. 2



Section B - B' pt. 4

Typical Scene in Logan Canyon.

Photograph thru the courtesy of Max Brunson, Photographer, Logan, Utah.

T E R T I A R Y   S Y S T E M

Two groups of Tertiary rocks are recognized in this area: the early Tertiary Wasatch group and the late Tertiary Salt Lake group. The former is interpreted as the piedmont deposit of streams draining the Laramide Mountains of early Tertiary time eastward into the Green River Basin, before Cache Valley came into being; while the latter appears to be sediments that have accumulated in the valley since its creation as a down-faulted basin or graben. The red color of the sandstone and conglomerate of the Wasatch group is believed to indicate the warm humid climate of the subtropics which existed over piedmont areas not far above sea level; the lack of iron oxides in the matrix of Salt Lake group conglomerates, and their substitution by calcium carbonate, is partial evidence of the regional uplift generally interpreted for western North America in Oligocene or Miocene time, concommitant with or somewhat before the creation of Cache Valley.

WASATCH GROUP

The red sandstone and conglomerate of the Wasatch group is widely distributed over Cache County. In fact, it may have covered the whole area at one time. Presently its outcrops on the west side of Cache Valley are limited, but eastward in the Bear River Range, it covers increasingly wider areas. Ant Valley, where the headwaters of Blacksmith Fork approach the Ogden River drainage, is covered with Wasatch conglomerate which at the southeastern corner of the county is continuous across Monte Cristo summit with that underlying the Wasatch and Green River Basins to the east. Its thickness in this area has not been measured but is thought to be several hundred feet. On the high country between the drainages of Logan and Blacksmith Fork Rivers, stretching eastward from Logan Peak, another continuous cover of Wasatch sediments extends eastward. Here it seems thin because of the numerous inliers of Cambrian rocks exposed through it. Upper Logan Canyon, where the river and highway parallel Temple Ridge, is largely underlain by Wasatch, visible in Red Banks, and again a mile up canyon and on the east side of the road, beneath morainic material. The road to Tony Grove Lake follows a westward extension of this formation which reaches its extremity in the conglomerate cliffs visible above Tony Grove Lake to the southwest. On the backslope of Temple Ridge, the group is widespread, joining the continuous masses to the east.

No outcrops of Wasatch are known on the east side of Cache Valley, but in South Hills, thin beds of red sandstone and conglomerate, between the light-colored Salt Lake group rocks and the Oquirrh formation are interpreted as Wasatch, for example along the McMurdie Hollow road in Sec. 30, T. 10 N., R. 1 E. South of this exposure in the same stratigraphic position are other outcrops.

Northwest of Wellsville, just above the Bonneville shoreline, an erosion scar exposes red conglomerate visible widely (pl. VI). Other patches of Wasatch lie along the mountain front largely concealed by mantle. At the mouth of Pole Canyon, west of Mendon, similar patches mark the end of an outcrop belt that may be followed northwestwardly across the end of the mountain to points southeast of Collinston. Here the formation appears to be several hundred feet thick. Northward at the west end of the Wheelon Narrows, and on the opposite side of Junction Hills at Cache Butte, thin red

Plate XII. Red Rock Pass, showing scabland to left of main channel and bedrock inliers in channel. View to south.

rocks between the Salt Lake group and the Paleozoic rocks appear to represent the Wasatch group.

The basal beds of the Wasatch group are of particular interest in lower Cowley Canyon, on the divide above the canyon head at the "White Bedground," also along the highway just above Laketown, Rich County, and at several localities south and east of Cowley Canyon to the boundaries of the Logan quadrangle, where they consist of stromatolitic limestone. In lower Cowley Canyon concentrically laminated masses are attached to the underlying blocks of Garden City limestone; between and above these roundish bioherms, growths from boulder to granule size, are intermixed with sand and gravel or buried in a matrix of compact limestone. Most have pebbles as nuclei. The stromatolitic particles are intermixed with sand and pebbles in decreasing quantity upward, so that the stromatolitic limestone grades into regular Wasatch conglomerate. In Sec. 21, T. 12 N., R. 3 E., 83 feet of section was measured in this member (Williams, 1948, p. 1144). At White Bedground numerous steeply conical snail shells have been coated with a laminated growth of calcium carbonate. Youngsters collecting these have named the area "Peanut Flat."

The only fossils known from the Wasatch group in Cache County are snails from the basal limestone in Sec. 17, T. 9 N., R. 4 E. They seem to indicate a lower Eocene age for these rocks (Williams, 1948, p. 1146).

SALT LAKE GROUP

The light-colored, younger Tertiary rocks of the area were named Salt Lake group by Hayden in 1869 from outcrops in Morgan Valley, some 50 miles south of Cache Valley. Vertebrate remains found in these beds by Eardley and Clark in 1940 (Eardley, 1944, p. 845) indicate an Oligocene age, much older than the generally accepted age of the group, which was thought to be late Tertiary, Pliocene. In 1955 Adamson, in a study of the group in Cache Valley, visited Morgan Valley and recovered agriochoerid bones, perhaps as old as upper Eocene (p. 39). Eardley has mapped these rocks as far north as south Ogden Valley, perhaps within ten miles of Cache County.

Light-colored Tertiary rocks, younger than the Wasatch group are wide-spread in the foothill areas of Cache Valley, the benches that surround the deeper parts of the valley. They have been studied particularly by Adamson, and Keller and Prammani have made important contributions. A tentative separation of the group into three formations was made by Williams in 1952, and published by Smith in 1953 (p. 75). The formations are, from bottom to top, the Collinston conglomerate, the West Spring formation, and the Cache Valley formation. The Collinston conglomerate is a thick unit lying at the base of the group at the north end of Wellsville Mountain. It is here apparently hundreds of feet thick. It is thin to absent in Hyrum Bench. Above this an older unit of tuff and conglomerate, about 1500 feet thick, and separated from the still younger tuffaceous sandstones and conglomerates by an apparent unconformity, is present. At the base it contains fresh water limestones. This is the West Spring formation. The thickness of the Cache Valley formation is not known, but is presumably thousands of feet.

Plate XIII. Closer view of channel at Red Rock Pass. March Creek entering from left. View to southeast.

In 1952 Keller completed a study of the Salt Lake group in northeastern Cache Valley at Mink Creek. Here he measured 5700 feet of conglomerate, tuff, and limestone which he divided into a lower tuff member (2200 feet) and an upper conglomerate member (3500 feet). In 1955 Adamson studied a thick section east of Preston, Idaho, between Mink Creek and the Utah line. Here are some 7700 feet of tuff, tuffaceous sandstone, and limestone lying on the Paleozoic rocks without a basal conglomerate, and overlain by 1000 feet of conglomerate, apparently the equivalent of Keller's upper conglomerate member.

In a synthesis attempted by Adamson, Hardy, and Williams (1955) it was agreed that the Collinston conglomerate might be in part a valley-side facies of the Cache Valley formation; that the West Spring formation, not being recognized beyond its type locality in Hyrum Bench was probably better merged with the Cache Valley formation; and that Keller's upper conglomerate member deserved formational rank as the Mink Creek conglomerate.

A basal conglomerate was discovered in Prammani's area at the contact of the Paleozoic rocks, but it is only a few feet thick. At Red Rock pass a much thicker conglomerate, presumably the equivalent of the Collinston, lies on the Paleozoic rocks and is in turn overlain by a tuff which may be the equivalent of part of the Cache Valley formation. The pebble conglomerate at the base of the section in Junction Hills bears little resemblance to the coarser unit on Wellsville Mountain (Adamson, Hardy, Williams, p. 12).

In summary it may be said that the Salt Lake group in Cache Valley has proven to be astonishingly thick, nearly 9,000 feet. It begins with a basal conglomerate in places, which basal unit may reach hundreds of feet in thickness. The basal conglomerate has been named the Collinston conglomerate. The Cache Valley formation, generally tuffaceous sandstone, tuff, fresh water limestone--both compact and oolitic--with minor beds of pebble conglomerate, comprises most of the group. Along the northeast side of Cache Valley it is overlain by another conglomerate, the Mink Creek, some 1000 feet thick.

Unfortunately no vertebrate fossils have yet been recovered from the Salt Lake group in Cache Valley. Plants recovered near Paradise have been studied by Brown (1949); snails and clams from Junction Hills by Yen (1947); and ostracods from the same locality by Swain (1947). Brown assigned the plant fossils to the Pliocene, probably mid or late Pliocene. These fossils were collected from the Cache Valley formation, and seem to indicate that for the most part it is Pliocene, although parts of it, not now recognized, but such as the West Spring formation, may be as old as the Norwood tuff to the south in Ogden Valley.

GEOLOGIC STRUCTURE

GENERAL

In keeping with the general pattern that has emerged from the study of the geology of the western United States, geologic structures in northern Utah may be divided into (1) Laramide structures, produced at the end of the Mesozoic Era in the Laramide orogeny and

(2) younger structures, principally those faults associated with the formation of the Basin and Range physiographic province, and hence called Basin and Range structures. Both categories are well represented in Cache County. As a matter of local discrimination, Laramide structures are older than the Wasatch group, while Basin and Range structures are younger. Laramide structures are readily recognized in the Bear River Range where they lie beneath the Wasatch cover. They are much more difficult to discriminate from younger structures in the mountains west of the valley, where this reference formation is so discontinuous as to be nearly useless.

The following tectonic elements may be recognized in the area of Cache County.

The Bear River Range block
The South Hills - James Peak homocline
The Pisgah Hills - Wellsville Mountain homocline
The Junction Hills homocline
The Clarkston Mountain homocline
The Cache Valley graben

It is thought that these elements are defined primarily by Basin and Range faulting. However, each may be assumed to have some Laramide structures, which may or may not be discernible.

BEAR RIVER RANGE BLOCK

This block is separated from the Cache Valley graben by the north-south trending East Cache fault zone. The zone continues between the south end of this block and the South Hills--James Peak homocline. The block contains two major Laramide folds, the Logan Peak syncline and the Strawberry Valley anticline. These are part of the Idaho - Wyoming arc of folds and overthrust faults (Eardley, 1939, p. 1294). The high-angle, north-south trending faults of the block are considered to be younger than the Wasatch group, and hence of Basin and Range origin. It appears from the distribution of Wasatch conglomerate relative to the Temple Ridge fault, for example, that the fault is younger than these beds, but the actual extension of this and the other faults into the Tertiary rocks is difficult to observe. Similarly the Klondike, Mud Flat, Herd Hollow, and Hayes Ridge faults are thought to be Basin and Range faults. Presumably there was some faulting associated with the Laramide folding, but the field work accomplished to date does not make possible recognition of these old faults. The east-west trending fault between Dry and Logan Canyons in the face of the range may possibly be a tear fault associated with the folding.

SOUTH HILLS - JAMES PEAK HOMOCLINE

This structural unit lies at the south end of the county between Cache and Ogden Valleys. The general strike of the beds is east-west, with a moderate northward dip toward Cache Valley. At the base of the homocline lies the Precambrian Big Cottonwood series, not far from, but not necessarily continuous with the Precambrian rocks of the Willard thrust sheet to the southwest. To the west the homocline is terminated in a series of north-south faults against the Pisgah Hills - Wellsville Mountain homocline. This structural mass, as at present understood, is comparatively simple, with one major north-south fault displacing it near the middle, and with one east-west fault repeating the section in the southern part. Stratigraphically this block stands higher than the blocks east and west of it; yet it is in line with the Cache Valley graben, a topographic low.

The Laramide Logan Peak syncline of the Bear River Range may be projected southwestwardly into the area of South Hills, but the homocline there bears no trace of the fold. This seems to require movement and perhaps creation of the homocline after the folding. Whether this is in part Laramide movement is not known. Conceivably the dip of the homocline could be of Laramide origin, while the displacement athwart the truncated Laramide fold is Tertiary.

PISGAH HILLS - WELLSVILLE MOUNTAIN HOMOCLINE

This large structure, in which Paleozoic formations from Cambrian through Pennsylvanian and probably Permian strike north-northwestward and dip to the northeast, lies west of South Hills and southern Cache Valley. In the vicinity of Mt. Pisgah its trend swings to north-south, and south of Mantua Valley there is even a slight swing toward the west. This homocline is separated from the South Hills block by the fault zone through Sink Valley previously described. The homocline is bounded on the west by the Wasatch fault zone, trending nearly north-south, and truncating the homocline in a steep escarpment. Likewise, it is thought to be bounded on the east by faults, named the Hyrum and Wellsville faults in the writer's earlier report (Williams, 1948, pp. 1155-1156). Recently Bues and Gelnett have discovered the Mt. Hughes fault, generally parallel to the east face of Wellsville Mountain, but at some distance from its border. At its northern end Wellsville Mountain may be separated from Junction Hills by a transverse fault.

Principal interval structures in the large homocline are transverse faults of no great displacement. These are most numerous at the south end, from the south end of Mantua Valley to the north side of Dry Lake Valley. In fact, both of these depressions may be related to these faults. Farther north several faults of this type have recently been discovered by Bues and Gelnett.

If the homocline represents a limb of a large Laramide fold, or an overthrust mass moved eastward in Laramide time (Williams, 1948, p. 1151), it is easy to conceive of the transverse faults as tear faults related to this movement. An example of such is the Blackfoot fault, described by Mansfield (1927, p. 160). However, there are transverse faults younger than the Salt Lake group at the north end of Clarkston Mountain (Hanson, 1949) and the north end of Wellsville Mountain, and these might belong to that genre. On the west side of the homocline these faults do not have topographic expression, as does the north-south Basin and Range Wasatch fault, which would seem to be evidence that the transverse faults are older. Where South and Pisgah Hills join, faults of both trends intersect and terminate each other without a clear chronological relationship. The writer is inclined to believe these transverse faults to be Laramide in age, but there is no conclusive evidence now known.

JUNCTION HILLS HOMOCLINE

The Junction Hills horst, bounded by a very youthful fault escarpment on the west, and another perhaps less spectacular fault escarpment including Cache Butte, on the east, contains another homoclinal mass, this with a northeast strike and a northwest dip. Paleozoic formations from the Swan Peak to the Oquirrh crop out through the Tertiary cover.

If this picture of the structure here is real, it seems difficult to relate this to the two adjacent homoclines (both with easterly dips) by high-angle faulting, either Laramide or Tertiary, and the writer is still inclined to believe that they may be related through overthrusting.

CLARKSTON MOUNTAIN HOMOCLINE

This homocline, northernmost of the three along the west side of Cache Valley, has been mapped in detail by Hanson (1949). While having the same general trend as the Wellsville Homocline, it involves only Middle Cambrian to Silurian rocks, and is much more faulted than the Wellsville Mountain block. Hanson reports the average strike as north 30 degrees west, and the average dip as 30 degrees northeast. He considers the range a horst, bounded both east and west by Basin and Range faults. Faults within the range he reports as having two general trends, north-south and east-west, with the former more numerous. These internal faults, he believes, largely antedate deposition of the Salt Lake group. Hanson favors the hypothesis that includes the idea of post-Salt Lake group transverse faulting between Junction Hills and Clarkston Mountain (1949, p. 76). Similarly Adamson (1955) and Bues and Gelnett (1958) have found post-Salt Lake group faulting on an east-west trend at the north end of Wellsville Mountain.

The degree to which these three homoclines reflect Laramide structures is not known. They do not seem to be related to folds. They may be individual thrust masses. The extent to which the blocks have been rotated by Basin and Range faulting again is not known, but the presence of the Wasatch group along the northeast side of Wellsville Mountain only, suggest strong rotation toward the northeast, after Wasatch time.

THE CACHE VALLEY GRABEN

With Clarkston and Wellsville Mountains essentially horsts, Cache Valley appears to be in a general way a graben, bounded by Basin and Range faults on both sides. Interestingly enough, the graben appears to have formed in an area of older rocks. It has been pointed out that the rocks in James Peak and the South Hills homocline are older than those east and west across the boundary faults. Similarly to the north, Precambrian rocks occur in the valley bottom in Little Mountain, northwest of Preston, and in the fault escarpment of the Dayton fault northwest of Weston (pl. V). The Portneuf Range at the north end of the valley exposes wide areas of Precambrian rocks.

That the valley block itself is broken by numerous north-south faults, with a resulting unevenness in its floor, is attested by the numerous hills or small mountains within the valley, such as Cache Butte, Bergeson Hill, Crow Mountain, and Franklin Butte and

Little Mountain in the Idaho part. This same unevenness creates the Foothill benches, and brings Salt Lake group rocks to the surface along the Cub River northwest of Richmond, in the small hillock at Petersboro, and in the long hill south of the Hyrum Reservoir and the north end of Hyrum Bench (pl. IV).

R E S U M E O F G E O L O G I C H I S T O R Y

Northern Utah occupies a position near the eastern margin of the Cordilleran geosyncline, a seaway that existed for hundreds of millions of years in western North America. The history of this geosyncline is generally considered as starting with the Cambrian period. The only geographic elements recognized for Precambrian times are the Northern Utah Highland (Eardley, 1939, p. 1285) and the Beltian geosyncline that lay east of the highland, and trended from the Grand Canyon area northward through the Uinta Mountains and into western Montana. The Big Cottonwood series was deposited in this geosyncline, and hence in terms of the geography of Cache County's site, the highland lay nearby to the southwest, while the seaway covered the whole of the area. Glaciers on the ancient highland deposited till in the margin of the seaway, producing the Little Mountain tillite (Blackwelder, 1932) and the Mineral Fork tillite (Crittenden, et. al., 1952) in the Central Wasatch Mountains. Similar rocks have been reported from the Precambrian of the Idaho part of Cache Valley. As the Paleozoic Era opened, the Cambrian sea invaded the Cordilleran geosyncline from the southwest.

THE CORDILLERAN GEOSYNCLINE AND ITS SHIFTING BASINS

As Early Cambrian time came to a close, the shoreline reached northern Utah and the Brigham quartzite represents sand and gravel deposited in the littoral zone. Through Medial Cambrian time the shoreline lay well north and east of the future site of Cache County. The Worm Creek quartzite (Haynie, 1957) represents a brief return of shore-zone conditions, but through the remainder of Late Cambrian time the shoreline was far east of northern Utah.

The Swan Peak formation and the unconformity accompanying it represent withdrawal of the sea through most of Medial and part of Late Ordovician time. The returning Fish Haven sea was widespread over North America. Either the sea persisted here throughout Silurian time, or its withdrawal in Early and Late Silurian times has left no evidence other than the possible absence of sediments. In Early Devonian time the terrestrial Water Canyon formation was being deposited near sea level, and we are sure the sea did not again cover northern Utah until Late Devonian time. The Jefferson formation clearly records an epoch of increasing diastrophism with nearby lands contributing much sand to the northern Utah sea. Finally, at the end of the period, the area apparently became emergent, and was rather strongly disturbed, at least moderately warped.

After the widespread return of the seas in Early Mississippian time, diastrophism again increased, elevating much of the area east of northern Utah, and creating the rapidly sinking Oquirrh Basin. This basin lay mostly west and south of the area of Cache County. In it the thick Upper Mississippian sections of the Oquirrh Mountains and Dry Lake accumulated.

In earliest Pennsylvanian times the sea was restricted to the Oquirrh Mountains region, the Uinta Mountains area, and northwestern Colorado. Cache County may well have been a part of a highland adjacent the restricted basin. The Pennsylvanian seas fluctuated and shifted. Cache County received sediments in the Des Moinesian epoch, perhaps not in the Missourian epoch, but in Virgilian and perhaps earliest Permian times. The extraordinary Park City-Phosphoria sea with its deposits of phosphorite probably covered this area entirely, but its sediments are not now exposed here.

In Triassic time northern Utah shared the regional history. There is little doubt that it was covered by the same sediments exposed nearby in Weber Canyon and Bear Lake Valley. The same would be true of the Jurassic Period, except that the Logan area must have been near the western shore of the sea which deposited several formations in southeastern Idaho.

LATE MESOZOIC OROGENY

Cache Valley was well within the orogenically active belt during the growth of the great Laramide Mountains. When their growth ceased, and the erosive agents were unopposed in their destruction, Cache Valley soon lay in a heavily alluviated piedmont area, first levelled by streams draining from the mountains to the Green River Basin to the east, and then later buried under the debris the shrinking rivers were no longer able to carry as they themselves brought low the moisture-collecting highlands. Into this piedmont area, probably after a long continued erosion, Cache Valley was born as a sinking faulted area between adjacent blocks that continued to stand relatively high.

TERTIARY HISTORY

The present drainage pattern of the Bear River Range is thought to date from this time, perhaps the Miocene epoch. Since then these streams, and small ones from the western mountains, have carried debris into the valley. Continuing diastrophism has repeatedly tilted and jumbled the valley fill, but has never reversed the initial pattern which lowered the valley area and uplifted or held fast the mountain blocks. The long history of this semi-arid valley is contained in the thousands of feet of Salt Lake group rocks, the gravels of the Cache Valley streams, the breccias and fanglomerates of the mountain faces, the marls of ponds, and the oolitic limestones of shallow lakes.

Bear River is thought to have first crossed Cache Valley when the valley was deeply filled, and the bordering passes to the north and west shallow and easily crossed. Subsequent diastrophism has deepened the valley and superposed the river across the end of the Portneuf Range at Oneida Narrows and Junction Hills at the Wheelon Narrows.

E C O N O M I C   G E O L O G Y

PROSPECTING FOR METALS

Cache County is without a successful metals mine. Mineralization along the East Cache faults, and along faults of similar trend in the Bear River Range block, has long been of interest to the local prospectors, but has not proven sufficient to support a continuous mining operation. According to Arrington (1956) this prospecting began within the first decade after settlement, was stimulated by the coming of the railroad to the valley in 1872, and reached a boom stage in the 1890's when Cache County included three organized mining districts through which hundreds of claims were filed. The most famous area is La Plata near the south county boundary west of Ant Valley and east of James Peak, a ghost town that is alleged to have had a population of hundreds for several years. Heikes reports (1920, p. 218) only 8 tons of ore shipped from La Plata (galena) and that the most important underground developments produced no finds. Similarly 18 tons of lead ore were produced near Avon, and 10 tons at the Lucky Star Mine in Blacksmith Fork, according to the same writer. The zinc deposit at the boundary of Paradise Bench and the Bear River Range just south of the mouth of Blacksmith Canyon is reported to have furnished two carloads of ore; similar prospects lie in the boundary fault zone east of Providence, and are reported to have furnished tons of high grade ore. Arrington reports (1956, p. 237) that the Amazon prospect, in Logan Canyon near the Temple Ridge fault, once produced a shipment of ore worth $5,000. In addition to the slightly mineralized fault zones, other prospect holes have tested the black shales in the Cambrian, Ordovician, and Mississippian rocks.

NON-METALLIC RESOURCES

The non-metallic resources of the county are more real, though they are as yet little developed. They consist of dolomite, limestone, building stone, gravel, and clay.

There are thick dolomite beds in several of the formations of the area. Some of these are exposed in accessible locations from which the rock might be trucked away to a plant, or the railroad, at little cost. These thickest, most accessible, and probably highest grade localities were sampled by the author under a grant from the Utah State Department of Publicity and Industrial Development. The results have not hitherto been published. The analyses are summarized in the following tables.

FORMATION SAMPLED: Langston dolomite
LOCALITY: South of Mantua, Box Elder County, Utah (Sec. 27, T. 9 N., R. 1 W., SLB&M)

Sample No.	Description	Silica	R_2O_3	Calcium Oxide	Magnesium Oxide
1....	Samples 1 to 6, inclusive, came from a light	4.30	4.32	29.32	17.85
2....	gray coarsely crystalline dolomite of Lang-	10.40	4.00	27.40	16.92
3....	ston, weathering with a brown rind. Samples	1.60	3.36	30.60	18.76
4....	taken at approximately 25-foot intervals	4.20	5.44	30.00	16.47
5....	across the outcrop behind a mine at this	0.70	3.80	31.28	18.87
6....	locality.	2.60	2.92	31.40	18.46

FORMATION SAMPLED: Fish Haven dolomite
LOCALITY: Green Canyon, Cache County, Utah (Sec. 19, T. 12 N., R. 2 E., SLB&M)

Sample No.	Vertical Interval	Accumulated Thickness	Description	Silica	R_2O_3	Calcium Oxide	Magnesium Oxide
7	25	25...	Samples 7 to 10, inclu-	0.28	0.40	31.32	21.12
8	25	50...	sive, came from a massive	0.28	0.44	31.24	21.15
9	27	77...	black crystalline dolomite	0.28	0.44	31.24	21.24
10	31	108..................................		0.28	0.48	31.48	20.84

FORMATION SAMPLED: Laketown dolomite
LOCALITY: Green Canyon, Cache County, Utah (Secs. 19 & 20, T. 12 N., R. 2 E., SLB&M)

Sample No.	Vertical Interval	Accumulated Thickness	Description	Silica	R_2O_3	Calcium Oxide	Magnesium Oxide
11	36	175...	Samples 11 through 26, ...	0.32	0.64	31.44	20.84
12	43	218...	inclusive, came from a	0.28	0.52	31.32	20.81
	48	266...	light and medium gray, ...				
	66	332...	generally well-bedded				
13	68	400...	crystalline dolomite, ...	0.24	0.52	31.28	21.15
14	76	476...	generally thick-bedded.	0.20	0.48	31.36	21.14
15	117	593...	Some beds show consider-	0.28	1.00	31.32	20.82
16	46	639...	able porosity. Corals	0.56	0.80	30.40	21.35
	181	820...	and stromatolite present				
17	49	869...	in some beds, fossil	1.66	1.40	30.50	20.16
18	82	951...	"shadows" abundant in	0.98	0.80	30.54	20.88
19	110	1061...	others. Internal 20	0.88	0.92	30.66	20.66
20	110	1171...	quarried for lime.	0.58	0.80	30.80	21.17
21	110	1281..................................		0.24	0.44	30.44	21.07
22	114	1395..................................		23.76	1.08	23.10	16.10
23	52	1447..................................		1.38	0.70	30.30	20.99
24	32	1479..................................		1.40	0.72	30.30	20.89
25	50	1529..................................		2.20	0.76	30.20	20.59
26	69	1598..................................		1.18	1.08	30.48	20.62

Note: 1600 feet combined total thickness of Fish Haven and Laketown

FORMATION SAMPLED: Upper St. Charles formation
LOCALITY: Green Canyon, Cache County, Utah (Sec. 19, T. 12 N., R. 2 E., SLB&M)

Sample No.	Vertical Position	Description	Silica	R_2O_3	Calcium Oxide	Magnesium Oxide
29	0........	Generally thin-bedded limestone..........	3.52	0.68	50.76	2.59
30	115........	Light gray, medium-bedded dolomite.......	0.84	0.96	31.08	19.98
31	175........	Light gray compact rock. Massive........	0.56	0.84	30.60	20.52
32	240........	Light gray compact rock. Massive........	0.56	0.92	30.76	24.43
33	290........	Massive, light gray......................	0.68	0.72	30.92	20.44
34		Light gray, compact,.....................	2.12	0.80	30.40	19.87
35		thin-bedded, 5 per cent chert............	2.20	0.64	30.36	20.46
36	420........	Massive, apparently pure.................	0.92	0.80	30.68	20.44
37	479........	....	0.88	0.72	31.00	20.41
38		Generally mottled, thin-bedded, algal shadows?...............................	4.72	1.76	29.40	18.61
39	572........	....	2.56	1.20	30.20	19.80
40		Massive to thin-bedded...................	2.20	0.76	30.40	20.26
41	624........	Massive medium gray, coarsely crystalline dolomite, no chert..........................	1.88	0.88	30.68	20.01
42	674........	Top, just below contact of Garden City limestone................................	2.44	0.88	28.84	18.46

FORMATION SAMPLED: Fish Haven dolomite and Laketown dolomite
LOCALITY: Right Fork Blacksmith Fork Canyon, Cache County, Utah (Sec. 3, T. 10 N., R. 2 E., SLB&M)

Sample No.	Vertical Position	Description	Silica	R_2O_3	Calcium Oxide	Magnesium Oxide
43	15	Fish Haven dolomite. Dark gray, medium crystalline	0.60	0.68	30.92	20.96
44	45	Same	1.16	0.56	30.52	20.67
45	93	Fine-grained, light gray, medium-bedded. Base of Laketown	0.44	0.60	30.80	20.80
46	292		9.56	1.20	27.80	18.57
47	402		1.40	1.00	30.68	20.07
48	457		0.80	0.76	30.72	20.96
49	503		0.64	0.48	31.20	20.40
50	562		0.40	0.40	30.80	21.15
51	647		0.42	0.44	31.00	20.68
52	837	Mottled light and dark gray with silicified corals	0.76	0.48	30.96	20.95
53	932		0.48	0.40	30.84	19.55
54	1082		27.28	0.60	22.80	14.77
55	1182	5 per cent scattered chert at this locality	0.80	0.52	30.80	21.18
56	1232	Massive, light gray	0.60	0.64	30.76	20.70
57	1328		0.80	0.52	31.12	21.02
59	1697	Dark gray, siliceous?	1.80	2.12	30.24	19.51
58	1797	Top of Laketown formation	1.52	0.84	30.72	20.11

FORMATION SAMPLED: Langston dolomite
LOCALITY: Right Fork Blacksmith Fork Canyon, Cache County, Utah (Sec. 7, T. 10 N., R. 3 E., SLB&M)

Sample No.	Vertical Position	Description	Silica	R_2O_3	Calcium Oxide	Magnesium Oxide
60	0	First outcrop at road level. Medium gray, medium crystalline	2.90	3.40	29.80	18.34
61	50	Light gray, fine-grained	1.08	2.20	30.80	19.48
62	80	Coarsely crystalline, white, no chert	0.80	3.60	30.72	18.44
63	110	Same	1.20	1.80	30.64	19.56
64	145	Generally same, no chert or other impurity	1.36	4.64	30.44	15.50
65	175	At top of exposure and formation	0.48	0.76	30.80	20.72

FORMATION SAMPLED: Blacksmith dolomite
LOCALITY: Right Fork Blacksmith Fork Canyon, Cache County, Utah (Sec. 7, T. 10 N., R. 3 E., SLB&M)

Sample No.	Vertical Interval	Accumulated Thickness	Description	Silica	R_2O_3	Calcium Oxide	Magnesium Oxide
66	61	61	Samples 66 to 73, inclusive,	1.16	7.36	31.16	15.19
67	19	80	came from a medium to light	1.40	1.28	30.80	20.12
68	105	185	gray, medium to finely cry-	2.60	1.24	30.56	19.65
69	88	273	stalline dolomite; thin- to	2.20	2.16	30.72	19.29
70	50	323	thick bedded; little or no	1.00	0.80	30.80	20.23
71	23	346	chert.	1.32	1.28	30.64	20.01
72	50	396		0.84	2.80	31.80	18.00
73	46	442		0.88	3.36	30.92	18.61

FORMATION SAMPLED: Basal Nounan dolomite
LOCALITY: Right Fork Blacksmith Fork Canyon, Cache County, Utah (Sec. 1, T. 10 N., R. 2 E., SLB&M)

Sample No.	Vertical Interval	Accumulated Thickness	Description	Silica	R_2O_3	Calcium Oxide	Magnesium Oxide
74	50	50	Samples 74 to 77, inclusive,	0.72	0.72	30.72	20.10
75	110	160	came from a light gray,	0.36	0.68	31.60	20.37
76	42	202	thick-bedded dolomite.	1.90	1.08	30.52	20.13
77	130	332		1.20	0.84	31.00	20.23

FORMATION SAMPLED: Hyrum dolomite member of the Jefferson formation
LOCALITY: Right Fork Blacksmith Fork Canyon, Cache County, Utah (Sec. 1, T. 10 N., R. 1 E., SLB&M)

Sample No.	Vertical Interval	Accumulated Thickness	Description	Silica	R_2O_3	Calcium Oxide	Magnesium Oxide
78	75 (low)	75	Samples 78 to 93, inclusive,	10.00	2.04	31.24	14.76
79	75 (high)	75	came from a light to dark	6.00	1.56	31.96	17.88
80	50	125	gray, thin-bedded to massive,	4.48	2.04	31.00	18.75
81	50	175	generally medium-grained	6.00	2.44	29.20	18.26
82	0	175	dolomite; some intraforma-	1.60	1.08	31.60	19.72
83	25	200	tional breccia; some chert	1.64	1.32	31.24	19.78
84	25	225	in a few of the beds.	2.10	1.44	30.68	19.78
85	25	250		1.20	0.80	31.32	20.88
86	25	275		1.20	0.88	30.80	20.62
87	25	300		2.00	0.92	30.72	20.10
88	25	325		2.40	1.24	32.20	18.73
89	25	350		8.20	2.00	28.96	17.85
90	25	375		1.24	1.40	31.60	20.03
91	25	400		0.72	0.80	31.08	20.46
92	25	425		0.72	0.96	30.96	19.84
93	25	450		6.80	3.16	28.92	17.53

Pure limestone beds are developed in the Brazer formation, and these have been quarried for years in Providence Canyon, to supply the factories of the Amalgomated Sugar Company.

Shaly limestone, with a mixture of clay and calcium carbonate suitable for the manufacture of Portland cement, is present in great quantities in the outcrops of the Garden City formation. These are closest to the railroad in Green and Logan Canyons. Even larger areas of exposure are present in the Bear River Range, on the east side of the syncline, but these are far from the railroad.

Another formation probably of the same composition is the Bloomington limestone of Cambrian age. Exposures of this formation in Smithfield and High Creek Canyons are close enough to the valley to someday be exploitable.

Since the earliest days of settlement the canyons east of Logan have furnished building stone for foundations, walls, and chimneys of the homes, commercial buildings, and religious edifices of Cache Valley. Principal contributors have been the Garden City and Swan Peak formations, particularly from quarries in Green Canyon; the Salt Lake group, east of Franklin, Idaho, and in Junction Hills; and to some extent the Brigham quartzite from quarries in Blacksmith Fork.

In Green Canyon, northeast of Logan, Ordovician rocks form dip slopes into the canyon from its north side. Here the old-timers were able to strip off beds of limestone and quartzite, about one foot thick, because of the shaly partings that separated them. These sites provide by far most of the stone used for many years. The light blue-gray Garden City limestone made a pleasing contrast with the dark-brown Swan Peak quartzite. Both stones are used in the Mormon temple and tabernacle.

Soft tuffaceous sandstone has been quarried in Junction Hills, and on Richmond Bench, and has been used sparingly in buildings. Old Main Building at Utah State University has lintels and balustrades made of this stone. In recent years, some builders have utilized Brigham quartzite, with interesting color patterns from Liesegang banding, for chimneys and trim. Near Junction Hills some early ranch houses were built of blocks of oolitic limestone of the Salt Lake group.

SUBSURFACE WATER

GENERAL

Cache County may be divided into two subsurface water provinces, (1) the mountains and foothills, where subsurface water is important in springs only and (2) the valley proper, where underground water may be obtained in gravity wells and artesian wells, and where there are numerous seeps, swamps and ponds, and some artesian springs. In the former province the regional water table is in most places far beneath the surface, and wells would not be practical; in the latter the regional water table is everywhere near the sufface, and gravity wells may be obtained at shallow depth everywhere, and artesian wells may be obtained most any place in the area. In the former province a few of the smaller springs have been improved for stock watering, or to supply municipalities, while the larger springs maintain the perennial streams. In the valley there are some 1200 wells producing about 100 second feet (Peterson, 1946), used for irrigation, stock water, and culinary purposes.

SPRINGS IN MOUNTAIN AREA

In general, the number and size of the springs in the mountains surrounding Cache Valley are both large, because the mountain blocks consist mostly of carbonate rocks which readily develop underground drainage channels. This is reflected in the regimen of the principal streams which provide flows of clear carbonate waters which are well sustained throughout the year. In addition to the large fissure springs in the limestone and dolomite formations, there are numerous contact springs where water issues above shale members, such as the Spence shale, the shale member in the Swan Peak formation, and the shale at the base of the Brazer formation. In other occurrences the water issues from beneath Tertiary rocks, morained, or alluvial deposits.

In mapping the geology of the Bear River Range, the writer made the following inventory of springs. It probably represents the majority of the springs in the range, and shows that, in general, few of the natural water sources have been improved.

On the following tables, the springs are listed under the capacity of either small, intermediate, or large. A small spring refers to a discharge of one gallon of water per minute to 45 gallons per minute. An intermediate spring discharges 45 gallons a minute to one second foot, and a large spring discharges any amount over one second foot.

Township	Section	Elevation	Capacity	Improvements	By Nature of Openings	Origin	Remarks
14 N 2E	Center sec. 1	7650	small	none	filt	From beneath moraine	
	NE 10	6120	small	none	filt	Contact on Spence shale member	2 springs of this description at this place
	SW 11	6150	inter	none	filt	Probably contact on shale member of Ute	At flat near end of road up right fork High Creek
	SE 11	6350	small	none	filt	Contact on Hodges shale member	
	NE 14	6650	large	none	tubular?	Brought out by shale member in Bloomington?	
3E	SE 10		large	none	tubular	Small N-S fault in St. Charles dolomite?	Uppermost large spring on Logan River
	SW 14		large	none	tubular?	Small N-S fault?	Lowermost of 5 large springs at head of Logan River on east side.
	SW 14		large	none	tubular?	E-W joints, water from Hell's Kitchen or Steep Hollow areas?	Just east of road. Lower spring on west side river
	East central 15		large	none	tubular?	E-W joints, water from Hell's Kitchen or Steep Hollow areas?	Just east of road. Upper spring on west side river.
	SW 25		large	some	tubular	E-W joints	Spring near Crookston cabin north of mouth of Brush Canyon
	SE 36		large	none	tubular?	Issues on Temple Ridge fault	
4E	Middle sec. 8	7400	small	none	filt	May issue along Willow Springs fault	Seep.
	NE 18	7000	large	none	tubular?	Small N-S fault in Nounan	Spring at head of lower Beaver Creek Canyon
	West Boundary 30	6935	small	none	filt	Probably contact on upper shale member of Bloomington	Brush Canyon
13 N 2E	SW 2	6850	small	none	tubular?	N-S joints?	Uppermost spring in Smithfield Canyon
	NE 3		intermediate	none	tubular?	N-S joints	North side upper Smithfield Canyon
	SE 3	6800	intermediate	none	tubular	E-W joints and dip slope in Nounan	West side upper Smithfield Canyon
	N1/2 12	8700	small	none	filtration		Head Cottonwood Canyon
	SW 34	7250	intermediate	none	filtration	Underflow in valley fill	Collected below for North Logan water supply. Remainder lost by inseepage
	SW 35	7720	small	trough	filtration?	Dip slope in base of Madison	Uppermost spring in Green Canyon
	SW 35	7500	small	none	filtration?	Dip slope in base of Madison	
13 N 3E	E1/2 7	8630	small	trough	filtration	Issues from beneath Wasatch cover on hill to north	On Tony Grove Cottonwood Trail
	SW 8	8500	small	none	filtration	Issues from beneath Wasatch cover on hill to west	On Tony Grove Cottonwood Trail

Township	Section	Elevation	Capacity	Improvements	By Nature of Openings	Origin	Remarks
	SE 12	6450	large	yes	filtration	Issues on Temple Ridge fault, also near Langston-Brigham contact	Supplies Forestry School U.S.A.C.
	NW 15	7800	small	none	filtration		Twin Creek
	SW 18	7500	small	trough			Just above Tony Grove-Green Canyon Trail bottom Cottonwood Canyon
	E1/2 25	6500	large	none	tubular?	Issues on Temple Ridge fault	Springs near sawmill mouth Spawn Creek Canyon
	N1/2 31	6500	large	none	tubular	Small fault or joint in basal Jefferson	Heads Cottonwood Creek
	E1/2 27		large	no	tubular	Small N-S fault in Garden City	Ricks Spring
	SE 27		small	no	filtration	Seep from alluvium	
	N boundary 34		small	no	tubular	Joints in Garden City	Subaqueous spring just east of highway bridge
13N 4E	SW 8		small	no	tubular?	Small N-S fault in Blacksmith	
	SE 18	7190	small	no	filtration	Contact on Hodges shale member	Has produced landslide on down-dip slope
	NE 29	7600	small	no	tubular	Small N-S fault in Nounan	Heads Spawn Creek
12N 2E	SE 22		large	yes		Horizon - base of upper member of Jefferson	Logan City water supply
	SW 27		large	no	tubular?	Horizon - base of Madison. Issues at to of large rock fall	Spring Hollow spring
	NW 31		small	no	filtration	Contact on shale member of Swan Peak four	
	SE 36	6920	small	no	filtration		Near top of Card Canyon on trail
12N 3E	NE 5		large	no	tubular	From N-S joint in upper Garden City	Logan Cave spring
	South boundary 12	7330	small	trough	filtration	Seep in Wasatch	On Long Hollow Trail
	N1/2 13	6960	small	guard	filtration	Issues from Wasatch	On Long Hollow Trail
	S1/2 15	5775	intermediate	none	tubular	Mud Flat fault in St. Charles	Heads Right Fork Logan River
	SE 16	5600	large	none	tubular	Small N-S fault in Garden City	In Right Fork at mouth of Ricks Canyon
	S1/2 16	5570	intermediate	yes	tubular	Small N-S fault in Garden City?	Supplies Boy's Camp
	W1/2 19		small	yes		From Nounan	Supplies Card Ranger station?
	SW 34	6860	small	trough	filtration	Seep in Wasatch	Near head of Ricks Canyon
12N 4E	NE 5		large	none	tubular	N-S joints or fault in basal Nounan	Heads Temple Fork

Township	Section	Elevation	Capacity	Improvements	By Nature of Openings	Origin	Remarks
	West boundary 6		large	none	tubular	Temple Ridge fault	At mouth of right fork Temple Fork
	East boundary 19	7000	small	none	filtration	Seep in mantle	
11N 2E	NE 6	7200	small	trough	filtration	Probably contact on basal Brazer shale, water following down	South side Dry Canyon under mantle
	SE 7	6740	intermediate	none	filtration	Contact on basal Brazer shale	North side Providence Canyon
	W1/2 17	6000	small	none	filtration	Contact on basal Brazer shale	Heads Providence Canyon Creek
	NE 18	5320	large	yes	tubular?	Joints in Madison limestone	Providence City water supply
	SW 30	6000	large	no	filtration	Contact on basal Brazer shale	Several separate springs and large seeps. Millville Canyon.
	NE 33	5600	intermediate	no	filtration	Contact on basal Brazer shale	Leatham Hollow
11N 3E	E1/2 3	7400	small	trough	filtration	Seep from Wasatch	
	NE 5	6850	small	guard	filtration	Contact on Swan Peak?	West of Cowley-Herd summit
	NW 7	6800	intermediate	none	filtration	Contact of Wasatch on Laketwon	Head Richards Hollow
	NE 10	7000	small	none	filtration	Seep contact of Wasatch on Nounan	North side Bear Hollow
	West boundary 16						Above road east side Herd Hollow
	W1/2 21		large	none	tubular	Herd Hollow fault in Bloomington	At road in left fork Blacksmith
	West boundary 24	5900	large	none	filtration	Contact on shales in top Brigham	Just above road north side left fork Blacksmith
	SE 26		small	none	filtration	Contact on shales in Ute	
	Center 28	6470	small	none	filtration	Contact on Hodges shale	Mahogany Hollow
11N 4E	NE 18	6900	small	none	filtration	Seep in Wasatch	South side mouth Dip Hollow
10N 2E	NE 12	5300	large	yes	filtration?	From Nounan	Hyrum City water supply
	NW 23	7600	small	none	filtration	Contact on Swan Peak	
	NE 29	6450	intermediate	yes	tubular	Small N-S fault in Brazer	Paradise water supply
	North boundary 34	6770	small	none	filtration	Seep in mantle	
10N 3E	SW 8	5400	intermediate	none	tubular	N-S joints	Mouth north Cottonwood
	W1/2 20	5900	small	none	filtration	Contact of Langston on Brigham	
	NE 31	6900	small	none	filtration	Seep from mantle close to Langston - Brigham contact	
9N 2E	N1/2 16	5400	large	none	tubular	Small N-S fault in Laketown	Large spring above tufa terrace
	NW 17	5225	small	none	filtration	Contact on basal Brazer shale	

In addition to these springs well into the mountain block, a series of large springs issue from the base of the mountain blocks at the valley margin. These, of course, are particularly valuable for irrigation. According to Peterson (p. 23), 27 such springs discharge a total of 120 second feet.

VALLEY PROVINCE

In the valley proper where earth materials are largely sediments of the Lake Bonneville group, with minor amounts of post-lake alluvium, springs are perhaps subordinate to wells, but several categories are of interest. Where coarse alluvium lies on lake-bottom silt and clay, contact springs are common. The most notable example is the deltas of the Provo formation in which large quantities of gravel were deposited into the lake, as foreset and topset beds, upon the bottomset beds of silt and clay. The gravel part of the delta presents a rather steep front, and beneath this the springs occur. The delta of the Logan River and the large composite delta of the Blacksmith Fork - Little Bear are the most notable. Similarly, where coarse post-lake alluvium in the form of alluvial fans or stream channel deposits extends out on the old lake bottom, springs occur at the end and sides of the deposit. Examples are the alluvial deposits along High Creek, Smithfield Creek, and Providence Creek.

Large springs occur at several places in the valley, but particularly southwest of Logan, where the only satisfactory explanation of their being is that of artesian springs. They issue from pools in well-formed depressions, and the low permeability of the surrounding lake beds precludes their being water table springs. Generally the pool is deep proportional to its width, and the water is rather warm, about 60° F. A group of such springs feed Spring Creek, which flows for 30 to 80 second feet. (Peterson, 1946, pp. 28-30).

Artesian wells apparently can be obtained most everywhere in the lower parts of the valley below 4500 feet. Most of the wells are located between 4450 and 4500 feet. The typical well has been jetted into the lake sediments. The pipe is 2-5 inches in diameter, and only the upper part of the hole is cased. If the pipe is 2 inches, the flow is several tens of gallons per minute. For the larger pipes it may reach several hundreds of gallons per minute. Most wells are less than 200 feet deep.

The aquifers appear to be sheets and channel fillings of gravel, grading valleyward into sand, that have been deposited by the streams of the valley during interlake ages, such as the present. Aquifers thicken and coarsen toward the mouths of the canyons. Isopiestic lines curve valleyward past the principal streams indicating that they not only constructed the aquifers, but also now recharge them. Since the canyon mouths have been fixed in position since the earliest times of the valley, distribution of alluvium on the valley floor has probably followed the present pattern for a long time. This seems to explain why the most productive artesian areas are opposite the mouths of the principal canyons. In southern Cache Valley between Wellsville and Logan, Little Bear, Blacksmith Fork and Logan Rivers have spread coarse alluvium widely over the valley producing the most productive artesian area. Another area of importance surrounds the alluvial fan of Summit Creek at Smithfield.

Two principal aquifers are encountered in wells 150 feet deep, one at about 60 feet, the other at about 120 feet. These vary in thickness, generally thinning valleyward, but in the best artesian wells are 10 or more feet thick.

TOPOGRAPHIC FEATURES DUE TO SOLUTIONS

Solution valleys, sink holes, and caves are interesting geologic features of Cache County, due to the erosion of the widespread limestones and dolomites. Several features of this nature are of particular interest.

Logan Cave is the best known and most accessible cavern in the county. It opens into Logan Canyon 14 miles above its mouth and a few tens of feet above the canyon floor. It is about 2000 feet long, commonly 59 to 10 feet wide and sometimes 50 to 70 feet high. It is developed in a zig-zag pattern on two sets of joints in the Garden City limestone. A stream occupies its floor through most of its length. Two levels are developed near the front. Victor Church has mapped and described this case, and discussed its origin (1942).

Providence Cave, located near the head of Providence Canyon, is known to many who have hiked that way, but has not been described by a geologist. There are numerous other alcoves or shallow caves throughout the mountains of the county. The one from which Ricks Spring issues in Logan Canyon is seen by many.

On the higher parts of the Bear River Range, particularly on Temple Ridge, on Front Ridge near Mt. Naomi, and on and about Beaver Mountain, there are numerous sink holes, swallow holes and, small solution basins. Often these are related to faults, which at stream level in the canyon also localize springs. Sink hole, fault zone, and spring are parts of the system. At the east boundary of the county along U. S. 89, Sink Valley or The Sinks is a long strike solution valley developed on the Bloomington formation. It is composed of numerous separate sinks.

In South Hills and Pisgah Hills (pls. I, II), where carbonate formations of the whole section from Cambrian to Mississippian lie badly faulted in these rather low terraines, solution valleys are particularly well developed. These include Fry Lake Valley along U. S. 89, the floor of which supports a perched water table; Mantua Valley, which has been widened and deepened by solution and which now intersects the regional water table and draws into itself large springs on three sides; Clay Valley, just east of Mantua Valley; Devils Gate Valley, southeast of Mantua Valley and scene of an unsuccessful attempt to develop a solution valley into a reservoir; and Sink Valley between Devils Gate and Clay Valley, with a well-developed swallow hole into which the snow melt disappears each spring. This is perhaps the largest development of such solution features in a wide area.

LAKE BONNEVILLE IN CACHE VALLEY

Cache Bay was an important part of ancient Lake Bonneville, an Ice Age lake that occupied northwestern Utah for an unknown part of the Pleistocene Epoch. Lake Bonneville was first studied by G. K.

Gilbert, and was the subject of his famous monograph (1890) the first to be published by the U. S. Geological Survey. Gilbert's monograph describes the major features of lake-formed topography in the valley including the deltas of Logan River, the shore embankments near Wellsville (pl. VI), and the outlet channel at Red Rock Pass (pls. XI, XII, XIII). Another feature that particularly attracted his attention was the "Gates of Bear River" because, at lower levels of the lake, it connected the main body to its major tributary, Bear River, and also to its outlet channel.

At their highest elevation, 5135 feet, the waters of the lake lapped well up on the foothill benches (pl. III), and Newton Mountain was a small island, while Bergeson Hill made a peninsula north of a largely submerged Clarkston Bench. The north end of Hyrum Bench was submerged (pl. IV), as was the lowest section of Junction Hills. Logan and Blacksmith Fork Canyons made long, narrow bays back into the Bear River Range.

The major elements in the history of the lake, as interpreted by Gilbert, are still accepted by most geologists concerned with the problem. The lake is thought to have risen to near 5100 feet in its first cycle, then to have receded to a low level, probably withdrawing completely from Cache Valley before returning in a second cycle that carried to 5135 feet, the low elevation in the basin rim at Red Rock Pass. Spilling now began, and an outlet channel formed through the Paleozoic and Tertiary rocks of the rim (Williams, 1952) (pls. XI, XII, XIII). The cutting is thought to have been comparatively rapid, so that before this cycle was completed by another dessication, the outlet had been lowered to about 4770 feet, its present elevation. There is evidence that there has been a third cycle, bringing the lake up again to the elevation of the outlet, the so-called Provo level. The lake has not risen above Danger Cave, near Wendover, Utah and about 110 feet above the present level of Great Salt Lake, for over 11,000 years (Jennings, 1953).

The only erosional landform produced by the lake in Cache Valley, a sea cliff, is particularly noticeable at the Bonneville shoreline. The depositional forms are shore embankments, spits, bay-bars, and deltas. At most places about the valley a shore embankment from zero to tens of feet thick once covered the slope between the Bonneville and Provo shorelines. It is now mostly dissected (pl. III), and in places completely removed. The material in the embankment depends, of course, upon the nature of the sediments available in that particular part of the shore zone. Along the east side of the valley the embankment is composed mostly of silt and fine sand, generally buff colored. It is particularly thick between Logan and Providence Canyons, and for a mile or two south of Blacksmith Fork Canyon (pl. III). Around Hyrum Bench (pl. IV) and Clarkston Bench, the silt and sand was obtained from the Salt Lake group, and is lighter colored, reflecting a component of volcanic ash from that tuffaceous material. Along the Mendon-Wellsville piedmont, and southward along Pisgah Hills, the embankments are gravel, obtained from Tertiary conglomerates and the Oquirrh formation (pl. VI). Here are many well-developed spits, invariably grown southward from the headlands. Notable bay-bars cross the mouth of Sardine Canyon, south of Wellsville.

The large deltas, shaped by a gravel top, and partly reworked to a series of lower, smaller deltas by the parent stream as the lake receded from the Provo level, are the most striking landforms produced by the lake. The one at the mouth of Logan River w sketched for Gilbert's monograph. Logan City occupied the del north of Logan River; River Heights, the area to the south. Ut State University stands on the major surface at the Provo leve while the town occupies three or more of the small recession deltas. At the south end of the valley the deltas of Blacksmi Fork and Little Bear Rivers are merged, producing a flat of sever square miles area with Hyrum at its northwestern extension. Rece sional deltas on the Little Bear extend along that stream towa Wellsville; those along Blacksmith Fork as far north as Nible Natural levees along the Bear River, created as that stream follow the shrinking waters of the lake across the valley from the lar sand delta in the north end of the valley to the gates of the riv in Junction Hills, provide the higher sandy land on which the tow of Lewiston, Cornish, Trenton, and Benson have grown (pl. VIII).

P O S T - L A K E   H I S T O R Y

The geomorphic changes in Cache Valley since the waters Lake Bonneville disappeared have been small. The major strea have maintained the channels which they first cut in the lak bottom sediments, reworking the sand and gravel in their flo plains. Intermittent streams from the steep mountain-face gulli have in favored places built long tongues of poorly-sorted alluvi out onto the old lake bottom. In Logan and Green Canyons relative large alluvial fans now occupy a large part of the valley flo which once was graded to a flood plain by the waters of the Pro pluvial climate. This has been interpreted as evidence of t Altithermal age, some 8000 to 4500 years ago, when world clima in the middle latitudes was much warmer than at present (William 1956). It is believed that the rigorous climate of that time, wi perhaps only half the precipitation of the present, so deplet the plant cover as to make rapid erosion by infrequent rai inevitable, at the same time drying up the perennial Logan Riv so that the alluvium from the steep canyon sides accumulated witho interference.

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