

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

AFFILIATED WITH

THE COLLEGE OF MINES AND MINERAL INDUSTRIES

UNIVERSITY OF UTAH

SALT LAKE CITY, UTAH

GEOLOGY OF
LAKE MOUNTAIN, UTAH

BY

KENNETH C. BULLOCK



Bulletin 41

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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.
3. "The investigation of the kind, amount, and availability of the various mineral substances contained in State lands, with a view of the most effective and profitable administration of such lands for the State.
4. "The consideration of such other scientific and economic problems as, in the judgment of the Board of Regents, should come within the field of the Survey.
5. "Cooperation with Utah state bureaus dealing with related subjects, with the United States Geological Survey and with the United States Bureau of Mines, in their respective functions including field investigations, and the preparation, publication, and distribution of reports and bulletins embodying the results of the work of the Survey.
6. "The preparation, publication, distribution and sale of maps, reports and bulletins embodying the results of the work of the Survey. The collection and establishment of exhibits of the mineral resources of Utah.
7. "Any income from the sale of maps and reports or from gifts or from other sources for the Survey shall be turned over to the State Treasurer and credited by him to a fund to be known as the Survey Fund to be used under the direction of the Director of the Survey for publication of maps, bulletins or other reports of investigation of the Geological and Mineralogical Survey."

The Utah Geological and Mineralogical Survey has published maps, circulars, and bulletins as well as articles in popular and scientific magazines. For a partial list of such publications see the inside back cover of this bulletin. For other information concerning the geological and mineralogical resources of Utah address:

Director, UTAH GEOLOGICAL AND MINERALOGICAL SURVEY
College of Mines and Mineral Industries
University of Utah
Salt Lake City, Utah

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FOREWORD

Lake Mountain occupies an intriguing position within the triangle formed by connecting the greatest three mining districts of Utah, Bingham, Park City, and Tintic. Because of this and of its ease of accessibility, prospectors have combed the area since General Albert Sidney Johnston established Camp Floyd in 1858 on South Creek, the present site of Fairfield in Cedar Valley, and Porter Rockwell "settled down" at his Pony Express station in Rush Valley to the west.

However, except for rich pockets of manganese ore, pure calcite for Utah's poultry industry, exquisitely banded onyx and spectacular limonite pseudomorphs for avid mineral collectors, pumiceous lavas for light weight aggregates, and last but not least, the wreath of clays which drape the bow of this synclinal "ship of the desert" few minerals have been found to reward the prospector. But "hope springs eternal and faith dies hard" with men who search the earth for its usable contents and who must win from mother nature that which she hides from her very own. And so with the coming of Geneva Steel to the east shore of Utah Lake, it was but natural that a "clamor" should become more than audible for a geologic examination of the mountain mass on the opposite shore. Manganese was needed for steel making; limestone was needed for flux; clays were in demand as refractories. How could we be sure that other economic minerals were not waiting to be tapped? A careful investigation seemed justified. But only cursory examinations could at first be made. Neither time nor facilities were adequate during World War II for a thorough study. However, two papers were published on "The Manganese Deposits of the Lake Mountains", and "Geology and Mineral Deposits of the Lake Mountains" by Crawford and Buranek. And, these were later combined and amplified in "A Reconnaissance of the Geology and Mineral Deposits of the Lake Mountains, Utah County, Utah," which appeared as Circular 35 of the Utah Geological and Mineralogical Survey, then a part of the Raw Materials Division of the Utah State Department of Publicity and Industrial Development.

In the meantime, Professor Kenneth C. Bullock, Brigham Young University had secured the sponsorship of the U. S. Smelting Refining and Mining Company and the approval of the Department of Geology, Wisconsin University, for a more ambitious undertaking featuring the geology and stratigraphy of Lake Mountain for a Ph.D dissertation at Wisconsin.

With the hope of contributing to a better result through cooperative effort than could be obtained through active competition, the Utah Geological and Mineralogical Survey underwrote part of Professor Bullock's expenses and withdrew its projected preparation of a bulletin by its own staff. The high quality of the present treatise justifies this procedure. Because of the excellence of his study, Professor Bullock was awarded the doctorate degree.

While it is to be regretted that Dr. Bullock has not seen fit to re-evaluate the economic possibilities of Lake Mountain in more detail, all students of the region will be grateful for his keen analysis of the structure, stratigraphy and geomorphology. His contribution will be valuable as a basis for all future studies in this area.

Arthur L. Crawford, Director
Utah Geological and Mineralogical Survey

GEOLOGY OF LAKE MOUNTAIN, UTAH

By Kenneth C. Bullock

INTRODUCTION

Location and Area

Lake Mountain is located immediately to the west of Utah Lake, west-central Utah. The 112° meridian bounds the west side of the area, and the 40°15' parallel bisects its north-south elongation. The area lies about 25 miles directly south of Salt Lake City. Provo lies 10 miles to the east of Lake Mountain on the opposite side of Utah Lake. The bulk of Lake Mountain is located in Townships 5, 6, and 7 South, Range 1 West, Salt Lake base and meridian. Small lowland masses project into T. 5 S., R. 2 W.; and T. 6 and 7 S., R. 1 E. The total area included in this report is approximately 110 square miles.

A branch of the Los Angeles and Salt Lake Railroad traverses the northern end of Lake Mountain. Improved motor roads pass along the north and east sides of the range.

General Physical Features

Lake Mountain constitutes one of the eastern ranges of the Basin and Range Province. The northeastern boundary of this province is outlined by the Wasatch Mountains. Lake Mountain is one of the first ranges to the west of this boundary, separated from the Wasatch Mountains only by Utah Valley. The undrained basin of Cedar Valley lies to the west of Lake Mountain and separates this range from the southern Oquirrh Mountains. Immediately to the north and northeast lies the Traverse Range, a small east-west trending range that divides Utah and Salt Lake Valleys. On the southeast end of Lake Mountain is located Goshen Valley, and a small narrow range consisting of West Mountain and Long Ridge. Southwest of Lake Mountain lies the East Tintic Mountains.

Lake Mountain is a partially crescent-shaped, north-south trending range. It is approximately 15 miles long and has a maximum width of 7 miles. The maximum elevation is 7693 feet, and the local relief is 3200 feet.

The outer east and west margins of the main divides of Lake Mountain are rather rugged. The divides in the summit area are comparatively broad with low rounded slopes. The southern end has a somewhat more subdued topography than that of the central area, whereas the northern end consists of low rounded masses.

Great alluvial deposits extend out from the mountains into the adjacent valleys. Many of these coalesce to form bajada topography. The alluvial deposits form very gentle slopes in the valleys, but rise with increasing gradients toward the mountains. Pediment slopes are well exposed on the eastern side of the range.

The three adjoining valleys to Lake Mountain were formerly occupied by the waters of Lake Bonneville. Many of the shore features of that water body, both depositional and erosional, are clearly recognizable. The most marked shoreline features occur on the east side of Lake Mountain, where the water body was less confined and was approximately 300 feet deeper than in Cedar Valley.

The drainage from the area is accomplished by many small canyons and a few large ones. The principal drainage courses of the west side of Lake Mountain are: from north to south, Sage Brush Valley, Wiley and Mercer Canyons; on the south end, from west to east, Long and Piefer Canyons; on the east side, from south to north, Chaparral, Potter, Limekiln, Clark, Israel, and Lott Canyons. All these canyons contain only intermittent streams.

Climate and Vegetation

The climate of Lake Mountain, in common with the rest of the Basin and Range Province, is arid to semi-arid. The only weather station within the area mapped is located at the pumping station at the north end of Utah Lake, elevation 4497. The 40-year average of the annual precipitation of this station is 12.45 inches. It is probable that the summit areas of Lake Mountain may approach or even exceed 20 inches of annual precipitation.

The Utah Lake station records a temperature range from -28° to 106° F. It is possible that this maximum is not greatly exceeded anywhere in the area mapped. On the higher peaks of Lake Mountain the minimum temperatures may be somewhat lower than this.

The vegetation of the area varies widely. The mountain slopes bear considerable growth of juniper, locally called cedar, and mountain mahogany. Varieties of these two trees form the only notable larger vegetation. Only two small patches of aspen and one of Douglas fir were found on Lake Mountain. Scrubby maply is confined largely to the bottoms of the washes and canyons. Sage brush, bulb cactus, prickly pear, rabbit brush, and shadscale are ubiquitous over the whole area. Brigham tea (*Ephedra viridis*), cliff rose, buck brush, deer brush, June berry, etc., grow on many of the mountain slopes. Bunch grasses and salt grass grow in scattered tufts, but are apparently dead most of the summer. Mariposa lily (Sego lily), aster and many other flowering plants are rather widely distributed.

GEOLOGY

STRATIGRAPHY

General Features

The sedimentary rocks of Lake Mountain have a total thickness of at least 13,400 feet. They include Devonian, Mississippian, lower Pennsylvanian, Tertiary, and Quaternary strata. The Devonian rocks consist only of the Pinyon Peak formation, possibly equivalent to the Jefferson dolomite. The Mississippian formations are the Gardner dolomite, Pine Canyon limestone, Humbug formation, Great Blue limestone, and the basal portion of the Manning Canyon shale. The lower Pennsylvanian is represented by the upper horizons of the Manning Canyon shale, and several thousand feet of the Oquirrh formation. The Oquirrh formation contains a prominent basal limestone member which was mapped separately from the rest of this formation. The Tertiary system consists of the Salt Lake formation. The Quaternary system is represented by alluvium bordering the mountain masses and includes pre-Bonneville conglomerates, Bonneville lacustrine deposits, and Recent alluvial sediments, all of which lie unconformably on portions of the Paleozoic strata.

Devonian System

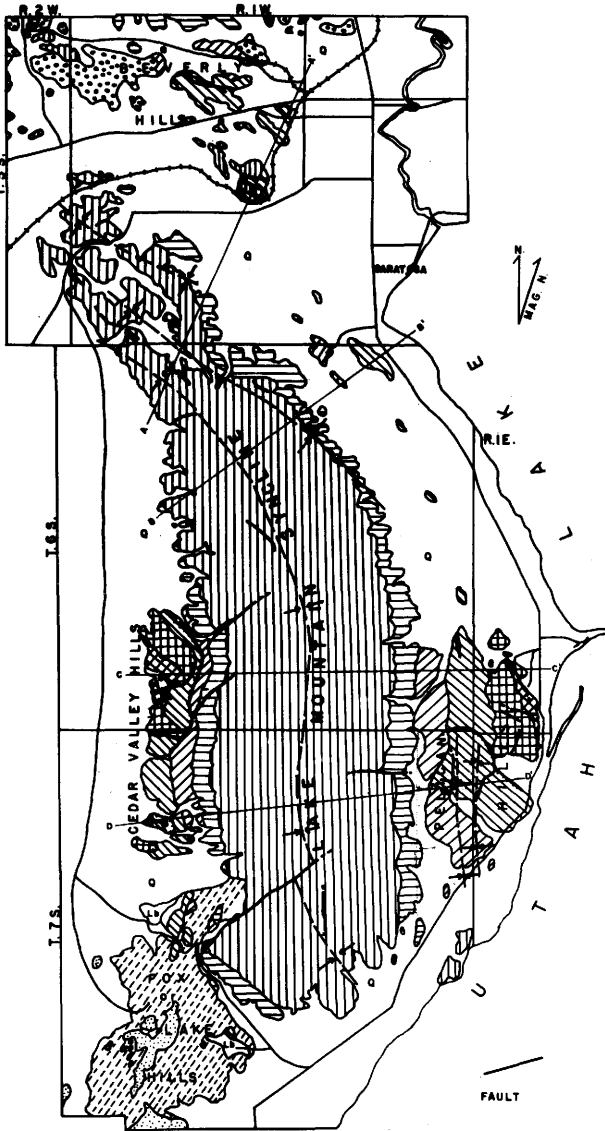
Pinyon Peak limestone

Distribution. The Pinyon Peak limestone occurs only on the western side of Lake Mountain in the Cedar Valley Hills. It outcrops just north of the mouth of Rock Canyon in a fault block that rests unconformably on the upper Humbug limestones, sandstones, and orthoquartzites. The Pinyon Peak limestone is 331 feet thick (Calderwood, 1951) as compared with 261 feet measured by Lovering (1949) in the Tintic district.

Lithology. The Pinyon Peak limestone is composed predominantly of dolomite in the Cedar Valley Hills, whereas in the Tintic District it is largely limestone. The lower contact is unconformable with the upper Humbug formation due to a thrust fault which displaced the Devonian strata upon the Upper Mississippian beds. The formation is divisible into three distinctive members. The basal beds are composed of medium to coarse-grained dolomites and limestones which weather to a sandy texture. The most distinctive beds of the Pinyon Peak limestone are the irregularly mottled dolomites which make up the middle part of this section. Both fresh and weathered rock surfaces vary from light to dark gray tints. The upper part of the Pinyon Peak limestone consists of calcareous and sugary dolomite. Silicified colonies of Syringopora and crinoid stems are common. The sugary dolomite forms a prominent light-gray ledge which contains abundant horn corals and pink chert. The upper contact of the Pinyon Peak limestone is conformable with the Gardner dolomite.



GEOLOGIC MAP of LAKE MOUNTAIN, UTAH

by KENNETH C. BULLOCK





LEGEND


SEDIMENTARY ROCKS

- QUATERNARY {  ALLUVIUM & LAKE BEDS
- TERTIARY {  UNCONFORMITY
- SALT LAKE FORMATION

UNCONFORMITY

-  OQUIRRH FORMATION


- PENNSYLVANIAN {  BASAL OQUIRRH L.S.

-  MANNING CANYON SH.

-  GREAT BLUE L.S.


- MISSISSIPPIAN {  HUMBUG FORMATION


-  PINE CANYON L.S.

-  GARDNER DOLOMITE

- DEVONIAN {  PINYON PEAK L.S.

IGNEOUS ROCKS

- TERTIARY {  BASALT

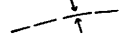
-  LATITE TUFF-BRECCIA

-  LATITE, 100% TUFF-BRECCIA

SYMBOLS

 FAULT

 THRUST, HACHURES ON UPPER PLATE

 SYNCLINAL AXES

0 .5 1 2 3 MILES

SEDIMENTARY ROCKS OF LAKE MOUNTAIN, UTAH

Age	Formation	Thickness	Lithology
Quaternary	Alluvium and lacustrine deposits Unconformity	Variable	Unconsolidated and partly consolidated gravel, sand, silt, and clay.
Tertiary	Salt Lake Formation Unconformity	400 ±	Interbedded limestones, marls, sands, and pyroclastic sediments.
Pennsylvanian	Oquirrh Formation	6334	Alternating beds of sandstones, limestones, and orthoquartzites, very subordinate amounts of shale and dolomite, prominent basal limestone member 1303 feet thick.
	Manning Canyon Shale	1121 to 1419	Dominantly black and variegated shale, orthoquartzite beds common in lower horizons, and limestone beds common in upper horizons.
Mississippian	Great Blue Limestone	2590	Massive to thin-bedded, blue-gray limestone, 91 foot shale near the base, upper horizons contain abundant chert.
	Humbug Formation	1034	Alternating sandstones, limestones, and orthoquartzites. Limestones near the base are encrinal and cross-bedded, limestones near top are lithographic.
	Pine Canyon Limestone	751	Limestone containing large resistant bands of chert parallel to the bedding. Chert in the upper horizons occurs in small bands and nodules.
	Gardner Dolomite	574	The basal member consists of sugary dolomites. The upper member is primarily fossiliferous limestones containing good guide fossil <i>Euomphalus</i> .
Devonian	Pinyon Peak Limestone	331	Mottled dolomite, and sugary textured dolomites predominate. Some calcareous dolomites are present.

Correlation and Age. The type locality for the Pinyon Peak limestone is the Tintic district and was described by Lindgren and Loughlin (1919). Little correlation has been attempted regarding this formation, except for the recent work of Lovering (1951). His work has resulted in a re-definition regarding the stratigraphic position of this formation. According to Lovering the Pinyon Peak limestone had been faulted below the Victoria quartzite and was unknowingly mapped by Loughlin and Lindgren in that sequence. Lovering's corrected section places the Victoria below the Pinyon Peak and assigns the latter formation to Upper Devonian. Syringopora, spiriferid brachiopods, and other fossils may be useful in correlating this unit with better known Devonian sections outside Lake Mountain. The tentative correlation is with the Jefferson dolomite as described by Gilluly (1932).

Mississippian System

Gardner Dolomite

Distribution. The Gardner dolomite is the oldest of the Mississippian rocks, and similar to the Pinyon Peak limestone, occurs only on the western side of Lake Mountain in the Cedar Valley Hills. Two outcrops of this formation are found in the Cedar Valley Hills, namely, in the vicinity of the mouth of Rock Canyon and at the southern end of the Cedar Valley Hills. Both outcrops are associated with thrust masses. At Rock Canyon the Gardner dolomite rests unconformably on the upper Humbug beds, whereas at the southern end of the Cedar Valley Hills it rests unconformably over the Great Blue limestone.

Lithology. The Gardner dolomite rests conformably over the Pinyon Peak limestone, and is divisible into two main lithologic units. The basal rocks consist of sugary dolomites that are coarse grained and dark gray-blue in color. This member is 150 feet thick. The upper beds of the Gardner dolomite are typical biostromal limestones containing spiriferid brachiopods, zaphrentid corals, and numerous gastropods of the genus Euomphalus (Calderwood, 1951). The coral Lithostrotionella is also present. The upper contact is drawn at the base of the first cherty limestones. The upper member of the Gardner dolomite is 424 feet thick, and the total thickness of this formation in the Cedar Valley Hills is 574 feet.

Correlation and Age. The Tintic District is the type locality for the Gardner dolomite (Lindgren and Loughlin, 1919). The faunal assemblages and lithology of the Cedar Valley Hills correlates closely with the Tintic District. (Gilluly (1932) suggests that the Madison of the Oquirrh Range can possibly be correlated with the Gardner dolomite of the Tintic District. On the basis of lithology, index fossils, and stratigraphic position this formation can be referred to lower Mississippian age.

Pine Canyon Limestone

Distribution. The Pine Canyon limestone occurs on both sides of Lake Mountain, both in the Cedar Valley Hills and in the Pelican Hills. The best outcrops occur near the northern end of the Cedar Valley Hills, where a complete section of undisturbed strata are present. In the Pelican Hills the Pine Canyon limestone can be traced for one and a half miles, yet the areal outcrops do not exceed one-fifth of one square mile.

Lithology. The Pine Canyon limestone is characterized by an abundance of chert that is present throughout the entire formation in the Cedar Valley Hills. The chert occurs in bands that are parallel to the bedding. The chert bands range in thickness from one inch to six inches, and are separated by dark blue-gray to dark gray limestones from six inches to more than one foot thick. The chert is more resistant to weathering than the limestone and stands out in relief as distinctive bands. In the Pelican Hills the Pine Canyon lithology somewhat closely resembles the Deseret limestone, the upper horizons are characteristically dolomitic and cherty, whereas the lower horizons are fine-grained to coarsely crystalline limestone. The upper contact of the Pine Canyon limestone is conformable with the overlying Humbug formation. The contact is drawn at the base of the first sandstone bed that occurs in the section. The total thickness of the Pine Canyon limestone is 751 feet (Calderwood, 1951).

Correlation and Age. The Tintic District is the type locality of the Pine Canyon limestone (Lindgren and Loughlin, 1919) and is referred to by them as being Madison in age. Rigby (1949), Williams (1951), and Hoffman (1951) have mapped the Pine Canyon limestone in the area between the Tintic District and Lake Mountain. Foraminifera of the genus Endothyra were collected in the Cedar Valley Hills by Calderwood (1951) and identified by Thompson and Zeller of the University of Wisconsin. They assign these fossils tentatively to the lower Meramec.

Humbug Formation

Distribution. The Humbug formation is well exposed both in the Pelican Hills and Cedar Valley Hills. Three prominent ridges are present in the Pelican Hills, of which the eastern-most one consists largely of the Humbug formation. The Humbug formation forms some prominent outcrops in the Cedar Valley Hills, especially at the northern end.

Lithology. The Humbug formation consists of interbedded light to medium-brown sandstone, orthoquartzite, and light brownish-gray, fine-grained dolomites, and dark blue-gray limestones. The lower boundary of this formation is placed at the base of the first sandstone member. The beds have a distinct lithofacies change, and often the sandstones grade into sandy limestones that are difficult to distinguish except by acid tests. The lower 150 feet of beds are characterized by sandy limestones and several encrinite and fossil hash beds. Many beds of sandstone and orthoquartzite

display prominent cross-bedding. Dark blue-gray limestones and light buff-colored dolomites alternating with limy orthoquartzites are typical of the middle Humbug formation. The sandstone and quartzites are more abundant than the carbonates. The limestones are commonly fine-grained lithographic limestones in the upper part of this formation. The upper contact is placed at the top of the highest considerable group of sandstone beds. The Humbug formation varies from 680 feet to 1134 feet thick. The thickest section is in the Cedar Valley Hills, whereas the thinner section occurs in the Pelican Hills where a portion of this formation may be eliminated by faulting.

Correlation and Age. The Humbug formation was named by Tower and Smith (1899) from their studies in the Tintic District. This formation was named for a mine formerly known as the Humbug mine, but now known as the Uncle Sam mine. The Humbug is correlated largely upon lithology since it is the most distinctive and characteristic feature of the formation. It is easily correlated with similar lithologic units in the Tintic, Oquirrh, and Wasatch Mountains.

Great Blue Limestone

Distribution. The Great Blue limestone is widely distributed around the main Lake Mountain mass. It extends for the full length of the Cedar Valley Hills on the western side of Lake Mountain; and on the eastern side of this range it crops out as the main ridge of the Pelican Hills. The Great Blue limestone can be traced northward from the Pelican Hills in a series of small outcrops completely surrounded by alluvium. It is also exposed in a series of low outcroppings in the Beverly Hills.

Lithology. The Great Blue limestone consists of massive to thin-bedded blue-gray limestone. It contains considerable chert, some sandy limestone, and shale. The only complete section of the Great Blue limestone occurs in the Pelican Hills where 2590 feet of rocks occur. The basal beds of the Great Blue limestone consist of light to medium gray-blue fossiliferous limestones containing abundant bryozoans of the fenestellid type and measure about 328 feet thick. A 91 foot thick shale overlies the fossiliferous limestones. The shales vary from black to variegated colors, and form valleys where exposed. The thick upper Great Blue limestone measures 2171 feet and consists of massive to thin-bedded blue-gray limestone with considerable chert.

Correlation and Age. The Great Blue limestone was named by Spurr (1895) from its exposures in the Mercer Mining District. The name has no geographic significance, yet the name has become firmly established for the upper Mississippian limestones in central Utah. The formation is easily correlated with its counterpart in the Oquirrh and Wasatch Mountains, although the Great Blue is somewhat thinner in Lake Mountain than it is in the Oquirrh Mountains. Girty (Gilluly, 1932) assigns the Great Blue limestone to Brazer. Microfossils and the brachiopod Chonetes chesterensis were studied by Calderwood (1951) in the Cedar Valley Hills where the rocks are Meramec in age.

Mississippian and Pennsylvanian Systems

Manning Canyon Shale

Distribution. The Manning Canyon shale crops out in a narrow band from Wiley Canyon southward to Mercer Canyon on the west side of Lake Mountain. Here it produces the strike valley between the main Lake Mountain mass and the Cedar Valley Hills. Three small outcroppings are also found to the south of Mercer Canyon. On the east side of the range, in the Pelican Hills, the Manning Canyon shale shows a similar relationship to that in the Cedar Valley Hills. Poleline Draw has been produced by the erosion of the Manning Canyon shale, but in addition this formation produces the western-most of the three ridges in the Pelican Hills. Northward from the Pelican Hills the Manning Canyon shale can be traced in a small series of outcrops, two of the most prominent ones are in section 34, T. 5 S., R. 1 W., and extending into section 3, T. 6 S., R. 1 W. Several outcrops are also found in the Beverly Hills to the north of Lake Mountain.

Lithology. The Manning Canyon shale is composed predominantly of shales, although it contains several beds of sandstone, orthoquartzite, and limestone. Gilluly's (1932) measurements of the Manning Canyon shale range from 750 to 1,140 feet. The western side of Lake Mountain has 1,121 feet of Manning Canyon shale and the eastern side has 1,419 feet. Baker (1947) measured 1,645 feet in the Wasatch Mountains. These measurements suggest that this formation thickens toward the east, that it includes larger particles toward the east and that the sediments were derived from the east. The shale beds range from black to multi-colored hues, and are likely derived from a thick soil cover developed on the elevated lands to the east. The thickest shale member observed in the Manning Canyon formation occurs at its base in the Cedar Valley Hills and measures 316 feet thick. The quartzites are typically brown in color and scintillating due to tiny reflecting crystal faces of quartz. The quartzite horizons are most abundant in the lower horizons of the Manning Canyon shale. The thickest observed member of orthoquartzite in the Cedar Valley Hills is 94 feet, and in the Pelican Hills thicknesses of 92, 58, and 36 feet were measured for various members. Orthoquartzite is more abundant in the Pelican Hills than in the Cedar Valley Hills. The limestone members are fine-grained, black, and carbonaceous. The limestone members are largely restricted to the upper horizons of the Manning Canyon shale. In the Pelican Hills the thickest limestone member is 20 feet, whereas in the Cedar Valley Hills one member attains a thickness of 94 feet. The lower boundary of the Manning Canyon shale is drawn where the Great Blue limestone passes into a predominantly shale unit. The upper boundary of the Manning Canyon shale is drawn where the Manning Canyon shale passes into a predominantly sandy or limestone unit.

Correlation and Age. The Manning Canyon shale is unusual in that the boundary between the Mississippian and Pennsylvanian periods lies within the formation. Abundant fossils were obtained from this formation in the Oquirrh Mountains by G. H. Girty and

J. Gilluly (1932). Mr. Girty's studies showed that the Manning Canyon shale is in part upper Mississippian and in part Pennsylvanian. Poor exposures, lack of distinctive beds, and few good fossiliferous horizons make positive separation of the Pennsylvanian and Mississippian portions of the formation difficult if not impossible. The Manning Canyon shale was therefore mapped as a lithologic unit of two different ages. The Manning Canyon shale is lithologically easily recognized in the Oquirrh and Wasatch Mountains.

Pennsylvanian System

Oquirrh Formation

Distribution. The Oquirrh formation is not only the thickest stratigraphic unit in Lake Mountain, but also has the greatest areal distribution. The main Lake Mountain mass is composed entirely of this formation. In addition this formation occurs in parts of the Beverly Hills and in two small exposures south of the Pelican Hills.

Lithology. The Oquirrh formation consists of great masses of alternating limestones, sandstones, and orthoquartzites. The Oquirrh formation is at least 8,000 to 10,000 feet thick in the Bingham District (Boutwell, 1905). In the Stockton and Fairfield quadrangles, to the south of the Bingham District, measurements are in excess of 15,000 feet (Gilluly, 1932). Measurements made in the south-central Wasatch Mountains exceed 26,000 feet (Baker, 1947). The Wasatch Mountains record by far the greatest measurements of the Oquirrh formation. The total thickness of this formation in Lake Mountain is over 6300 feet. Two distinctive units are readily mapped in the Oquirrh formation. The basal member, lying conformably over the Manning Canyon shale, is herein referred to as the basal Oquirrh limestone, and was mapped separately from the overlying beds of the Oquirrh formation. The basal Oquirrh limestone consists of a basal member of orthoquartzite 154 feet thick, overlain by 1149 feet of limestones which contain three relatively small orthoquartzite beds. The limestone is medium-gray to dark-gray, thin-bedded to thick-bedded, and contains considerable quantities of chert, especially in the upper half of this member. West dipping outcrops of the basal Oquirrh limestone are found along the eastern base of the main mountain mass for practically its full length. The western base of the range has eastern dipping exposures, that are found in the area adjacent to the Cedar Valley Hills. A third outcropping is found along the southern end of Lake Mountain. The part of the Oquirrh formation above the basal limestone member is composed of interbedded limestone, sandy limestone, calcareous sandstone, sandstone, and orthoquartzites. The quartzite and sandstone are gray to buff where fresh, and weather brownish hues. Both silica and calcareous-cemented quartzites are common. On weathered surfaces the orthoquartzites appear to be cemented with silica, but where fresh they often contain considerable calcite. The portion of the Oquirrh formation that overlies the basal Oquirrh limestone is divisible into four rather distinct members. The lowest member, overlying the basal Oquirrh limestone, consists of interbedded blue-gray limestone, orthoquartzite, and sandstone, measuring 2826 feet thick.

This is overlain by 1516 feet of predominantly gray to buff orthoquartzites. The third member is composed of 414 feet of blue-gray, thin-bedded, fossiliferous, cherty limestone. The uppermost member of the Oquirrh formation exposed in Lake Mountain consists of interbedded orthoquartzites, sandstones, and thin beds of limestone, and measures about 275 feet thick.

Correlation and Age. The Oquirrh formation of Lake Mountain contains many lithofacies that are common to the Wasatch Mountains and to the type locality mapped by Gilluly (1932) in the Oquirrh Mountains. The sandstone and orthoquartzite beds are decidedly lenticular and could not be used for correlation with other areas, the limestones on the other hand are rather continuous and could be very useful in correlation. It is probable that the much thinner Weber quartzite of the Wasatch Mountains may be correlated with some parts of the Oquirrh formation.

Tertiary System

Salt Lake Formation

Distribution. The Salt Lake formation occurs only at the southern end of Lake Mountain in the Fox or Lake Hills. Approximately 400 feet of sediments are exposed in this area, the best outcrops occur on the eastern side of this area.

Lithology. The Salt Lake formation consists of marls, limestones, sands, clays, and pyroclastics. These deposits are intimately interbedded. The limestone members are most abundant. Many outcrops of the limestone are dense and hard, whereas others are loose and friable. Platy, concentric, and porous varieties are present. On fresh fractures the limestone is white, whereas on weathered surfaces it is light-gray, buff, tan, pink, pale blue, and reddish-brown. The limestone is in part travertine deposited from thermal waters. A 20-foot bed of clay is mined commercially. Sharp (1950) regards the clay to be of sedimentary origin. Crawford and Buranek (1948) consider the clay to be altered volcanic ash, the alteration of which was accomplished by ground waters. The writer regards the clay to be a hydrothermally altered volcanic tuff bed of the Salt Lake formation. The pyroclastic sediments and sands are decidedly lenticular and variable in thickness, and are largely water-laid. These beds are laminated, sorted into coarse and fine layers, and occasionally larger fragments are arranged in lenses. Certain horizons of the volcanic deposits have been altered to halloysite and endellite, clay minerals of commercial value.

Correlation and Age. The Salt Lake formation of the Lake Mountain area is correlated lithologically with outcrops along the Jordan Narrows (Marsell, 1931), with two small exposures near Payson (Bissell, 1948), and with the large outcrops of materials in southern Idaho and northern Utah (Wilmarth, 1938).

Quaternary System

Pre-Bonneville Fanglomerates

The pre-Bonneville alluvial deposits are commonly regarded as Pleistocene in age. They are well exposed as alluvial aprons at the base of Lake Mountain, and extend for several miles into the valleys. Fanglomerates are best preserved on the west side of the range, particularly adjacent to Wiley and Mercer Canyons. The fans are composed of poorly sorted, angular to subrounded boulders, cobbles, and pebbles in a sand and silt matrix. Some exposures of the fanglomerates show lenticular bedding and fair to poor sorting.

Lake Bonneville Sediments

The deposits that were laid down in Lake Bonneville are divided into three formations, each of which represents a different stage in the level of the lake. Gilbert (1890) referred to these as the Intermediate, Bonneville and Provo stages of Lake Bonneville. Recently Hunt and Bissell (1948) have classified the Lake Bonneville deposits of Utah Valley into the Alpine, Bonneville, and Provo deposits. No attempt was made by the writer to separate these formations in the Lake Mountain region. A brief description of the stratigraphy of these formations, however, is given below.

The oldest of the Lake Bonneville deposits is the Alpine formation. Gilbert used the name Intermediate to refer to the lake stage represented by these deposits, the name having been derived from the fact that they are intermediate in position between the Provo and Bonneville levels. The name Alpine formation was introduced by Hunt from the town in northern Utah Valley, around which the formation is abundantly and typically exposed. The Alpine formation contains a high proportion of fine-textured sediment, mostly silt. Sorting is excellent and the bedding is distinct. The formation commonly weathers yellowish-gray. The eastern side of Lake Mountain displays some Alpine deposits.

The Bonneville formation includes those deposits that accumulated in the Lake at its highest stage. It forms a thin and discontinuous beach deposit along the high shoreline. It is gravel, containing some cobbles and boulders in a sandy matrix. Deposits of this formation are patchy, but encircle Lake Mountain.

The youngest of the Lake Bonneville deposits is the Provo formation. It is abundantly developed along the base of the Wasatch Mountains in the form of terraces, deltas, spits, bars, beaches, and deeper-water deposits. Exposures are good and numerous. Stratification and sorting are well developed. It has been divided into four units: gravel, sand, silt, and clay members. Deposits of this formation are fairly well developed on the eastern side of Lake Mountain. No deposits of the Provo formation are found on the west side of Lake Mountain, since the waters

were drained from Cedar Valley when Lake Bonneville fell to the Provo stage.

Recent Deposits

Recent deposits are largely of fluvial origin, and consist of alluvial fan deposits, stream channel deposits, and a discontinuous mantle of boulders and finer sediment that has been washed from the mountains since the time of Lake Bonneville. Sorting and stratification of the deposits are poorly developed. The alluvial deposits made since Lake Bonneville are quantitatively small compared to the pre-Bonneville deposits. At the mouths of Israel and Clark Canyons on the east side of Lake Mountain, the present day streams have breached wave-cut terraces in the old conglomerates and are now building alluvial fans.

STRUCTURE

General Features

The main structural elements of Lake Mountain consist of one major syncline and anticline; minor folds; thrust, tear, normal and reverse faults. The bulk of Lake Mountain consists of a broad syncline, whereas the largest anticline is situated in the lowland landforms in the northeastern part of the area mapped. Small folds are located in the northeastern part of Lake Mountain proper, and in the southern portion of the Pelican Hills. The synclinal axes are shown on the Geologic Map of Lake Mountain.

Thrust faulting and tear faulting are associated with the folding in the main mountain mass. Three notable areas involved in thrust faulting include the western, eastern, and northeastern sections of Lake Mountain. These areas are referred to as the Cedar Valley, Pelican, and Beverly Hills respectively. Normal and reverse faults are widely distributed but only those with considerable displacement were mapped.

Folds

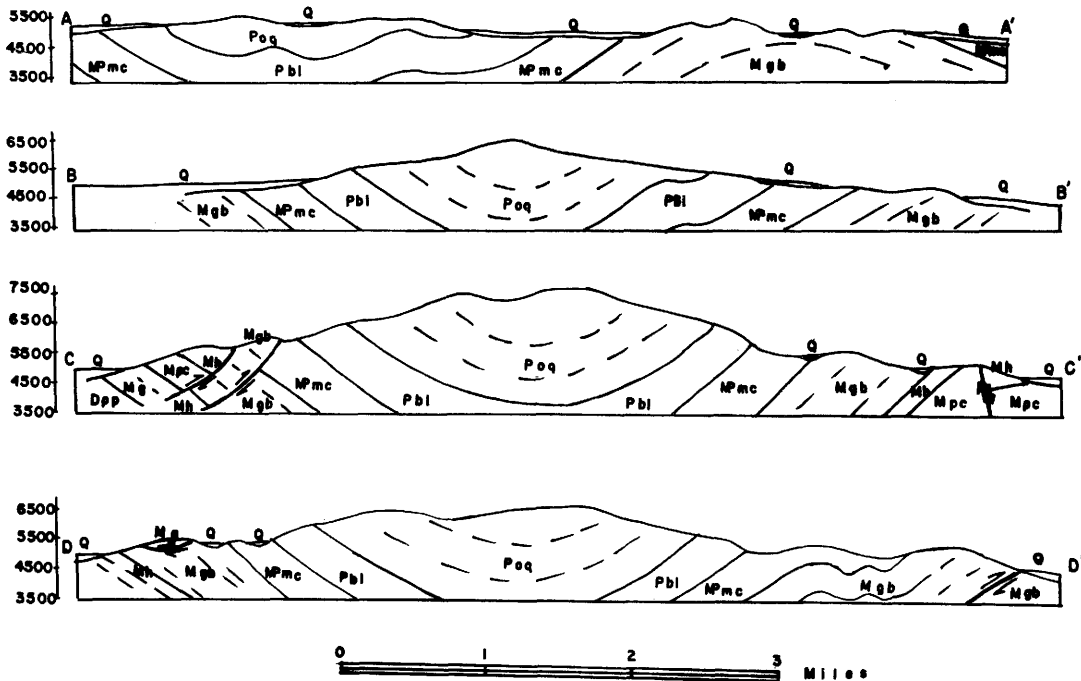
The dominant structural feature of Lake Mountain is an open downfold, here named the Lake Mountain syncline. The Lake Mountain syncline can be traced approximately eleven miles. The axis of the fold is exposed on the southeastern end of Lake Mountain in Sec. 23, T. 7 S., R. 1 W. Here the axis trends N. 27° W. for two miles where it is then displaced eastward about one-third of a mile by a tear fault. From this point the synclinal axis continues four miles true northward parallel to Mercer Canyon. The fold then swings westward trending about N. 35° W for two miles. The trend for the next three miles is about N. 55° S., the axis emerging on the northwestern end of Lake Mountain in Sections 5 and 6, T. 6 S., R. 1 W. The syncline in ground plan is, therefore, reverse S-shaped with the southern end only partly developed. The Lake Mountain syncline is slightly asymmetrical. The dip of the beds varies considerably in different portions of the fold, the maximum dip being near 55°. The fold plunges about 14° to the north. The north end of the Lake Mountain syncline is in structural continuity with the Bingham syncline in the Oquirrh Mountains, and the two appear to be parts of the same fold.

A broad anticline with a northwest trend is exposed in T. 5 S., R. 1 W. or the northern portion of the area mapped. This fold includes the northeastern outcrops of strata in Lake Mountain, the Beverly Hills, and the southern end of the Traverse Range. The axis of this fold passes through the central area of the Beverly Hills, and plunges to the northwest. Minor folding and thrust faulting somewhat complicate this upfold.

In the northern portion of Lake Mountain two smaller anticlines and two synclines lie between the Lake Mountain syncline and the western limbs of the Beverly Hills anticline. These four structural

GEOLOGIC SECTIONS OF LAKE MOUNTAIN, UTAH

SYMBOLS- Q Quaternary, Poq Oquirrh fm., Pbl Basal Oquirrh Ls., MPmc Manning Canyon Sh., Mgb Great Blue ls., Mh Humbug fm., Mpc Pine Canyon Ls., Mg Gardner Dol., Dpp Pinyon Peak Ls.



elements are all confined to the northern and northeastern end of Lake Mountain proper. The axes of these folds parallel the trend of the northern portion of the Lake Mountain syncline, approximately N. 55° W.

Close folding occurs in the southern portion of the Pelican Hills. This close folding includes a block affected by thrust faulting and involves two small synclines and two anticlines. One syncline is paralleled by a reverse fault.

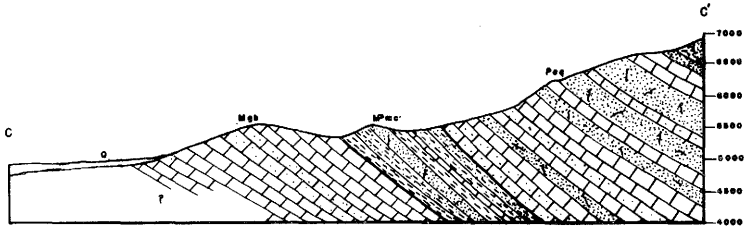
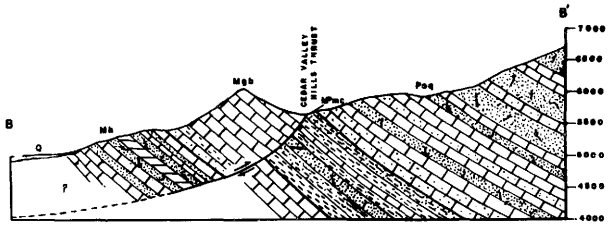
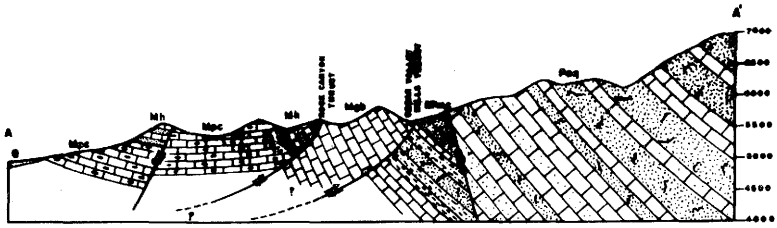
Other minor folds are found in the Pelican Hills, Cedar Valley Hills, and Beverly Hills. These represent local warps and variations in strike and dip. Many of these minor structural features are associated with faulting, and often controlled by faulting.

There is no direct evidence bearing on the age of folding in Lake Mountain. However, abundant data are present within adjacent mountains which permit rather accurate dating of various orogenic movements. The Nevadan orogeny occurred within Upper Jurassic time and formed isoclinal folds in western Nevada. The orogeny likely spread eastward and its effects are noted only in coarse clastics formed during the beginning of the Cretaceous in central Utah. The epoch of folding of the strata of Lake Mountain probably began in middle Cretaceous time. Thick beds of conglomerate, sandstone, and other coarse clastics in central and north-central Utah indicate an orogeny starting at this date. Eardley (1949) believes that this deposit, comprising the Indianola group, marks the beginning of several orogenies comprising the Laramide revolution.

The next orogeny occurred between middle and late Montana time which Spieker (1946) terms the Early Laramide orogeny. The sediments of central Utah were intensely folded along axes which in general strike north-south. Several large thrusts came into being during this period, either concomitant or late in the stage of folding. This orogeny is recorded in the intensely folded and thrust strata of the south-central and southern Wasatch Mountains, West Mountain, and Lake Mountain.

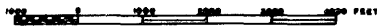
The Middle Laramide orogeny likely formed the Willard thrust sheet of northern Utah (1949). It is highly probable that some of the tear faults of Lake Mountain and surrounding ranges were formed during this orogeny. In many places in the mountains surrounding Utah Valley evidence is present indicating that some of the tear faults displace thrust sheets of earlier date. The Lake Mountain syncline is broken and one segment displaced eastward by a tear fault.

The next orogeny which occurred involves folding of some of the Basin and Range structures and is termed the Late Laramide orogeny. Eardley (1949) states that in middle or late Eocene time a system of broad, gently north-south folds was superposed over the older and divergently trending folds and thrusts to define for the first time the modern ranges and intermontane valleys of the region.



GEOLOGIC SECTIONS OF THE CEDAR VALLEY HILLS AREA

Scale $\frac{1}{12,000}$



According to Eardley the ranges of the Great Basin immediately west of the Wasatch owe most of their relief to this folding and not to the much later high angle faulting of the Basin and Range orogeny. Possibly the arcuate pattern of Lake Mountain as well as some of the uplift and tilting southward of the range may have taken place during this epoch of diastrophism.

The latest orogeny, which Eardley (1949) named the Absarokan orogeny, likely affecting Lake Mountain, occurred in latest Eocene and Oligocene time. Deformation and igneous activity characterize this movement. It was followed, perhaps with little or no great time interval, by the epoch of Basin and Range normal faulting which imparted to Lake Mountain much of its present form and relief.

Faults

Considerable faulting accompanied the folding of the strata of Lake Mountain when it was subjected to compressive forces. Where the acting stresses were greatest or where the rocks were most brittle or weakest, the strata were broken and thrust. There are three main areas in Lake Mountain where thrust faulting is prominent, namely, Cedar Valley, Pelican, and Beverly Hills areas. There is a good possibility that Lake Mountain itself is a great thrust block.

The Cedar Valley Hills possess three different thrust faults. The largest of these is the Cedar Valley Hills thrust which separates the bulk of these hills from the main Lake Mountain mass. This thrust fault can be traced for over two miles (Bullock, 1949). From the mouth of Wiley Canyon on the north end of the Cedar Valley Hills the trace of this thrust extends southeast near the bottom of the canyon and crosses a small saddle between Wiley Canyon and Rock Canyon. From here it extends south, crosses a saddle separating Rock Canyon and Wildcat Canyon, and extends southwest to a point 500 yards from the saddle where it forks. One prong extends into Wildcat Canyon, the other veers due west transversing the Cedar Valley Hills. (See Geologic Map of Lake Mountain, and Geologic Map of Cedar Valley Hills.) Between Rock and Wildcat Canyons the Cedar Valley Hills were thrust over practically all of the Manning Canyon shale, and omitted as much as a thousand feet of the Great Blue limestone along this fault. It is not feasible to measure the exact displacement of this large thrust, however, it is believed that the strata comprising the Cedar Valley Hills were thrust to their present position from an area at least one mile to the west.

The trace of the second large thrust outcrops in Rock Canyon and is referred to as the Rock Canyon thrust fault. This fault can be traced for approximately one mile. This fault is likely an imbricate slice rising from the sole of the larger Cedar Valley Hills ramp thrust. Its greatest displacement is seen near the mouth of Rock Canyon where the Pinyon Peak formation (Devonian) rests unconformably on the upper limestones of the Humbug formation. A minimum thickness of 2600 feet of lower Mississippian and Devonian strata

were omitted by this thrust. The trace of this thrust extends from near the mouth of Rock Canyon over a small spur and into the left-hand fork of Rock Canyon. From here it veers northeast up the valley and crosses a spur; thence slightly east of north to the head of the left-hand fork of Rock Canyon. At the latter locality the displacement is not nearly so great as at the mouth of the canyon.

The third area of thrust faulting in the Cedar Valley Hills occurs at the southern end. The Gardner dolomite has been thrust over the younger formations and rests unconformably on the Great Blue limestone.

Thrust faulting is also evident on the eastern side of Lake Mountain in the Pelican Hills. In this case the thrust masses have been thrown into close folds and thrust northeastward over less disturbed strata. The main thrust, here named the Pelican Hills thrust, more or less bisects the Pelican Hills. The best exposures are found in Crooked Canyon where segments of the Great Blue limestone have been thrust over itself. The Pelican Hills thrust can be traced eastward from the upper right-hand fork of Crooked Canyon across a ridge of Great Blue limestone; then it swings southeastward where it crosses Crooked Canyon. From here it passes over a saddle where the Great Blue limestone and the Humbug formation are in thrust contact, thence southeastward to the shores of Utah Lake where it passes under alluvium. This thrust fault is about one and one-half miles long. In the northwest quarter of Sec. 6, T. 7 S., R. 1 E. the thrust segment of Great Blue limestone has developed abundant gouge in which large pseudomorphs of limonite are found.

Two small thrust faults are found in the Pelican Hills. One is confined to the Humbug formation, and the other consists of a segment of Manning Canyon shale thrust over the Great Blue limestone.

The third area showing evidence of thrust faulting is found in the broad anticline in the northern part of the area mapped. The best exposures are found in Sec. 21, T. 5 S., R. 1 W. Here orthoquartzites of the Oquirrh formation are thrust over fossiliferous Great Blue limestone. The sole of the thrust is exposed. The orthoquartzite beds are near vertical to overturned and have truncated the Great Blue limestone beds that dip about 30° to the southwest. The thrust masses have moved at least two miles from the west to their present position. Thrust faulting in the Beverly Hills can be traced northwestward out of the area mapped.

Several localized areas in the Lake Mountain mass show thrust faulting. The abundance of thrust faulting indicates that it has played an important part in the formation of this range.

Tear faults are fairly well developed in Lake Mountain, two of which are very prominent. The tear fault along Long Hollow on the southwestern side of Lake Mountain can be traced for two miles. It has a horizontal displacement of approximately one-half mile, and has displaced the Lake Mountain syncline. The tear fault in

Potters Canyon on the eastern side of Lake Mountain has a displacement of about one-quarter of a mile. Many other smaller tear faults were observed in Lake Mountain proper and in the adjacent hill lands.

Normal and reverse faults are common throughout the mountain mass. Only those of large displacement have been mapped. One of the largest normal faults occurs on the western side of Lake Mountain, which displaces the Oquirrh and Manning Canyon formations. The heave of this fault is approximately 1500 feet and the throw about 500 feet. Other normal faults in the Cedar Valley hills show displacements of 100 to 150 feet. One of the largest normal faults in the Pelican Hills has a displacement of at least 250 feet and has brought the Humbug formation into contact with the Pine Canyon limestone. This fault is of special note since it has been mineralized with calcite. Several small faults are distributed throughout Lake Mountain with displacements of only a few feet. These were not mapped since they were too small to show on the geologic map.

The main orogenic paroxysms which affected the structure of central Utah, and the order in which they occurred, were discussed under the section of "folds" in the preceding pages, and need not be repeated here.

IGNEOUS ROCKS

General Features

Only volcanic igneous rocks occur in the immediate vicinity of Lake Mountain. These rocks are found in two distinct areas, exposures occurring at the extreme northern and southern ends of the range. The western half of Beverly Hills, at the northern end of Lake Mountain, consists largely of latite flows with minor outcroppings of latite tuffs and breccias. This area includes the southernmost exposures of the large volcanic field of the Traverse and Oquirrh Ranges. The Lake or Fox Hills, at the southern end of Lake Mountain, form the second volcanic field. This area represents the northernmost outcrops of volcanics that are probably associated with those in the East Tintic District. The volcanic rocks of the Lake Hills include pumiceous latitic breccias, volcanic tuffs, and olivine basalt.

Beverly Hills

Field Relations

The volcanic rocks in the Beverly Hills were poured out on an undulating surface. In consequence of this, and the unequal distribution of the erupted materials, the volcanic rocks present different facies at its base in different parts of the area. In some areas latite breccias form the base, whereas in most areas latite flows are in contact with the sedimentary rocks. The volcanic rocks lie unconformably upon the Paleozoic rocks. In all instances the latite flow rocks are underlain by pyroclastic rocks. Quantitatively, the flow rocks predominate over the breccias in the Beverly Hills. This relationship apparently is reversed in the large adjoining volcanic field of the Traverse and Oquirrh Ranges (Gilluly, 1932). The total thickness of the volcanics in the Beverly Hills exceeds 255 feet.

General Petrologic Features

There is considerable diversity in structural and textural characters of the volcanic rocks. The flow rocks predominate, but there are several exposures of pyroclastics in the Beverly Hills. All the rocks studied are latitic in composition. Megascopic or microscopic study alone would classify them as andesites, but chemical analyses demonstrate that the potash equals or exceeds the soda, and they should be classified as latites. No attempt was made to map the flows and pyroclastics separately.

Latite Tuffs and Breccias

The exposures of latite tuffs and breccias show little or no stratification. The rock fragments composing the pyroclastics range from dust-like particles to those 8 inches in diameter. The most abundant fragments are medium-gray to purplish-gray porphyritic latite. Plagioclase, biotite, and hornblende are recognizable as

phenocrysts. The pyroclastic rocks weather to a light-gray color, considerably lighter in hue than the latite flow rocks. No beds of true tuffs were found in the exposures of pyroclastic rocks; however, dust-like particles are abundant and intermixed with the coarser fragments. The maximum thickness attained by the latite pyroclastic rocks is 75 feet in the area mapped.

Latite Flows

The lava in the Beverly Hills consists of biotite-hornblende latite. It forms most of the knolls in the western part of these hills. The latite flows overlie the latite pyroclastics. The principal variety of latite is a light-gray porphyritic rock. Weathering produces various hues of red, purple, and brown. Plagioclase forms the largest phenocrysts ranging from 1 to 7 millimeters, whereas biotite phenocrysts rarely exceed 2 millimeters in diameter. These minerals are set in a glassy to cryptocrystalline groundmass. Flow structures are commonly visible in hand specimens and field exposures.

In thin-sections the plagioclase crystals show zoning, and are twinned according to the albite, percline, and Carlsbad laws. The extinction angles and indices are those of oligoclase-andesine. The plagioclase laths of the groundmass are somewhat more sodic than the phenocrysts. The principal ferromagnesian mineral present is basaltic hornblende. It is strongly pleochroic (X light yellow-green, Z dark reddish-brown). It occurs chiefly in elongated prismatic crystals. The extinction angle is small and variable, ranging from 0 to 10° . The mineral is optically negative. Biotite is much less prominent than hornblende. It is pleochroic (Z deep red-brown, X light greenish-brown). Augite is found as minute crystals and is light green in color. The accessory minerals include magnetite, apatite, zircon, and iron oxides.

None of the rock sections observed carry recognizable orthoclase, and from a purely mineralogical classification the rocks would be classified as andesite. The glassy to cryptocrystalline groundmass, however, contains so much potash that the rock proves on chemical analysis to be as high in potash as in soda and falls into the group of latites. The conclusion seems inevitable that if the rocks were entirely crystalline orthoclase would be a prominent constituent, comparable quantitatively to the plagioclase. Accordingly, the rocks are classified as latites. Chemical analyses showing these relationships are given below.

Partial analyses of latites from central
Utah, and an average latite

	1	2	3
SiO ₂	62.53	61.09	57.65
CaO ²	4.61	4.70	5.74
Na ₂ O.....	3.59	3.00	3.59
K ₂ O.....	2.85	3.77	4.16

1. Biotite-hornblende latite from the Beverly Hills, north end of Lake Mountain, Utah. Erma Chadbourn, analyst.

2. Augite-biotite-hornblende latite from Oak Spring Canyon, Fairfield Quadrangle, J. G. Fairchild, analyst.
Gilluly, J., U.S.G.S., Prof. Paper 173, p. 46, 1932.

3. Average latite. Daly, R. A., Igneous Rocks and the Depths of the Earth, p. 13, New York, 1933.

Lake or Fox Hills

Field Relations

The pyroclastic rocks of the Lake Hills at the southern end of Lake Mountain were deposited on an undulating topography, and show an unequal distribution and variable thickness of materials. Volcanic breccias were the first materials erupted, and they lie unconformably over Paleozoic sedimentary rocks. They are rather limited in their areal extent, since only two outcrops were found in the area mapped. The breccias may have a wider distribution, but they are covered by younger rocks. A series of interbedded limestones and volcanic tuffs overlies the volcanic breccias, and are unconformable with the Paleozoic rocks. This series of rocks form the bulk of the materials in the Lake Hills. The youngest rocks in the area are represented by volcanic flows of basalt.

General Petrologic Features

Both pyroclastic and flow rocks are present in the Lake Hills. The pyroclastics are latitic in composition, and contain a considerable quantity of pumiceous materials. The flow rocks are basic in composition. The principal variety is basalt porphyry containing phenocrysts of plagioclase and olvine. Aphanitic basalt is also common.

Latite Breccias

The latite breccias are confined to two main areas, one at the northern end of the Lake Hills and one at the eastern side. They represent the oldest of the volcanic rocks in this area, and they lie unconformably on Paleozoic rocks. The maximum thickness of these rocks does not exceed 75 feet. The breccias have been used commercially for the production of cinder blocks.

The latite breccia consists of variable particles ranging from dust-like particles to blocks 16 inches in diameter. The most abundant fragments are blocks of pumice, which give the rock satin sheen. Biotite, hornblende, and plagioclase form the only recognizable phenocrysts. Some obsidian fragments are present. One small exposure associated with the volcanic breccia consists of vitrophyre.

Basalt Flows

A basalt flow overlies the limestone and volcanic tuff deposits in the Lake Hills. The chief rock type is a porphyry with fine-grained matrix of almost black color. The only minerals visible megascopically are phenocrysts of plagioclase measuring up to 6 millimeters, and smaller phenocrysts of olivine. Basalt, olivine basalt, vesicular basalt, scoria, amygdaloidal basalt, and brecciated basalt types are present, although the latter ones are not abundant.

In thin-section the rock contains micro-phenocrysts of olivine as much as 1 millimeter in length, and of augite as much as 1.5 millimeters in length. Plagioclase crystals vary from tiny lath-shaped crystals to those of large megascopic dimensions. The feldspar is of the labradorite variety, and forms the most conspicuous phenocrysts of the basalt. Two generations of plagioclase are apparent. The first generation consists of large subhedral to euhedral phenocrysts of plagioclase. They are somewhat more calcic than the small lath-shaped crystals of the matrix. Most phenocrysts of plagioclase show broad twinning lamellae; some in addition show Carlsbad twinning. A few phenocrysts show good zonal structure. The second generation of plagioclase forms the groundmass and consists of lath-shaped crystals and irregular forms. Twinning is parallel to the elongation of the plagioclase laths. Augite is the second most abundant minerals present. It occurs as tiny single crystals and grouped in aggregates resembling phenocrysts. It has a pale-green to pale-brown color. The pleochroism of augite is absent to weak, whereas the birefringence is rather strong and the relief high. Olivine occurs in rounded to subhedral grains, showing the characteristic rough cleavage. The olivine shows alteration to light-greenish serpentine and to brownish-red iddingsite. Magnetite is a very conspicuous accessory. It occurs in euhedral, subhedral and irregular masses. Other accessory minerals include biotite, apatite, and iron oxides.

The maximum thickness of the basalt in the area mapped is 71 feet. Originally they may have been much thicker, and had a much wider areal distribution than at present. The basalt flows extend southward of the area mapped, and cover approximately and equally large area as found in the Lake Hills.

A partial chemical analysis of the basalt flow in the Lake Hills is given below.

Partial Analyses of Basalts from Utah
and an average basalt

	1	2	3
SiO ₂	47.85	54.79	48.78
CaO.....	9.45	8.13	8.91
Na ₂ O.....	2.72	2.97	3.18
K ₂ O.....	3.09	1.16	1.63

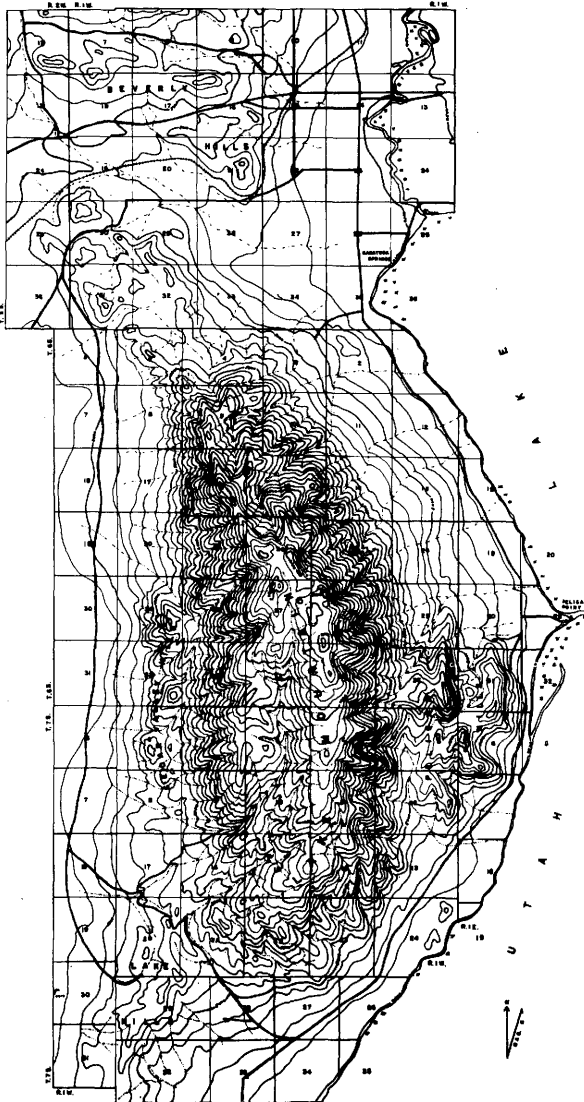
1. Basalt from the Lake (Fox) Hills, southern end of Lake Mountain, Utah. Erma Chadbourn, analyst.
2. Basalt from southern end of Pilot Range, Utah. R.W. Woodward, analyst. Hague, A., and Emmons, S.F., Descriptive Geology, U.S. Geol. Expl., 40th par., Vol. 2, p. 500, 1877.
3. Basalt. Daly's average of 161 rocks called basalt. R.A. Daly, Proc. Am. Acad. Sci., XLV, p. 224, 1910.

Regional Relations of the Volcanic Rocks

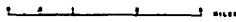
The volcanic activity observed in the western half of the Beverly Hills is areally, stratigraphically, and petrographically related to the volcanism recorded in the Traverse and Oquirrh Ranges. The sequence of volcanics in both areas includes the deposition of latite breccias and tuffs followed by latite flows. It is interesting to note that this same sequence of fragmental deposits overlain by flows is characteristic of many localities in western Utah. It is likewise noteworthy that there is a widespread regional similarity in chemical composition of the volcanics of the State. Chemically the volcanics are largely latites. This similarity of composition must reflect a regional magmatic character.

Greater difficulty is encountered in correlating stratigraphically the volcanic activity of the Lake Hills with those of the East Tintic District, to which they are related areally and petrographically. In a broad sense the volcanic sequence of the Tintic District may be divided into three units: (1) a "rhyolite" phase, (2) a latite phase, and (3) a basaltic phase. The earliest volcanics of major importance were described by Loughlin (1919) and others as the Packard rhyolite, but it actually is a biotite-quartz latite (Morris, 1947). The Packard consists of a lower tuff, a thick middle section of massive flows, and an upper vitrophyre phase. The latite sequence is characterized by heterogeneous deposits of tuffs, breccias, and volcanic agglomerates which are overlain by a series of andesites and latites of considerable thickness. The basaltic sequence of activity is found only in the southern part of the Tintic quadrangle.

It is assumed that the lower latite pyroclastics of the second volcanic sequence of the Tintic District may possibly be correlated with the pumiceous tuffs and breccias of the Lake Hills. The basalt



TOPOGRAPHIC MAP OF LAKE MOUNTAIN, UTAH
By Kenneth C. Bullock



Contour Interval, = 100 Feet.

sequence of both areas is likely of the same age, and represents the end of the volcanic cycle.

Age of Volcanism

The specific age of the volcanism from evidence available in the Lake Mountain area cannot be determined closely. However, the volcanic rocks of this region are younger than the folding of the Paleozoic rocks and their mature dissection. At the southern part of the East Tintic Mountains (Tower, 1899) and in the southern Wasatch Mountains (Eardley, 1933) the volcanism was later than the Wasatch conglomerate of Eocene age. Gilluly (1932) regards the volcanism as late Eocene and Oligocene in the Oquirrh Mountains.

The volcanism is older than the block-fault orogeny as indicated by the deformation of the flows both in the Lake Mountain area and in the Oquirrh Mountains. The general opinion of most geologists who have worked in the Basin-Ranges is that the Basin-Range orogeny became active during the Miocene. Therefore, the age of the volcanism can be tentatively assigned to the late Eocene and possibly continued throughout much of the Oligocene epoch.

GEOMORPHOLOGY

General Features

Lake Mountain is one of the eastern ranges of the Basin and Range Province, forming one of the first mountain masses west of the south-central Wasatch Mountains. Lake Mountain and its surrounding area belongs hydrologically to the Great Salt Lake Basin, or that part of the Basin and Ranges that drains into Great Salt Lake.

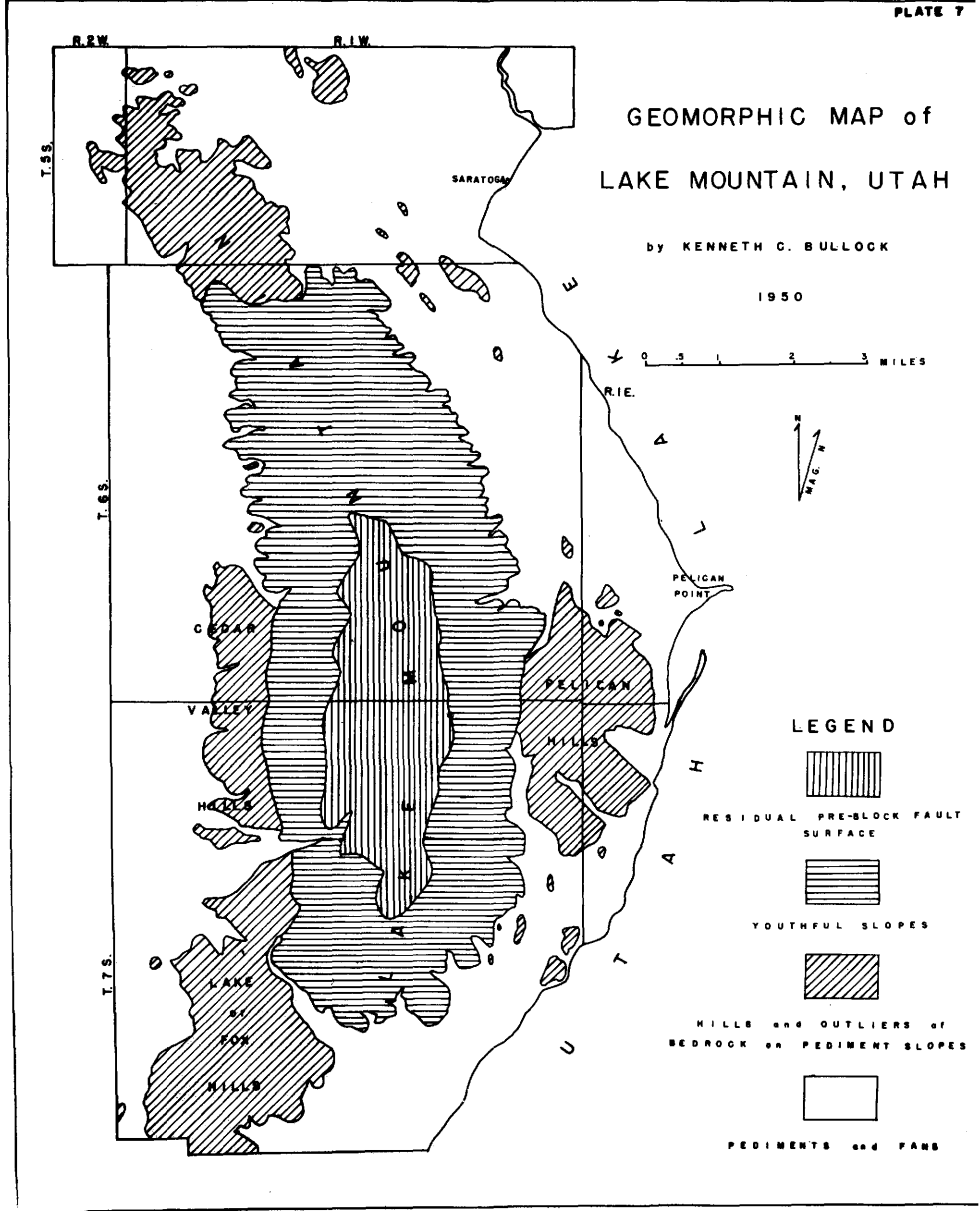
The present topography of Lake Mountain and the surrounding area are largely the products of erosional processes. The Lake Mountain block itself was outlined during the early part of the Basin and Range orogeny; however, the present mountain front is not a fault scarp but a product of erosion. The landforms of this range can be classified into four groups: (1) mountain and hill (2) pediments; (3) bajadas and fans; and (4) Lake Bonneville landforms. The first two groups are the products of erosion; the third group is depositional; and the latter group is both erosional and depositional.

Mountain and Hill Landforms

Lake Mountain

Lake Mountain is a north-south trending range that is slightly crescent-shaped. It is a true block-fault range as demonstrated by the following physiographic evidence: (a) the summit area possesses a mature topography, yet it is bounded on either side by steep slopes and youthful V-shaped canyons. (b) The mountain front is linear, although it cuts indiscriminately across rock structure. The axis of the Lake Mountain syncline is exposed on the southeastern side of Lake Mountain and emerges on the northwestern side. Similarly, the axes of two smaller synclines and anticlines in the northern portion of Lake Mountain can be traced from the eastern side of the range across Lake Mountain and emerge on the western side of the range. (c) The range rises abruptly from the structural valleys. (d) The lowest portion of Utah Valley is adjacent to Lake Mountain and is occupied by Utah Lake.

Lake Mountain is composed of two types of landforms: (a) an old subdued surface; and (b) youthful slopes. The old subdued surface is well preserved on the summit area of Lake Mountain. This surface is 7 miles long and has a maximum width of nearly 2 miles. The local relief is a few hundred feet. This old residual surface is now bounded by steep slopes and youthful canyons. It is believed that this landform development is, in a large part, a residual pre-block fault topography. The Lake Mountain block was tilted southward during the Basin-Range orogeny. This is indicated by the southward slope of the residual old land surface on the summit area. This surface slopes southward from an elevation of 7600 feet at the head of Mercer Canyon to 6000 feet near the southern end of the range. The southward tilting of the Lake Mountain block is further emphasized



by the southward drainage of Mercer Canyon, the largest and best integrated drainage system in the area, and the southward drainage of Long Canyon.

There are four major events in the geomorphic development of Lake Mountain. (a) In middle or late Mesozoic time a long period of intense folding and thrusting was inaugurated, and continued into the Eocene epoch. Lake Mountain was compressed into a broad open syncline and a few minor folds. Some thrust faulting and tear faulting accompanied the folding of the strata. (b) A long interval of erosion followed the period of diastrophism, and developed a mature to submature topography. (c) The Lake Mountain block was then uplifted by the Basin-Range orogeny, hence the pre-block fault erosion surface has been uplifted and preserved on the summit area. (d) A second major erosion cycle was inaugurated after the Basin-Range orogeny ceased in Lake Mountain, as evidenced by the extensive pedimentation that surrounds most of the range.

The main Lake Mountain mass is composed of the Oquirrh formation. The interbedded character of this formation produces a slope and ledge topography. The limestone beds are resistant to weathering and generally form the most prominent ledges. The sandstone and quartzite horizons commonly develop talus rapidly forming more gentle slopes, and locally mask much of the ruggedness of the terrane. The basal Oquirrh consists largely of limestone, and consequently is the important cliff-forming horizon in Lake Mountain.

The drainage from Lake Mountain is in part interior and in part exterior as far as the immediate region is concerned. The western drainage lines are into Cedar Valley, an enclosed basin or bolson; whereas the eastern drainage lines are into Utah Lake, thence northward into Salt Lake Valley by means of the Jordan River. The drainage patterns in Lake Mountain are dendritic and trellis. There are important controls of the drainage lines along synclinal axes, faults, joints, and stratigraphic horizons.

Hills

Lake Mountain is bounded on four sides by a series of discontinuous hills. The Cedar Valley Hills lie on the western side of Lake Mountain. They are separated from the main range by an erosional valley in the Manning Canyon formation. Structurally, the Cedar Valley Hills form part of the western limb of the Lake Mountain syncline. This group of hills consists of one major north-south trending ridge, that has been dissected by drainage lines from Lake Mountain. The maximum relief in the Cedar Valley Hills is about 1150 feet. They are composed of Devonian and Mississippian formations, which in a large part form uniform slopes, except in the northern portion where many bold outcrops form a slope and ledge topography.

The Pelican Hills are found on the eastern side of Lake Mountain, adjacent to Utah Lake. This hilly region consists of three prominent ridges, and structurally belongs to the eastern limb of

the Lake Mountain syncline. The Pelican Hills have been dissected by a more or less east-west trending thrust fault. To the north of the fault the formations dip westward, and to the south they are thrown into a series of close folds. Similar to the Cedar Valley Hills, the Pelican Hills are separated from Lake Mountain by an erosional valley in the Manning Canyon formation. This formation forms the western ridge of the Pelican Hills where prominent quartzite members are exposed. The central ridge of the Pelican Hills is composed of the Great Blue limestone which forms a bold, elongate ridge with steep but smooth slopes. The eastern ridge is restricted to the area north of the thrust fault. It is composed of the Humbug formation and the Pine Canyon limestone. The interbedded character of the Humbug formation produces a slope and ledge topography. The Pine Canyon limestone forms relatively steep but uniform slopes. Crooked Canyon is the only drainage line that is independent of the drainage lines from Lake Mountain. The maximum relief in the Pelican Hills is about 1400 feet.

The northern end of Lake Mountain consists of a series of hills composed of the Oquirrh formation and are included in the Beverly Hills. The local relief is about 800 feet. The remainder of the Beverly Hills lie to the north and northeast of Lake Mountain. The eastern portion consists of lowland masses of Mississippian and Pennsylvanian rocks, whereas the western portion is largely volcanics. The local relief is about 500 feet. All the landforms to the north of the main Lake Mountain mass are subdued and gently undulating.

The Lake Hills form a north-south trending series of hills at the southern end of Lake Mountain. They are composed largely of Tertiary volcanics and limestones, but also contain a few inliers of Paleozoic rocks. The eastern side of the Lake Hills in Utah Valley has been eroded to a greater depth than the western side in Cedar Valley, since Utah Valley is over 300 feet lower. A slope and ledge topography is pronounced on the eastern side of the Lake Hills, whereas on the western side the topography is subdued and rolling.

Pediments

Distribution

The term pediment is applied to the erosional rock plains that border Lake Mountain. These carved surfaces are thinly veneered with sediments, but bedrock exposures are sufficient to demonstrate their existence almost entirely around Lake Mountain. The best exposed pediments occur on the eastern side of the range. The distribution of the pediments and their relationship to the youthful slopes and residual old land surfaces is shown on the Geomorphic Map of Lake Mountain. Because of the great difficulty in attempting to distinguish true alluvial slopes from the pediment slopes thinly veneered with sediments, both pediments and alluvial fans are shown by the same symbol.

Lake Mountain is structurally a broad syncline, and through block faulting the Manning Canyon formation was exposed on both

sides of the upfaulted block. Consequently, the processes of pediment development easily attacked these zones and eventually produced rock-cut plains. The limestones and quartzites show less tendency toward pedimentation; but in some areas they have yielded to considerable pediment development.

The outcrops of rock-cut plains on the western side of Lake Mountain are confined largely to the areas adjacent to the mountain base. Considerable alluvial fan development has veneered the pediments, but good exposures of rock-cut plains are found near the mouths of the drainage lines. Only a few scattered outcrops of bedrock beneath the bajadas and fans indicate the presence of an alluvium-covered pediment. Most of the rock-cut plains are associated with the Manning Canyon formation, but some planation has taken place on the Oquirrh formation.

The broadest, and best developed, pedimentation occurs on the eastern side of Lake Mountain from the Pelican Hills northward. The main mountain mass consists of the Oquirrh formation. The pediment and bajada belt are underlain by the Manning Canyon formation and the Great Blue limestone. These two formations parallel the main mountain range, the shale (Manning Canyon) forming the zone adjacent to the mountain base. The pediment slopes are veneered by alluvium, but bedrock exposures are numerous. Several commercial clay pits have been opened on the pediment slopes on the northeastern side of Lake Mountain. The planation of the Manning Canyon formation is consistently more complete and uniform than that of the Great Blue limestone. The Great Blue limestone characteristically forms islands of bedrock above the general surface of the pediment slopes.

The pediments on the eastern side of Lake Mountain extend approximately two miles from the mountain front, and are believed to terminate roughly parallel to the western shore of Utah Lake. This shore is marked by a series of thermal springs that likely mark the position of old fault lines. A similar relationship on the western side of Lake Mountain is lacking, but there is good evidence that some pediments extend at least one mile from the mountain front.

Shape in Cross-Section

In cross-section the pediments of Lake Mountain show both convex and concave outlines. These features are referred to as fan-shaped and trough-shaped pediments. The origin of such outlines has long been a geomorphic problem. The writer was able to arrive at an origin for both of these types of pediments that surround Lake Mountain. These principles may be applicable to other areas showing pedimentation.

A trough-shaped pediment is best shown at the southern end of the Pelican Hills on the eastern side of Lake Mountain. Here the pediment has extended itself from the valley into Pole Line Draw. The pedimentation has been confined chiefly to the Manning Canyon formation. The shale of this formation consists of fine, friable,

and easily weathered products. Consequently, by means of rill wash, and weathering with subsequent removal of detritus by rills, the process of pedimentation has extended itself headward into Pole Line Draw. Similar trough-shaped pediments are found at the north end of the Pelican Hills and in the Cedar Valley Hills. In each case the concave outline is developed in shale. Hence, the nature of the bedrock is an important factor in the determination of the outline of pediments. Rill action is common on shaly slopes. The writer, therefore, is led to conclude that the trough-shaped pediments in Lake Mountain are associated with soft and friable rocks, and developed by the processes of rill wash and weathering with removal of detritus by rill wash.

A fan-shaped pediment is well shown at the mouth of Israel Canyon on the northeastern side of Lake Mountain. The convex outline has been developed largely on the basal Oquirrh limestone. The limestone contains sandy and shaly portions, yet it presents a hard and relatively resistant rock to erosive processes. Such rock masses cannot be expected to respond to rill wash, but rather to lateral planation by the streams issuing from the canyons. Fan-shaped pediments occur both on the eastern and western side of Lake Mountain. In each case they are confined principally to the Oquirrh formation, and show the fan-form best near the mouths of the canyons. The writer is led to conclude that the fan-shaped pediments are developed on hard and less friable rocks than those associated with the trough-shaped pediments. Lateral planation by streams is considered the chief process by which fan-shaped pediments develop.

In detail the pediments are entrenched with numerous small ravines that produce in cross-section on a gently undulating surface. These ravines are of two different ages; i.e., pre-Bonneville and post-Bonneville. The pre-Bonneville ravines usually do not exceed twenty-five foot depths, and have been largely filled by alluvium and lacustrine deposits. The post-Bonneville ravines have commonly re-established themselves on the former drainage patterns. Consequently, bedrock outcrops on the pediment slopes are most numerous on the divides rather than along the present stream channels, except where the present streams have cut down to bedrock. This has particular economic importance since the clay deposits of the Manning Canyon formation have the least alluvial covering on the highest land surface of the pediments.

Shape in Profile

The pediments are concave upward in profile. This is clearly demonstrated when the profiles are plotted on normal coordinates. The gradients along the largest stream courses. When the gradients of the pediments cutting different rock types are compared, it is clear that lithology also plays an important factor. The Oquirrh formation which yields relatively coarse, resistant debris, has steeper profiles than the Manning Canyon formation that yields fine, friable debris. The size, amount, and type of material yielded to the head of the pediments may impose a steeper gradient than would be normal for a given condition. For instance, the coarse fragments yielded from the mountains tend to increase the pediment gradient

of the Manning Canyon formation in several areas.

There is a definite pebble size decrease with decrease in slope away from the main mountain. The decrease in size results primarily from a decreasing competency of the stream as the gradient is lessened. The quantitative relationship between selective transport and the amount of pebble wear upon the diminishing of grain size and of slope is not known. Probably the most important factor is the competency of the stream. Decreased velocity on the lower portions of the slopes reduces the energy available to produce pebble wear; hence considerable selective transport of debris must take place.

Origin of Pediments

Various theories on pediment development have been proposed during the last seven decades. The active processes recognized in the formation of pediments include: lateral planation of streams, sheetfloods, rill wash, and weathering of slopes with the removal of debris by rills. The writer was able to recognize these as the dominant forces of pedimentation in Lake Mountain and the other adjacent areas, except for sheetfloods which appear to be a product of pedimentation rather than a process of pedimentation.

Bajadas and Fans

The term bajada is applied to the flanking detrital slopes of Lake Mountain. In detail they reveal themselves to be composed of coalescing alluvial fans, and are in most places separated from the mountain front by a pediment. The term appears to be useful to distinguish between detrital slopes and rock-cut slopes or pediments.

The two broad valleys bounding the eastern and western sides of Lake Mountain are the result of structural deformation, and have been buried by alluvium. Large fan-shaped aprons spread out into these valleys from the mountains, producing broad alluvial plains. These bajadas often cannot be sharply separated from the pediments that commonly skirt the mountains above them, because the pediments are veneered more or less with alluvium. In fact, in some instances the alluvium has spread itself over the pediment and into the mouths of the valleys draining Lake Mountain. On the other hand, parts of the pediment on the eastern side of Lake Mountain extends from the mountain front nearly to Utah Lake.

Alluvium consists of gravels containing boulders, cobbles, and pebbles, with a fine-grained matrix of sand and silt. There is a distinct size gradation from coarser to finer clastics from the mountain outward into the structural valleys. The coarser clastics are sub-rounded to angular. There is little tendency to produce good sorting or stratification. The detritus is the weathered products of Lake Mountain and the pediment slopes. The transporting agents of the detritus are streams, rill wash, and mud flows. the chief factors controlling the deposition are change

in volume of the stream due to evaporation and seepage of water underground, and changes in velocity of the stream due to decrease in slope, decrease in volume, and widening of the channels.

The profile of the bajada slopes normal to the mountain front, like the pediments, are concave upward. The valley slopes are gentle and increase in gradient as they approach the mountain front. In profile parallel to the mountain front the bajadas are undulating, the maximum convexity is approximately parallel to the axis of the streams draining the mountain masses.

The three largest bajadas or alluvial aprons are formed outward from the mouths of Wiley, Mercer, and Limekiln Canyons. In each instance their fan-form can be clearly recognized from 1 to 2 miles from the mountain front. The broadest and best developed alluvial aprons form a gently undulating plain of alluviation, separated, in the main, from the mountain base by a narrow pediment.

Lake Bonneville Landforms

The topographic features produced by Lake Bonneville in the Lake Mountain area include: wave-cut and wave-built terraces, deltas, and littoral deposits. These features are all best developed on the eastern side of Lake Mountain. Both erosional and depositional landforms are recorded on the main mountain mass, hills, pediments, and bajadas in the Lake Mountain area.

Of the several lake terraces produced in Utah Valley only three are of major importance, namely, the Alpine, Bonneville, and Provo. The wave activity of Lake Bonneville has produced prominent terraces in the Lake Mountain area only at the Bonneville and Provo levels. A minimum of 24 minor terraces are impressed on the pediment-bajada slopes between the Bonneville and Provo levels on the northeastern side of Lake Mountain. These levels indicate that the fall of Lake Bonneville from the higher to the lower level was interrupted and progressed in successive stages.

The only prominent lake terraces on the west side of Lake Mountain in Cedar Valley are those produced at the Bonneville level. This valley is considerably smaller and shallower than Utah Valley, hence the wave activity was less important. As Lake Bonneville fell from its highest level to the Provo level, Cedar Valley became a small independent lake at the time the waters fell below the 5000 foot elevation.

The formation of deltas has not been extensive in Lake Mountain, since the drainage area is restricted. However, a few small and well preserved deltas are present, the best one of which is found immediately north of the Pelican Hills. A commercial gravel pit has exposed topset and foreset beds in this delta, which shows fairly well developed stratification and sorting of sediments.

The littoral deposits consist mainly of small spits, bars,

and beach materials, composed of fine gravels, sand and silt. The features are minor but common topographic features in the Pelican and Beverly Hills, and on the pediment-bajada slopes between these two areas. Excellent beach conglomerates are found in the Pelican and Cedar Valley Hills.

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