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THE GEOLOGY OF LEHI QUADRANGLE

by

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THE GEOLOGY

OF

LEHI QUADRANGLE

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by

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ABSTRACT

The Lehi quadrangle, bounded on the east and west by meridians 111° 45' and 111° 52' 30" west longitude, on the north and south by parallels 40° 30' and 40° 22' 30" north latitude, is located on the eastern margin of the Basin and Range province. Only the East Traverse Mountains and the adjoining Wasatch Range located within this area received special investigation in this report; the geology of the remaining area was compiled from previous work.

Approximately 5000 (?) feet of highly fractured Atokan - Des Moinesian orthoquartzites of the Oquirrh formation represent nearly all of the sedimentary rocks within the East Traverse Mountains. They rise nearly 2000 feet above the valley floor, effectively separating the Utah Valley from the lower Jordan Valley. The Oquirrh formation represents a thick miogeosynclinal unit which has been thrust eastward (probably as part of the Late Cretaceous Laramide, Charleston thrust sheet) into contact with a thin, shelf section.

A series of Tertiary andesite flow rocks crop out in a narrow belt in the center of the East Traverse Range; faulted and fissured areas are hydrothermally altered to jasperoid or are kaolinized; pebble dikes are also present. The volcanics are in fault contact with late Eocene Cottonwood quartz-monzonite stock. A mylonite zone on the south and southwest margins of the stock suggests post-intrusive thrusting.

Pleistocene fanglomerates, locally cemented, fringe the southeast flank of the East Traverse Mountains; unconsolidated slope wash covers most of the area.

The East Traverse Mountains are considered a fault block spur resulting from Basin and Range faults which locally were most pronounced during late Pliocene to recent time. Most of the relief of the present topography was developed prior to Wisconsin time. The spur is bounded on the north and east by the Wasatch fault which locally expresses possibly 5,000 feet of throw; minor faults transect and flank the spur; internal minor adjustments are numerous.

Pleistocene glaciation was initiated in the higher elevations of the Cottonwood intrusive by a colder and more moist climate. At least two periods of glaciation are recorded by terminal and lateral moraines in the mouth of Alpine canyon. The stratigraphy of Lake Bonneville records four periods of alternate cycles of moist and dry climate.

Groundwater, sand and gravel are abundant in the lower valleys, and comprise the main natural resources.

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Utah

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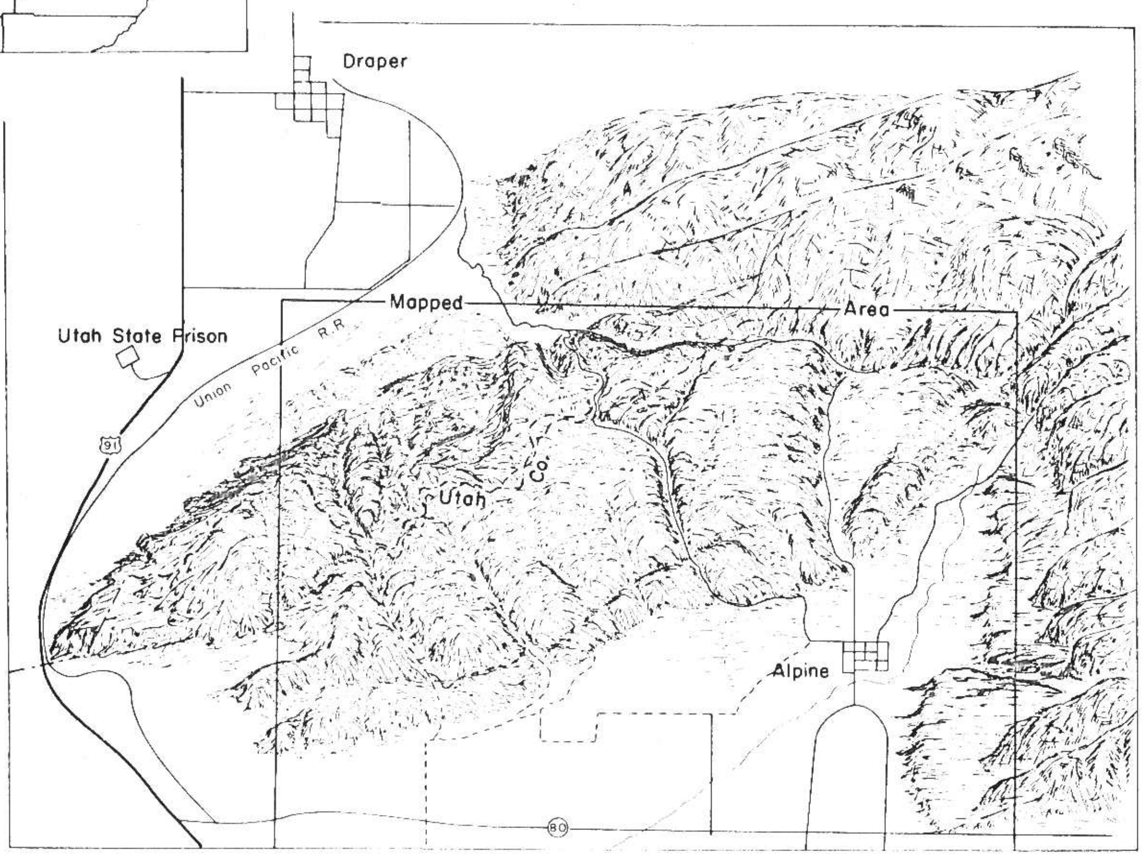
Scale in miles



INTRODUCTION

PURPOSE AND SCOPE

The purpose of the present work was to map and interpret the geology of the East Traverse Mountains, which completes the mapping of the geology within the Lehi quadrangle.

Except for the East Traverse Mountain area, the map represents a compilation of previous work done within the Lehi quadrangle.

The following problems were investigated: (1) the structure of the East Traverse Mountains; (2) age of the sedimentary rocks; (3) metamorphism associated with the contact of the intrusive; (4) age and composition of the various volcanic flows within the area; (5) time and magnitude of the thrusting; (6) extent and origin of the thick cover of alluvium which mantles most of the entire area in the form of slope wash and fanglomerate.

LOCATION AND ACCESSIBILITY

The Lehi quadrangle is located in Salt Lake and Utah Counties, Utah. It is bounded on the east and west by meridians 111° 45' and 111° 52' 30" west longitude, on the north and south by parallels 40° 30' and 40° 22' 30" north latitude. The East Traverse Range, the area under special investigation, includes approximately 20 square miles as shown on Plate VIII.

Geographically the East Traverse Mountains divide the Salt Lake Valley to the north and Utah Valley to the south, and the drainage divide also marks the boundary between Salt Lake and Utah Counties.

U. S. Highway 91 is the main route of travel traversing the state of Utah; it also links Lehi and American Fork, two small towns which are located in the southern margin of the Lehi quadrangle. From either of these towns numerous state and county roads extend north to Utah State Highway 80 from which several jeep roads make the Traverse Mountains accessible. The main road through the Traverse Mountains is approached through Hog Hollow via Alpine, Utah. The road crosses the East Traverse Mountains perpendicular to the general trend of the range, and it traverses approximately ten miles of terrain between Alpine and Draper, Utah.

TOPOGRAPHY

Looking north from Lehi or American Fork, the central part of the East Traverse Mountains rises gently to a low rolling topography approximately 1500 to 2000 feet above the lower valleys. Gilbert (1928, p. 22) describes this topography as mature. The Traverse Mountain front in the western portion of the mapped area is much steeper; many of the canyon walls slope as much as 35°. The north flank of the East Traverse Mountains is abrupt; drainages are short, narrow, quite steep and covered with oak brush.

Soft lake sediments on the north side of the range are cut by numerous gullies below Lake Bonneville's highest shore line at the 5135 foot elevation; below this 5135 foot level on the south side, the area is characterized by a typical lake bottom topography.

Fort Canyon is the largest canyon within the East Traverse Mountains; its lower portions are cultivated producing apples and alfalfa. Alpine Canyon divides the East Traverse Mountains from the high rugged Wasatch Range to the east.

PREVIOUS WORK

> "I have read many of these works with the keenest interest and pleasure; in fact some have been read until some of the more important findings seem to be my own." (Beeson, 1925)

The Lehi quadrangle, located on the boundary between the Rocky Mountain province and the Basin-Range province has received passing attention throughout the geological history of the west. With mining districts such as American Fork to the east, Park City to the northeast, Alta and Little Cottonwood to the north, Bingham to the northwest, Ophir to the west, and Tintic to the southwest, intensive local studies have been stimulated within areas bordering the Lehi quadrangle. Only the more important historical and comprehensive studies related to the immediate area under special consideration will be mentioned. Other work pertinent to this study will be referred to in the text.

A comprehensive study of Lake Bonneville was made by Gilbert (1890) wherein he described the shore line features about the Point of the Mountain. Butler (1920) directed by the work of Emmons, King, Geikie, Boutwell, and Blackwelder, described the ore deposits of Utah and consequently much of the geology associated with the Little Cottonwood intrusive. In 1925, Beeson illustrated the structural geology of Park City, Alta, and Bingham mining districts, relating them to regional trends.

Gilbert (1928) considered the structure of the East Traverse Mountains to be a fault-block spur. He also described the Wasatch fault between Alpine and Draper in detail, reflecting upon the evolution of stranded channels at Corner Creek Canyon.

The Traverse Range was mapped and studied in detail by Marsell (1932). He constructed a topographic map and made a careful study of the stratigraphy and petrography.

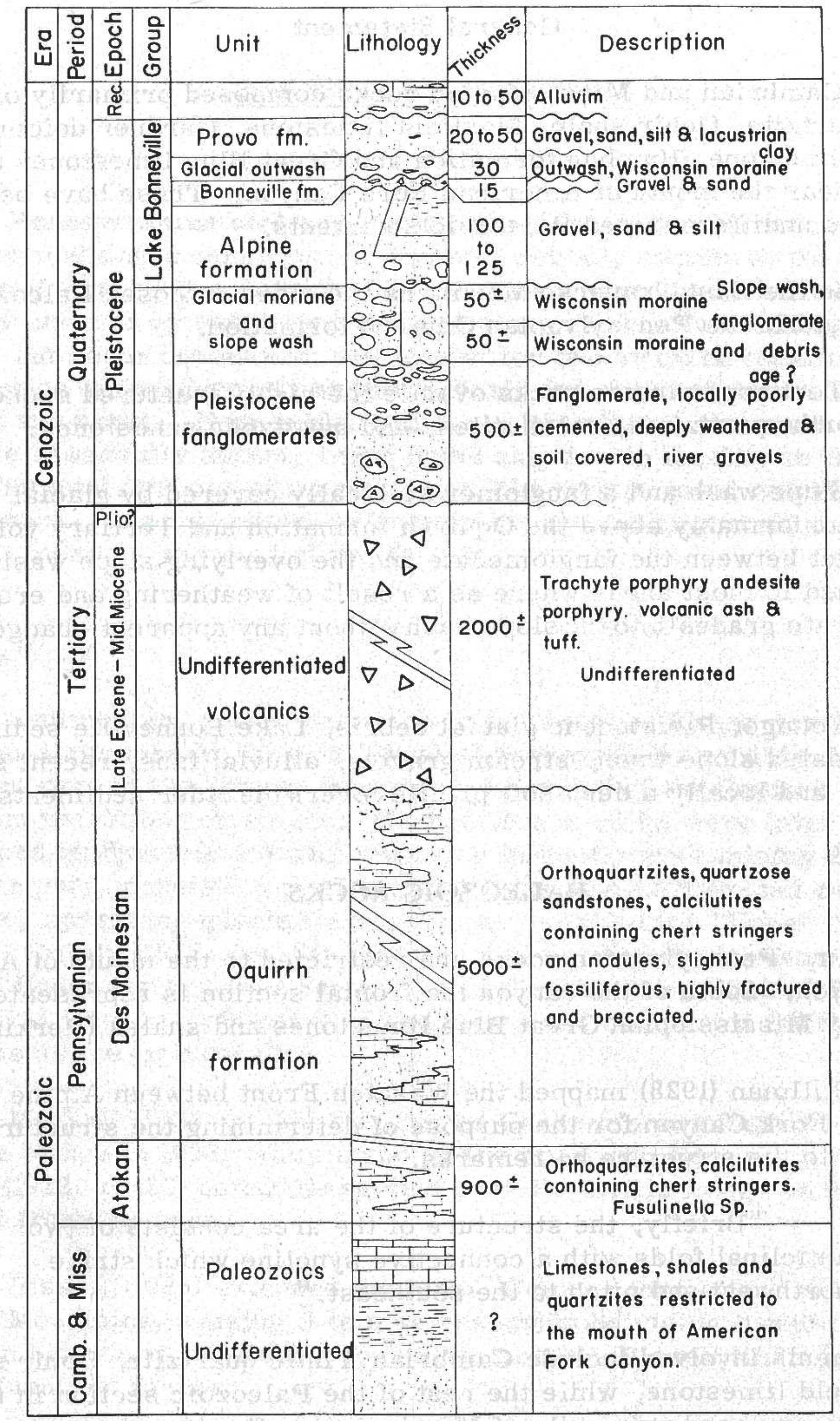
Eardley (1933) contributed to the understanding of this area by developing the concept of strong topographic relief prior to block faulting. Geologic structure encountered while boring the Alpine-Draper tunnel for the Salt Lake City aqueduct was briefly recorded and illustrated by Murdock (1941). A preliminary report by Baker (1949) projected the trace of the Charleston thrust fault west to flank the Cottonwood intrusion on its south flank and then north again below Lake Bonneville sediments.

Hunt (1953) mapped the geology of Lake Bonneville in the northern part of Utah Valley. His report covers most of the Pleistocene geology included within the Lehi quadrangle.

A radio-intensity survey of the East Traverse Range was done as a Master's thesis for the University of Utah by Dolan (1957).

Comprehensive historical and geologic progress reports pertaining to this immediate area may be found in U. S. G. S. Professional Papers 111, 153, 173, 201, and 257A.

Plate II



STRATIGRAPHIC SECTION

STRATIGRAPHY

General Statement

Cambrian and Mississippian rocks composed primarily of the Tintic quartzite, Ophir shale, Maxfield limestone, Gardner dolomite, Deseret limestone, Humbug formation and Great Blue limestone, are exposed near the mouth of American Fork Canyon. These have been mapped as undifferentiated Paleozoic sediments.

In the East Traverse Mountains the oldest exposed Paleozoic rocks are included in the Pennsylvanian Oquirrh formation.

Tertiary volcanic rocks overlie the highly fractured sequence of Oquirrh orthoquartzites, calcilutites, and quartzose sandstones.

Slope wash and a fanglomerate locally covered by glacial moraines, occur unconformably above the Oquirrh formation and Tertiary volcanics. The contact between the fanglomerate and the overlying slope wash is not well defined in most areas where as a result of weathering and erosion, the fanglomerate grades into the slope wash without any apparent change in lithology.

Younger Pleistocene glacial debris, Lake Bonneville sediments, unconsolidated slope wash, stream gravels, alluvial fans, recent slump material, and locally a deep soil profile covers the older sediments.

PALEOZOIC ROCKS

Pre-Pennsylvanian rocks are restricted to the mouth of American Fork Canyon. South of the canyon the frontal section is represented entirely by Mississippian Great Blue limestones and shales (Perkins, 1955).

Stillman (1928) mapped the Wasatch Front between Alpine and American Fork Canyon for the purpose of determining the structure. In reference to the structure he remarks,

> "Briefly, the structure of the area consists of two anticlinal folds with a connective syncline which strike northwest and pitch to the southeast."

The sediments involved include Cambrian Tintic quartzite, Ophir shale, and Maxfield limestone, while the rest of the Paleozoic section in that vicinity is composed primarily of Mississippian Gardner dolomite, Deseret limestone, Humbug formation, and Great Blue limestone.

Approximately a thousand feet of Cambrian and Mississippian limestones extends for a mile north of American Fork Canyon. These are mapped as undifferentiated Paleozoic rocks.

PENNSYLVANIAN SYSTEM

General Statement

Pennsylvanian rocks represented primarily by Oquirrh orthoquartzites make up a large part of the sedimentary section of the East Traverse Range. A few lenses of calcilutites are present, but they are generally covered by quartzite talus and slope wash. Fossil fragments are present, but not in abundance, and except for two or three localities, the identification of fossil specimens is difficult due to the highly brecciated nature of the rocks. Fusulinids, which are abundant to the south and to the west, are essentially absent, being found only in one locality in the mapped area. The total absence of marker beds, the ever present cover of talus and colluvium, and the extensive brecciation and faulting made it impracticable to measure any part of the section.

Previous Work

Sedimentary rocks within the East Traverse Range were first mapped as Cambrian by the 40th Parallel Survey (1876, p. 439). At the same time part of the "Upper Intercalated Series" of the Oquirrh Mountains was called the Weberian series. Carboniferous rocks were later recognized and mapped by Spurr (1895) while working in the Oquirrh mining district. The upper part, consisting of alternating beds of limestone and calcarious sandstone, appearing quartzitic in part, were called the "Upper Intercalated Series." Gilluly (1932, pp. 34-38) later redescribed the lower part of Spurr's "Upper Intercalated Series," applying the name Oquirrh formation for the first time to 15,000 feet of sediments and designated the Oquirrh Mountains as the type locality.

Marsell (1932, p. 25) discovered Carboniferous fossils in the East Traverse Range in 1923, while mapping the area with Beeson. Later Marsell (1932, p. 33) dated the section post-Pottsville in age on fossils collected from the area.

Bissell (1936) extended the term "Oquirrh formation" to the southern Wasatch Mountains, raising it to a series and subdividing it into the Kelley formation below and the Hobble formation above. Bissell (1939) later zoned it using fusulinid faunas.

Baker (1947) reported 26,000 feet of the Oquirrh formation in the Provo, Utah, area.

Fossils Collected

Fusulinella sp. was collected in the NE 1/4, Sec. 30, T. 4 S., R. 1 E., at fossil location B. Y. U., 10947. Dr. H. J. Bissell identified the specimens and suggested that they were of a type that commonly occurred within the upper 900 feet of the Derryan sediments of this area. Near the fault and west of the volcanics in section 30, southeast of the above location, Chaetetes was collected. It is reported by Baker (1947) to mark the basal portion of the Des Moinesian in this general region.

Fossils collected by the writer (locations marked on Plate VIII by a fossil symbol) include:

Fusulinella sp.	Linoproductus sp.
Chaetetes sp.	Mesolobus mesolobus
Fenestrella sp.	Neospirifer triplicatus ?
Rhombopora sp.	Spirifer opimus ?
Rhomboporella sp.	Composita ovata
Orbiculoidea capiformis	Hustedia mormoni
Derbya crassa	Acanthopecten carboniferous
Dictyoclostus sp.	
Juresania nebraskensis	Petrodus

From the general appearance of most orthoquartzites exposed in the area, H. J. Bissell (personal communications) said that the rocks strongly resemble the Des Moinesian sediments exposed elsewhere in central Utah.

Lithology

The Oquirrh formation in the East Traverse Range is highly fractured to the extent that few pieces were observed over a foot in maximum dimensions (Plate III, figure 5).

Except for a few orthoquartzite breccia outcrops which have been recemented with siliceous material, the entire mapped area is void of bold outcrops. Marsell (1932, pp. 28-29) wrote:

> "A striking feature of the sedimentary rocks in the Traverse Mountains is the general absence of outcrops. Cliffs are rare and ledges infrequent in their occurrence. . . . Here although the bedrock is everywhere near the surface, one may travel thousands of feet on a mantle of loose, angular rock waste without detecting an outcrop of any kind."

This condition is indicated on the map (Plate VIII) east of the volcanics where all of the outcrops found by the writer are marked by dip and strike or outcrop symbols.

To obtain a dip and strike, the author studied the talus fragments for material that showed bedding, and bedrock could usually be reached within a foot or two of the surface. The grain size is so uniform, and the jointing so intense in some locations, that it is difficult to tell bedding from jointing. Even where bedding was found, a number of readings in the same locality showed variations as much as 10 or 20 degrees due to differential movements on fracture planes.

On weathered surfaces, the quartzite is light tan, and on freshly fractured surfaces it is light gray. Bedding that is present appears to be due to variations in grain size and the presence of magnetite, which has altered to limonite, thus staining the more porous bands from light tan to pink. The grains are subangular to subrounded.

Occasionally an outcrop composed of a dirty gray to white quartzite, containing dark brown to black chert stringers up to three inches thick, was observed. Brachiopod and gastropod fragments were also present. In thin section the quartz grains proved to be angular to subangular.

Stringers of chalcedony and opal were also present. Lithologically, the light and dark fractions were similar except for the dark color which may represent organic material.

A series of light brown quartzites and gray calcarenites occur on the upper portion of the northeast spur of Steep Mountain, all part of intercalated beds of the Oquirrh formation. The light gray calcarenites contain fragments of crinoid stems and brachiopods, but identifiable specimens were not obtained.

In the vicinity of Oak Hollow on the north side of the range, the dominant lithology is orthoquartzite, interbedded with quartzose sandstones and siltstones which are quite friable. From the crest of the range to the southern flank of the range, the quartzites are very similar to those described above, varying only slightly in appearance. Three cherty calcilutite units, 10 to 30 feet thick, occur on the west side of Maple Hollow. In each case, differential erosion has developed a small saddle on each spur, where the calcareous material crops out. Thin sections show fine angular quartz grains in a matrix of crystalline limestone. Brachiopod fragments are rather abundant. Black chert nodules and stringers occur at random

Plate III

Figure 1

Highly fractured Oquirrh quartzite showing the depth of soil that frequently develops on hillsides with 35° to 40° slopes. This picture was taken in one of the draws located west of Fort Canyon.

Figure 2

A quartzite breccia outcrop which has been recemented with silica and highly stained with limonite. The picture was taken on the north face of Red Rock.

Figure 3

Poorly sorted and well cemented Pleistocene fanglomerate located in the first draw from the mouth of Fort Canyon on the west side.

Figure 4

A quartzite breccia outcrop showing three different zones of brecciation; zone A shown in Figure 6, and zone B shown in Figure 5. The background shows an ancient erosional surface which has been uplifted, and erosion has cut a sharp "V" drainage through the north flank fault scarp. This picture was taken south of Red Rock.

Figure 5

This picture shows zone B of Figure 4. It shows the lower zone of brecciation located below the rock-flour zone. Quartzite fragments up to three feet in diameter, partially rounded occur in the top part of this zone.

Figure 6

This picture represents zone A of Figure 4. It shows rounded pebbles which range from a fraction of an inch to an inch in diameter scattered through a two-foot zone of crushed rock flour.

Figure 7

A recemented quartzite breccia outcrop characteristic of many of the outcrops in this area. This picture was taken east and near the head of Right-Hand Fork.

Plate III

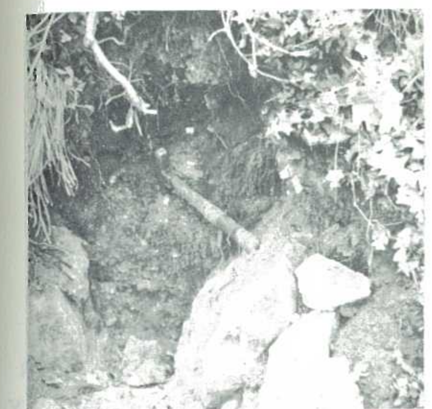


Fig. 1

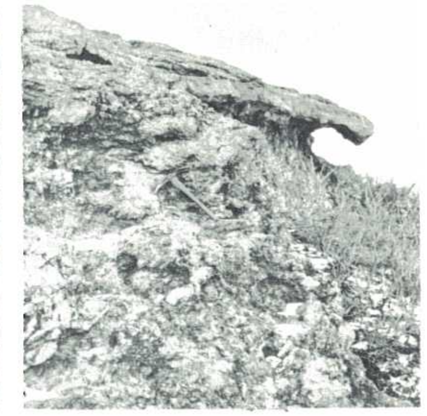


Fig. 2

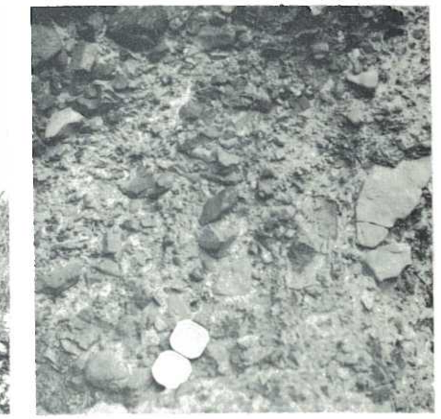


Fig. 3

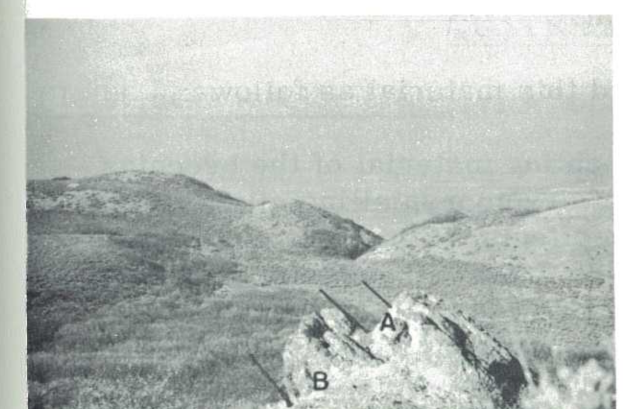


Fig. 4

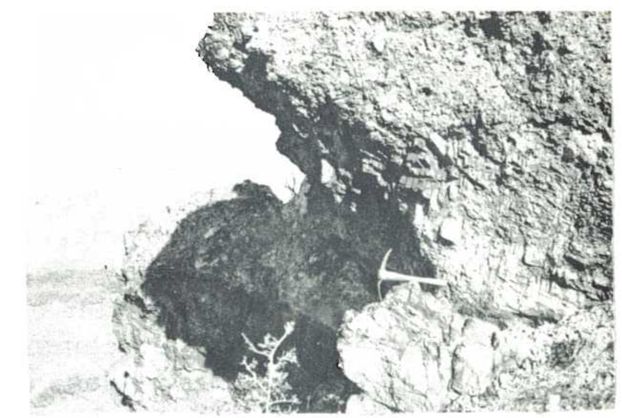


Fig. 5

Fig. 6

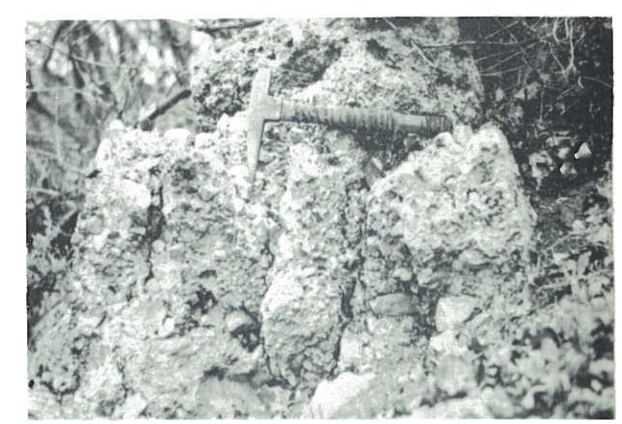


Fig. 7

throughout the limy members. Organic material has colored the rock dark grayish-brown on freshly fractured surfaces, while weathered surfaces are light-gray. Similar calcareous units appear as recemented breccia outcrops east of Spring Hollow and along part of the erosional scarp south of School House Springs.

In the NE 1/4, Sec. 30, T. 4 S., R. 1 E., a cataclastic breccia zone in excess of a thousand feet occurs north of fossil location 10947, trending in an easterly direction. The outcrops are characterized by siliceous cemented, ferruginous stained quartzite breccias, with the color ranging from dark yellow to nearly black.

Quartzite fragments range in size from a rock flour matrix to particles 7 or 8 inches in length. Several prospects have exposed this area to depths of 30 to 40 feet. The breccia zone is interrupted by approximately 900 feet of highly fractured Derryan sediments; below the fossiliferous Derryan sequence, the breccia zone is again in excess of a thousand feet. The quartzite fragments are characteristic of those described above, but the matrix is a purple siliceous material.

Marsell (1932, p. 43) described this material as follows:

> "In thin sections the cementing material of the breccias is seen to consist principally of cryptocrystalline silica showing aggregate polarization effects. Smaller amounts of fibrous chalcedony, commonly known as veinlets, and extremely fine granular quartz are generally present. All of the slides of this cementing material are heavily clouded with opaque iron oxides. . . . From the field evidence and from mineral relations shown in thin sections it appears that the original solution contained colloidal silica, which first solidified as the amorphous mineral "Opal", then later crystallized to both chalcedony and cryptocrystalline quartz. All stages in the transition from opal to quartz may be observed in the same thin section.

South of the breccia zone the lithology is characterized by a firmly cemented quartzose sandstone and in part by orthoquartzite. In places the rock has abundant molds or brachiopods and bryozoans, but all of the calcium carbonate has been completely leached from the rock. Near the fault which borders the southern margin of the East Traverse Range, the rocks commonly show intense silicification and limonite coloration. Dark red muds mark the trace of the fault in the bottoms of the freshly cut ravines.

TERTIARY SYSTEM

Patches of white, friable, volcanic tuffs crop out beneath volcanic flow rocks along the northwestern portion of the volcanic belt. Waterlaid, well stratified tuffs occur along the flanks of the East Traverse Range and have been tentatively correlated with those of the Salt Lake formation of late Pliocene age.

Located in the northeast corner of the NW 1/4, SW 1/4, Sec. 8, T. 4 S., R. 1 E., of the Lehi quadrangle, is an outcrop of friable to well cemented tuff exposed in the bottom of a wash, underlying Alpine sediments. The bedding, striking N. 30° W. and dipping 85° S., indicates extensive faulting in this area. Other exposures occur in the mouth of Oak Hollow on the north flank of the range. In the past, similar deposits have been mined in the northwest corner of NE 1/4, SW 1/4, Sec. 29, T. 4 S., R. 1 E., on the south flank of the range.

QUATERNARY SYSTEM

Pleistocene fanglomerate

Pleistocene fanglomerates were first mapped along the southeastern margin of the East Traverse Range by Hunt (1953); no effort was made to differentiate the unconsolidated material which varies in lithology from one location to another.

Located in the first draw on the west side of Fort Canyon, approximately 1000 feet from the Canyon road, nearly 310 feet of poorly cemented fanglomerate outcrops are exposed, striking N. 54° E. and dipping 57° SE; here the outcrops suggest bedding with very poor sorting. Well rounded cobbles and boulders believed to have been derived from Precambrian and Cambrian quartzites farther east along with dark red Ankareh siltstones and Tertiary volcanic flow rocks characterize the fanglomerate. Angular and subangular quartzitic debris derived from the Pennsylvanian Oquirrh formation makes up the bulk of the fanglomerate. A light buff-colored calcium carbonate mixed with very fine angular quartzite silts and sand, cement the poorly sorted material which yields readily to weathering. Except for the presence of an occasional well rounded cobble coated with white calcium carbonate, it is nearly impossible to distinguish it from recent colluvium in other areas. For this reason, the contact has been inferred on Plate VIII. A branch fault which intersects the fault bordering the southern margin of the East Traverse Range, elevates this poorly cemented fanglomerate material nearly along the strike between Dry Hollow and Hog Hollow.

Plate IV

Figure 1

This picture was taken on the summit east of Right-Hand Fork; it shows Oquirrh quartzite and cherty calcilutite boulders up to six feet in diameter which characterize the colluvium which mantles much of the area.

Figure 2

This picture was taken near the fork of Hog Hollow. It shows the nature of much of the slope wash which occurs in this vicinity. The boulders and cobbles are composed mainly of Oquirrh quartzite and volcanic flow rock.

Figure 3

This picture was taken southeast of fossil location (10947), near the bottom of the canyon. It shows a prospect which is dipping at an angle of 36° to the southeast which is away from the present drainage. The picture shows a two-foot zone of an ancient soil profile which is resting on highly fractured Oquirrh orthoquartzites. Stream gravels overlie the old soil profile and they are in turn covered by a quartzite fragment slope wash, which strongly resembles highly brecciated bedrock. The picture shows that the ancient drainages have been filled in and new drainages developed. Six specimens of the fossil "Petrodus" were recovered from the stream gravels.

Figure 4

This picture was taken near the mouth of Maple Hollow. It represents weathered slope wash derived from Pleistocene fanglomerates. The cobbles are composed of Precambrian quartzites, Oquirrh quartzites, Ankareh siltstones, and volcanic flow rocks. Some of the cobbles are well rounded and coated with calcium carbonate.

Plate VI

Fig. 1

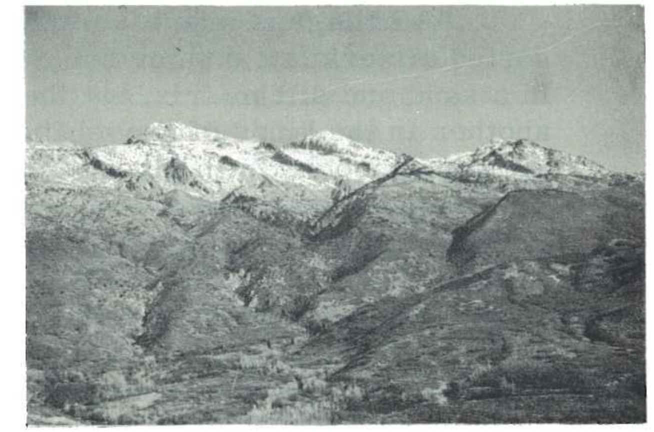


Fig. 2

Fig. 3

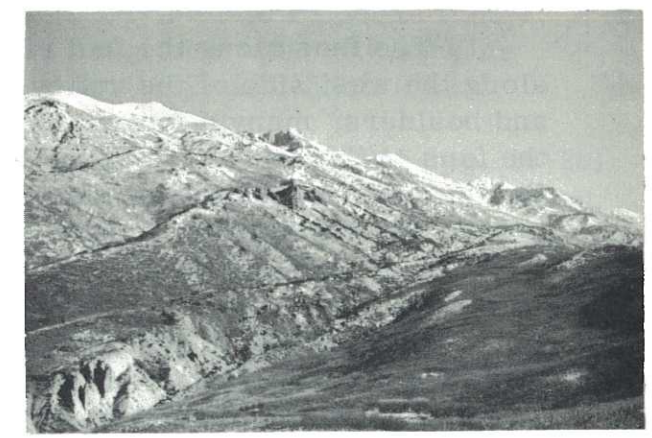


Fig. 4

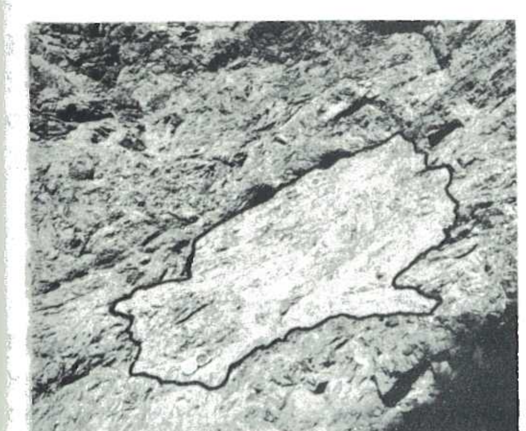


Fig. 5

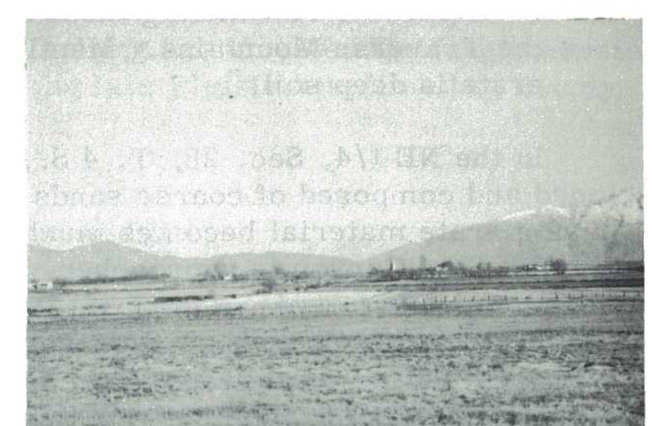


Fig. 6

Hunt (1953, pp. 14-15) discusses the fanglomerates of this area as follows:

"All the fans are alike in being composed of poorly sorted materials, angular boulders, cobbles, and gravel in a sand and silt matrix; but the fans differ from one another in the kinds of gravel they contain, depending on the source rocks in the immediately adjoining mountains. The fan materials are in large part poorly consolidated but in this report they are referred to as fanglomerate.

"The pre-Lake Bonneville fans along the west side of the valley and those along the south side of the Traverse Mountains were derived largely from the quartzitic part of the Oquirrh formation and are composed mostly of quartzitic material. The fans along the south side of the Traverse Mountains also include some material derived from the porphyritic and glassy lavas in the range. . . .

"The fans along the foot of the Wasatch Range and along the west side of the valley contain abundant cobbles and boulders, many a foot or more in diameter; whereas the fans at the south side of the Traverse Mountains contain fine gravels, probably because the Traverse Mountains are lower than the Wasatch and have not been deeply dissected. . . . .

"The surface of the fans and the obscure bedding in them slope several hundred feet per mile toward the basin. Commonly the fan form is perfectly preserved, but at several places the fan deposits have been faulted and the upfaulted segments are being eroded. The deposits northwest of Alpine have been rather maturely dissected into rounded hills resembling those formed on the bedrock in the Traverse Mountains. Mantling these hills of fanglomerate is deep soil."

In the NE 1/4, Sec. 28, T. 4 S., R. 1 E., the bedding is fairly well developed and composed of coarse sands and fine gravels; towards the east the fanglomerate material becomes much coarser, ranging to small boulders as Fort Canyon is approached.

Murdock (1941) mapped unconsolidated material for nearly a mile in the Draper-Alpine tunnel (see Plate V). Part of this material is possibly the lateral equivalent to the fanglomerate described above. Murdock (1941, p. 3) describes the fanglomerate material as:

"Talus Outwash 7

"The tunnel was in talus outwash material from Alpine portal to Station 1270, a distance of 5,100 feet. This material is clay, sand, gravel and boulders and was derived mainly from residual material from the slopes of Traverse spur. The material changed to large rounded boulders at the contact with the porphyry at Station 1270-00. This section was all supported with 4" steel supports and caused no trouble during construction."

This is conclusive evidence that the fanglomerate material which is believed to be in excess of 500 feet overlaps volcanics which are considered of late Eocene to late Miocene in age. From the tentative dating of the volcanics, the interval from late Miocene through the Pleistocene was a time of erosion and deposition of coarse gravels. Although there is no conclusive evidence to support the dating of any of the fanglomerates as late Tertiary, some of the material may be late Pliocene in age. The writer compared the poorly cemented conglomerates with similar fanglomerate material mapped by Gilluly (1932) and Slentz (1955).

While mapping fanglomerate deposits, Slentz (1955, pp. 19-20) found that, in general, the Tertiary beds were greater in aerial extent, more firmly cemented, and frequently showing slightly more deformation than the younger beds. He found the Pleistocene strata to be better sorted, more rounded, and less consolidated and displaying more geomorphic expression.

In view of the related deposits of nearby areas, it is tentatively concluded that the fanglomerates of this area are most likely early Pleistocene; the source of the well rounded material was probably derived from Tertiary conglomerates which since have been eroded away. At one time, Pleistocene fanglomerates covered most of the eastern part of the East Traverse Range. Pleistocene faulting has elevated the fanglomerate in part, and accelerated erosion during late Pleistocene time has deeply dissected the old erosional surfaces.

Lake Bonneville

Approximately 60 per cent of the Lehi quadrangle has been repeatedly inundated by Pleistocene lakes, the last of which was Lake Bonneville, considered to have been related to Wisconsin glaciation; its waters covered almost 20,000 square miles in western Utah with maximum depths of approximately 1000 feet.

The geomorphic units associated with Lake Bonneville were first described and mapped by Gilbert (1890); numerous local studies have since been made. Hunt's paper (1953) dealing with the geology of Northern Utah Valley is the most comprehensive study to date of the lake sediments within the Lehi quadrangle and represents the first attempt at mapping Lake Bonneville stratigraphy.

Water-laid volcanic tuffs associated with Pliocene sediments attest to the presence of ancient Tertiary lake bottoms located in this vicinity; and lakes similar to Lake Bonneville may have occupied Utah valleys during earlier periods of glaciation.

A brief summary of events relating to late Pleistocene lake history is compiled from the works of Hunt (1953) and Bissell (1952, p. 1358). Interpreting the sedimentary record of Lake Bonneville, the present concept regarding the history of the more recent lake began in mid-Wisconsin time, when its waters rose to an elevation between 5050 and 5100 feet. This stage developed the characteristically fine sands, silts, and clays which represent the major portion of the material composing the hillshore benches of the East Traverse Range. This stage was recognized by Gilbert (1890, pp. 135-154) and by him named the "Intermediate"; later Hunt (1953, p. 17), applying stratigraphic principles, named these sediments the Alpine formation, thus eliminating any possibility of confusing the name "Intermediate" to mean intermediate in age.

Hunt (1952, p. 40) reports that in the mouth of Alpine Canyon gravel deposits interbedded with the finer-grained sediments of the Alpine formation suggest that the initial advance of Lake Bonneville may have preceded the glacial maximum.

Due to cyclic climatic conditions, the lake fell, allowing Alpine sediments to be deeply dissected and completely removed locally. Later the lake rose to the Bonneville level at 5135 feet altitude. Lake Bonneville remained only a short time at this elevation; the shore gravels deposited during this stage in the mouth of Alpine Canyon were derived from the outwash of the youngest moraine, thus indicating that the rise of the lake was in response to the waning period of maximum glaciation recorded in this area. While at the Bonneville stage, the lake overflowed into the Snake River Valley at Red Rock Pass located at the north end of Cache Valley.

The spillway was lowered 335 feet to an altitude of 4800 feet, and the Provo stage of the lake was initiated; the lake level was maintained for possibly a few thousand years, finally yielding to a drier inter-glacial stage. From a low stage, the lake rose a third time and remained at a level below the Provo shoreline for a shorter period of time. Eardley (1957) states that following the second rise to the Provo level the lake began to fall, receding to a level below 4300 feet before raising a final time to approximately the

4450 foot elevation, suggesting that the last recession may have seen the lake completely desiccated about 6000 years ago.

Lake Bonneville Group

Alpine formation

Alpine sediments represent the oldest formation in the Lake Bonneville group. They were called "Intermediate" by Gilbert largely as a landform; however, later the formal stratigraphic name, Alpine formation, was applied by Hunt, and Bonneville was given group status (1953, p. 17). The Alpine sediments are characterized by fine textured sediments, mostly silts, believed to have been derived mainly from ancient soils. They are divided into three members in ascending order composed largely of (a) gravel, (b) sand, (c) silt and/or clay. Generally, sorting is excellent; bedding is very distinct, and individual beds commonly are only a fraction of an inch in thickness. Hunt (1953, p. 18) notes that there is difficulty in distinguishing gravel of the Alpine formation from that of the overlying Bonneville formation. He notes, however, that when mapped, the Bonneville is almost wholly gravel, whereas the Alpine gravels by lateral facies change grade to sands and finer clastics.

Bonneville formation

Bonneville gravels were deposited on the highest level reached by Lake Bonneville, 5135 feet altitude, and they also mark the boundary between fluviatile erosion and lacustrine deposition. The gravels are represented only by a thin narrow discontinuous beach deposit.

Provo formation

Most of the sediments covering Utah and the lower Jordan Valleys represent units of the Provo formation. The Provo stage of Lake Bonneville occurred during the ancient lakes' stillstand at an altitude of 4800 feet. Sediments composed of gravel, sand, silt or clay were deposited over a large area. Locally the Provo formation may be found to overlie pre-Lake Bonneville deposits. In places it lies on glacial outwash which in turn rests on Alpine sediments, but in general the Provo rests on the Alpine formation at or below the 4800 foot level.

Lake Bonneville Sediments North of the East Traverse Mountains

A thin deposit of Lake Bonneville sediments on the north flank of the East Traverse Mountains covers a gently sloping pre-Lake Bonneville topography, and it is doubtful if sediments are much over a hundred feet thick, due to post-Provo stage erosion. Along the north flank of the East Traverse Range, the unconsolidated Lake Bonneville sediments are highly dissected into rather steep, shallow ravines which frequently expose the highly fractured Oquirrh quartzites which underlie the lake sediments. In places the bedrock has been highly stained by iron-bearing solutions. Dark reddish purple andesites and water-laid volcanic tuffs are also exposed. Large quartzite and volcanic boulders are exposed on the old erosional surface which is covered by lake sediments.

Sands, silts and a few coarse gravels make up the bulk of the sediments. Close examination of the lacustrine deposits shows that the lithology changes rapidly, reflecting the nature of the source material. For the most part, the coarse detrital material was derived from the Cottonwood intrusive, East Traverse Mountain andesites, and Oquirrh orthoquartzites. Other fragments derived from the Precambrian, Paleozoic, and Mesozoic rocks present to the north are undoubtedly present, but they were not recognized in great abundance.

Near the 4660 foot contour north of Red Rock in Sec. 8, T. 4 S., R. 1 E., Provo sediments are composed of sand, poorly sorted subangular to subrounded grains, ranging from a fine silt to coarse sand. Individual grains are composed of quartz, quartzite, and some volcanic detritus. From the 4660 foot contour to the 4680 foot contour, the lithology was exposed by auger holes dug by another investigator, which showed the sediments to be quite uniform in nature, characterized by a dark brown, poorly sorted sand.

An erosional escarpment with relief of approximately 10 feet occurs at the 4700 foot contour level. Here 15 feet of sediments can be examined near the recently cut gullies. The lowermost beds are composed of poorly sorted, coarse sand and gravel with some pebbles approaching an inch in diameter. The material grades upward to a fine sand, and 10 feet from the bottom the sand grades into a silt which contains scattered rock fragments up to half an inch in diameter. The silt then becomes well sorted to form a three-foot bed of silt which grades back into a coarse sand and gravel. Bedding is not distinct, but the soft unconsolidated sediments are in general composed of silts and sands. No clay or coarse gravels were observed.

At the 4800 foot contour, the high water level of the Provo stage, there occurs a fault line scarp. Along the trend of the scarp, coarse debris derived from volcanic flow rock and Oquirrh orthoquartzites are exposed which are generally overlapped by Alpine (?) sediments.

The contact between Provo and Alpine sediments is not well defined, and the writer has relied upon the high water level of the Provo

stage as the boundary between these two formations. Above the 4800 foot contour the sediments are characterized by poorly sorted sands and silts which grade into a well sorted bed of very fine-grained sand and silt, approximately 18 feet thick, light tan, and composed mainly of quartz grains. The silt grades into a poorly sorted unit containing angular fragments of volcanic flow rock, probably derived from the Traverse Mountains. The volcanic grit composes approximately 30 per cent of material in places, and it is scattered evenly through the fine sand mass. A few subangular to subrounded pebbles composed of quartzite, quartz-monzonite, and andesite, occur through parts of the gritty silt.

Just below the 5000 foot contour level a good exposure shows a sequence of bedded sediments which is overlain by a thick bed of silt. This silt bed tends to form benches on the ridges between the ravines. Occasionally a large pebble, subangular to rounded, could be observed, but no zone or bed containing sorted pebbles of any size or number was observed.

The contact between the upper Alpine sediments and the overlying Bonneville sands and gravels is not well defined as the Bonneville sands undoubtedly contain large amounts of reworked Alpine sediments. In the larger gullies cut by the main drainages developed on the north side of the East Traverse Mountains, a coarse debris flanks the sides of the gullies which is interpreted as stream gravel and slope wash material.

Andesite boulders up to 12 feet in diameter, half exposed, are embedded near the head of the ravines north of Red Rock. This coarse fan material was deposited on the bench formed at the Bonneville level. Coarse gravels also occur east of Steep Mountain in the mouth of Oak Hollow with an abundance of quart-monzonite and andesite cobbles. West of this area small gullies which cut the Bonneville bench above the 5100 foot contour do not show a coarse facies to be present. If such a facies is present, it is not extensive, and it is effectively covered by talus and a mantle of soil. Discoidal pebbles are scattered along the Bonneville bench, but not in great abundance.

In the mouth of Corner Creek Canyon, stream gravels occur above Alpine sediments to an elevation in excess of 5160 feet, possibly due, in part, to faulting and the development of alluvial fans. Gilbert (1928, p. 29) considered these gravels to have formed a bar preventing the waves of Lake Bonneville from cutting cliffs along the canyon walls. The sediments in this area are very coarse, showing an abundance of stream boulders. Alpine deposits are well developed on the north and south sides of Corner Creek, and the writer believes that they once reached across the mouth of the canyon and were later removed by erosion. During Lake Bonneville stage, the area was probably filled in again with stream boulders and debris which has subsequently been cut away by stream erosion.

Post-Provo Deposits

Younger unconsolidated materials in the form of slope wash, eroded fanglomerate, colluvium, slump, alluvial fans, glacial moraines and outwash plains, fluviatile deposits, and deep soils cover most of the bedded sediments.

In the mouth of Alpine Canyon two periods of Pleistocene glaciation are recorded in the form of lateral and terminal moraines. Glacial outwash plains derived from the morainal material have previously been discussed in relation with Lake Bonneville sediments. Alluvial fan and fluviatile material is currently being deposited north and east of Alpine in the lower parts of Alpine Canyon.

Fluviatile and slope wash materials consisting of subangular to subrounded boulders up to two and three feet in diameter have been deposited on the higher elevations south of Nephs Lake. On the slopes and ridges farther south, the Pennsylvanian Oquirrh bedrock is mantled with angular slope wash debris derived primarily from its quartzites. Between the mouth of Fort Canyon and Big Hollow, it is difficult to distinguish the eroded fanglomerate from slope wash material.

Fort Canyon is covered by recent alluvium which merges with the slope wash and soil material on the lower flanks of the canyon slopes.

Between Fort Canyon and Hog Hollow, the few outcrops of bedrock consisting of Oquirrh orthoquartzites are represented by outcrop and dip and strike symbols on the geologic map (Plate VIII). Slope wash consisting of debris from the Oquirrh formation covers most of this area. Several exposures developed along road cuts, drainage controls, slump slides and watering reservoirs indicate that the slope wash is frequently in excess of 20 feet. Its maximum depth is not known. Enough bedrock was found, however, to regard it as essentially Oquirrh. Some volcanic flow rock is scattered throughout the slope wash, and it may represent two to three per cent of the detrital material.

The fault zone located next to the intrusive is characterized by a hummocky topography, suggesting slumping as described by Gilbert (1928, p. 27); some of the low rounded knobs, however, might be eroded fault blocks in the zone of faulting.

A coarse slope wash material covers the area between Mercer Hollow and Hog Hollow, extending from the bottom of Jacob's Ladder west and south to merge with the elevated fanglomerate. The boulders are angular to subangular in shape, composed mainly of quartzites and a few volcanics embedded in soil.

Clay and soil cover the narrow belt of volcanics, and Hunt suggests that the clay may be extensive enough to be used for brick-making material.

West of the volcanic belt and along the south flank of the East Traverse Mountains below the 5600 foot contour level, there occurs an erosional surface which is covered with fluviatile deposits and alluvial fan material. With progressive faulting the older gravel deposits have been eroded and later covered with recent stream gravels at lower elevations. The lithology is primarily that of Oquirrh orthoquartzites, but a large fraction of volcanic material is also present. This surface is well developed west of Dry Hollow. The fault that flanks the southern margin of the East Traverse Mountains exposes alluvial material overlying volcanic flow rocks which suggests that during Tertiary time the lower drainages were filled with volcanic flow rocks. Later faulting appears to have elevated blocks of Oquirrh orthoquartzites which have supplied detrital material, filling the old drainages, and subsequent faulting and erosion have developed new drainage patterns superimposed upon the ancient drainage. Plate IV, figure 3, shows a prospect following the relief of an old topography which dips 36^{o} away from the current drainage. The alluvial fan material which covers the old topography is derived entirely from the Oquirrh quartzite, and it is so clean that it resembles the orthoquartzite breccia in places.

Slump fans occur along the north flank fault; fluviatile gravel deposits overlie the lake sediments in front of the larger drainages.

Due to the highly fractured nature of the bedrock and the past humid climatic cycles, a deep soil profile has developed over most of the East Traverse Mountains.

IGNEOUS ROCKS

Cottonwood Intrusive

From the northeast corner of the Lehi quadrangle map, quartz-monzonite of Little Cottonwood stock extends for four miles to the west, nearly one mile to the south, and to an elevation of 7500 feet, covering approximately two square miles of the map area. The stock covers nearly 25 square miles. It was first considered to be Archean by the 40th Parallel Survey; later its intrusive nature was interpreted by Geikie in 1880, and later verified by Van Hise, Boutwell and Emmons. At present, the stock is considered to be late Eocene (Crittenden, 1952, p. 18).

Butler (1920, p. 239) described the stock as a granodiorite, giving the following chemical analysis on page 95:

SiO_2	67.02	Na_2O	3.85	CO_2	---
Al_2O_3	15.78	K_2O	3.67	P_2O_5	.26
Fe_2O_3	1.56	H_2O-	.29	S	.03
FeO	2.8	H_2O+	.63	MnO	.02
MgO	1.09	TiO_2	.37	BaO	.13
CaO	3.31	SiO_2	.04		

These same values are given in Professional Paper 201, where the stock is described as a quartz-monzonite intrusive.

The texture of the rock is quite uniform, appearing slightly coarser in lower exposures located near the fault. Where the stock is free of extensive jointing and fracturing, outcrops are light gray in color and distinctly porphyritic with phenocrysts, generally less than half an inch in diameter. In hand specimens, phenocrysts of pure white plagioclase, gray quartz, and irregular particles of biotite scattered nearly contiguously throughout, gives the rock a light gray appearance. Phenocrysts of potash feldspar are very inconspicuous on weathered surfaces, but on freshly fractured samples they have a light fleshy pink color without any definite crystal outline, and it is reported to be 60 per cent as abundant as plagioclase. Butler (1943, p. 39) notes that hornblende and biotite are more abundant near the contact than in areas where deep erosion has exposed the inner parts of the intrusive. This is the case on the southern flank of the intrusive.

The ground mass has a medium-grained granitic texture composed mainly of pure white, slightly transparent plagioclase, grayish quartz and a little interstitial orthoclase. Dark minerals are dominated by biotite, accompanied by a little hornblende, titanite and magnetite.

Butler (1943, p. 39) lists the original minerals seen in thin section, indicating their relative abundance as follows:

> "Plagioclase > quartz > orthoclase >> biotite >> hornblende > magnetite >< titanite > apatite >> zircon. A little secondary calcite, chlorite, sercite, and pyrite are found."

Outcrops are frequently cut by aplite dikes, ranging from small stringers to four inches thick; they are generally very light in color and more resistant than the quartz-monzonite; thus occurring as elevated patterns across the outcrops.

On one exposure approximately 12 feet in diameter, four dark, nearly round inclusions were observed, ranging from less than a foot to two feet in diameter. The inclusions contained phenocrysts of feldspar which approached three-fourths of an inch in diameter in a ground mass of dark mafic minerals. Similar features were described by Butler (1920, p. 240) as follows:

> "Dark inclusions, commonly a few inches in diameter composed of the same minerals as the dominant rock but containing a greater portion of plagioclase, biotite, hornblende and accessories, are abundant and conspicuous in the Little Cottonwood stock. They are regarded as representing material which crystallized against the walls of the stock at an early period and was subsequently broken up and scattered through the magma."

Later Butler (1943, p. 39) mentions similar structures associating their origin with dike material.

Near the zone of faulting, the quartz-monzonite occurs in several highly altered forms, and where extensive fracturing occurs, the femic minerals are altered to chlorite and epidote, giving the rock a green color. In places the dark minerals have been completely removed. Other features related to faulting will be discussed later.

Plate VI, figure 2, shows the south face of the intrusive with the faint trace of two ancient erosional surfaces that dip to the west. Aretes are also well exposed with associated hummocky moraines developed below, recording in part Pleistocene glaciation that occurred in the higher elevations. This area is located just above the northern limits of the Lehi quadrangle.

Extrusive Flows

Volcanic flow rocks were first mapped in the East Traverse Mountains by the 40th Parallel Survey and identified primarily as trachyte. At that time, the East Traverse Mountains were considered to consist mainly of volcanics. Beeson (1925, p. 76) published a map showing the narrow belt of volcanics in their relative proportion and location, referring to them as "largely andesites."

A comprehensive and detailed study of the volcanics of the Traverse Mountains by Wimber (1931) and Marsell (1932) showed that trachyte is rare and that andesite covers most of the area. This study was later verified by the boring of the Alpine-Draper tunnel for the Salt Lake City aqueduct (Plate V).

Murdock (1941) shows that andesite porphyry represented by far the most abundant material encountered while digging the tunnel. Although the volcanic section was highly fractured and weathered, four sections were sound and hard enough to stand without support. Murdock also noted that the quartzites were highly fractured, suggesting to the author that the quartzites were extensively brecciated prior to being covered by volcanic flows.

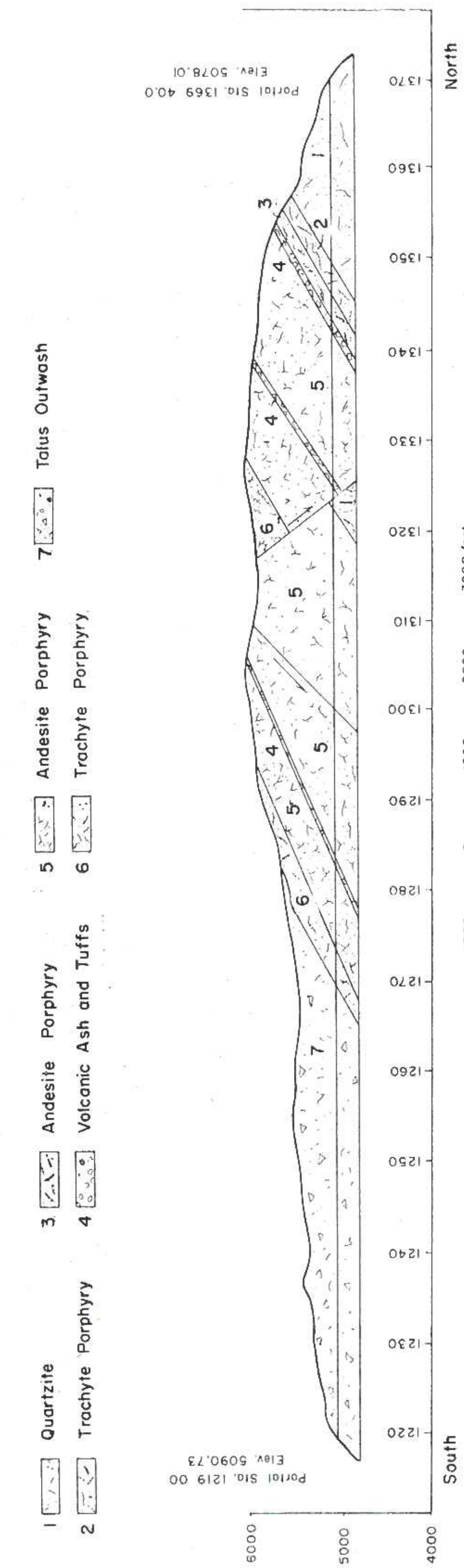
Marsell (1932, p. 58) remarks that the lavas of this area are quite uniform in character, readily divided into two principal types: "Andesite porphyry and augite-andesite porphyry, the former being by far the most widespread."

Five distinctly different samples were collected, and identified microscopically as andesites by Mr. Glenn Thomas. In two of the samples the groundmass represented nearly 75 per cent of the rock mass. Chemical analysis of similar flows located in the West Traverse Range, Bullock (1951, p. 32) and Gilluly (1932, p. 46) showed that the potassium oxide approximately equals the sodium oxide, suggesting that latites may be present in the East Traverse Mountains.

Due to extensive fracturing and weathering, it was not possible to differentiate the flows. The high content of magnetite which occurs in most of the andesite flow rock makes it difficult to obtain reliable strike readings, but where the attitude of the flow rocks was available, the highly faulted nature of the flow structures is at once apparent. Murdock (1941) remarks that old erosion surfaces between contacts of andesite and trachyte flows indicate long periods of weathering between successive flows. Flow structure of volcanic breccias were encountered, but not very frequently.

Probably the best exposure of andesite flow structure showing the greatest variation in appearance occurs in the steep canyon located just

Plate V



Structural Section Along Alpine-Draper Tunnel
after J.N. Murdock Sept. 1941

east of the road that traverses the north flank of the East Traverse Range. Where the road leaves the bottom of the canyon, making its first switch-back, the road-cut exposes a white to grayish white andesite flow. The attitude of the beds shows a strike of N. 35^{o} - 40^{o} E., dipping 22^{o} SE., and they are crudely stratiform.

Phenocrysts, dominantly andesine, occur in two generations, ranging up to 4 mm. in size scattered through a ground mass of glass which makes up 75 per cent of the rock.

Crystals of biotite and an abundance of hornblende laths evenly spaced through the rock give it a gray color.

In thin section, the primary minerals were identified as andesine and biotite, with accessory minerals consisting of magnetite, hypersthene, hornblende and augite. No quartz was observed in the sample.

A coarse reddish-gray to purplish-gray-colored porphyritic andesite flow characteristic of most of the flow rocks in this area overlies the white andesites. Marsell (1932, p. 63) has adequately described these flows as follows:

> "Local phases of the series show considerable variations in color and texture, and even in mineral composition. The typical rock in hand specimen has a coarse, porphyritic texture, a trachytic 'feel', and a vesicular structure.
>
> "In thin section, the rock is coarsely porphyritic. The chief mineral is oligoclase with a composition of Ab72 An28. The feldspar shows prominent zonal growth. Biotite is the chief femic mineral, accompanied by smaller amounts of hornblende and augite. Occasionally a little pleochroic hypersthene is present. Accessory minerals are magnetite, ilmenite, apatite, and rutile. All of the minerals have been considerably altered, the ferromagnesian in particular. Biotite shows alteration to chlorite, magnetite, and brown iron-oxides. Augite and hornblende crystals often display reaction rims of secondary minerals as a result of corrosion. Secondary caccite and sericite both appear as veinlets separating the mineral fragments. Some of the large feldspar pheno-crysts contain glass inclusions in which large bubbles appear. In general the feldspars are much fresher in appearance than the femic minerals. The groundmass is largely com-posed of gray glass filled with abundant laths and felty microlites of feldspar. The glassy base is commonly fluidal, showing flow orientation of the smaller feldspar laths and microlites.

> "The varieties of the red andesite flows include rocks that range in composition from auganite porphyry in which the chief feldspar is labradorite, of composition Ab42 An58, to black vitrophere."

Located in the lower half of the NE 1/4, Sec. 9, T. 4 S., R. 1 E., a dark black vitriphyric basalt flow crops out in the bottom of the canyon.

In thin section the texture is microlitic; an occasional pheno-cryst of labradorite in excess of 1 mm. makes the rock porphyritic. Generally the grain size is less than 1 mm. The approximate mineral composition present includes: primary essential minerals, labradorite 40 per cent and glass 42 per cent; primary accessory minerals, magnetite 4 per cent, apatite 1 per cent, biotite 1 per cent, lamprobolite 10 per cent, and augite 2 per cent. Labrodorite crystals show zoning and alteration to zeolites. The sample is classified as a vitrophyric basalt (2312 E) according to Johannsen's system (1937, p. 289).

Trachyte flows were mapped by Murdock (1941), but they were not observed by the writer.

Pebble Dikes

Throughout the area on the north flank of the East Traverse Range, an occasional piece of float rock composed of a pebble conglomerate may be found. The pebble fragments consist primarily of quartzite, which ranges in size from the rock flour matrix to fragments up to two or three inches in diameter. Rounded pebbles are common, but in general, the fragments are angular, subangular to subrounded in form. Fragments composed of quartz-monzonite, chert, and volcanic flow rocks are also present. Veinlets of chalcedony and opal are abundant throughout the conglomerate, and they are observed to cut pebbles, indicating a post-cementingorigin.

Pebble dike outcrops were observed at three different locations on the north flank of the East Traverse Mountains, and in each case they are observed to cut volcanics. Marsell (1932, p. 73) was the first to discover and describe the pebble dikes in the East Traverse Mountains, and he also directed the writer to the location of the dike which he described. The pebble dike described by Marsell (1932, pp. 73-78) is located on a pinnacle on the north flank of the range and in the southeast corner of the SW 1/4, Sec. 9, T. 4 S., R. 1 E. This location is less than a five-minute walk from a jeep road which traverses the summit of the range. The largest outcrop of the pebble dike occurs in a small saddle northwest of the pinnacle just above the 6100 foot contour level. Here the outcrop is elliptical in shape, but it trends towards the south around the west side of the pinnacle.

Marsell (1932, p. 74) has adequately described this pebble dike as follows:

> "In thin section, the groundmass in which the larger fragments and pebbles lie embedded is found to consist of a finely ground up aggregate of quartzite and granite rock flour, sprinkled with sharply angular fragments, which are mainly pieces of quartzite, although some slides show tiny bits of andesite, chert, and granite. Wisp-like shreds of sericite occur sparingly. This clastic aggregate is firmly cemented in a groundmass of cryptocrystalline quartz and opal, with numerous veinlets of fibrous chalcedony showing colloform structure. The grains of the quartzite particles show intense fracturing and granulation, especially around the borders of the particles and later recrystallized. Highly shredded flakes of biotite are scattered through the groundmass, which also contains grains of highly pleochroic hornblende and an occasional rounded remnant of orthoclase feldspar. The enclosed fragments of andesite porphyry are almost completely replaced by opal and cryptocrystalline quartz."

Just below this location and within the volcanic area above the 6000 foot level a quartzite breccia dike void of quartz-monzonite and other foreign pebbles also occurs.

Approximately a quarter of a mile due west of the pebble dike described by Marsell (1932) another pebble dike was observed, located in a saddle in the northeast corner of the NE 1/4, Sec. 17, T. 4 S., R. 1 E. of the Lehi quadrangle. The petrography of this pebble dike closely resembles that described above, but there is a decrease in the occurrence of quartz-monzonite pebbles. Float rock from this dike was found in abundance northeast and southwest of the dike, but the limits of the dike are approximately 90 to 110 feet long, trending northwest along the crest of the saddle and from a few feet to about 30 feet wide. The pebble dike material does not extend above the general topography, but it occurs at ground level as do all of the dikes which were observed.

A much smaller pebble dike exposure was also mapped near the margin of the volcanics in the southeast corner of the NW 1/4, NE 1/4, Sec. 9, T. 4 S., R 1. E. of this quadrangle. The petrography of this dike

is essentially the same as that described by Marsell; quartz-monzonite pebbles are abundant.

Marsell (1932, pp. 76-77) reviewed some of the possible environmental conditions relating to the origin of pebble dikes, which closely approach the present-day concept regarding their unique behavior.

Recent study related to pebble dikes in the Tintic Mining district by Farmin and Rollin (1934), Lovering (1949), Cook (1957), has extended the volume of facts revealing the nature of pebble dikes, and the present consensus of opinion is expressed by Morris (1957, p. 38) as follows:

> "Some of the pebble dikes apparently were emplaced by the sudden upwelling of viscous monzonite magma, but most of them seem to have been exploded into place by rapidly expanding gases, perhaps composed chiefly of steam generated by the instantaneous heating of groundwater by invading monzonite magma, in individual explosions triggered by tensional fault adjustments. This mode of emplacement has been descriptively though inelegantly termed a volcanic burp."

Observations of the writer indicate that the pebble dikes are generally associated with areas which show evidence of faulting, and it seems logical to conclude that the pebble dikes within this area, too, may be attributed to "volcanic burps" which have followed such zones of weakness.

CONTACT METAMORPHISM

Metamorphism of any importance that could be associated with the intrusion of the Little Cottonwood stock is absent for the most part in the Oquirrh sediments, probably due to erosion and recent faulting. However, a prospect which occurs approximately 300 feet southwest of Nephs Lake shows a crushed quartz-monzonite on the dump with specimens of garnitiferous country rock scattered about the mine portal. Approximately a quarter of a mile south of Nephs Lake there is a tactite zone that is highly brecciated. A large coarse-grained marblized boulder occurs east of the tactite zone, and altered breccias are found along the Alpine Canyon scarp. These features are indicative of the metamorphism that has taken place, and the rocks that have been altered are most likely of Oquirrh age.

HYDROTHERMAL ALTERATION

Along the south flank of the East Traverse Mountains, hydrothermal alteration is quite extensive, being confined generally to the andesite flows, although large quantities of silica have been deposited in the quartzite breccias within fault zones.

Located in the southwest corner of the central belt of andesite flows on the east flank of Maple Hollow, an extensive belt of silicified andesites occurs as bold outcrops. This zone may be extended up the bottom of the canyon for nearly 1200 feet. Small outcrops were also traced almost continuously in a direction N. 17° W. nearly to the summit of the range. This is in direct line with those that occur on the summit of the range and also in line with the pebble dike described in this report. The main body of silicified andesites is approximately 150 feet wide and holds this width for about 500 feet along the margin of the flow rocks. Vitreous, cream to gray-colored outcrops mark the outer zones of complete silicification; towards the central part of the silicified zone, the opalized andesites show various shades of pink, lavender, and brownish-red, increasing to a bright carmine red jasper. The silicification suggests upward-migrating, silica-rich hydrothermal fluids. Jasperoidization which occurred in the center of the silicified zone was probably closer to the fissures carrying solutions rich in iron and silica.

The siliceous material is very brittle and vuggy. In thin section, minute veins of chalcedony cut the red mass of opal which shows the ghost structures of feldspar phenocrysts which are replaced by colorless opal. Crustiform bands of chalcedony line the vuggy cavities. Replaced magnitite is represented by dark red iron oxide spotted through the mass.

Another silicified zone occurs directly in the center of section 29 on the south flank of the East Traverse Range. Here the silicified andesite breccia weathers a light tan to white color, while on freshly fractured surfaces the rock is a greenish-gray color, spotted with white opalized feldspar phenocrysts.

This zone has been quarried, and the exposure shows the original flow structure of the rock which varies in light shades of gray and tan due, possibly, to the amount of iron originally present in the flow or possibly to the amount of replacement. Northeast of the pit complete silicification grades into a zone of kaolinization. Here the replaced material is distinctly an andesite breccia which also contains quartzite fragments of the Oquirrh bedrock. The fragments are generally angular and may appear in various colors of gray, tan, pink, lavender, and white. Angular fragments of andesite appear as white kaolin, and in thin section they frequently show transparent, opalized feldspar phenocryst structures.

Other zones of hydrothermal alteration occur approximately half a mile west of the pit, on the summit southeast of the pebble dike, and on the extrusive contact southeast of Draper portal on the Salt Lake City aqueduct.

In the East Tintic Mining District similar alteration zones have been used as general guides to ore. In that district jasperoid was found in abundance and related to a stage of late barren alteration, but closely associated to fissures which later carried ore-bearing solutions.

Howd (1957, p. 132) remarks that Bear Creek Mining Company made a concentrated study on jasperoidization, comparing samples collected from nonproductive Jenny Lind Unit with samples associated with known ore bodies in the Tintic and East Tintic mining districts. By assigning point values to textural and compositional properties, a useable guide was developed that enabled Bear Creek to distinguish the productive jasperoids from the barren types. Then, if the productive-type jasperoid is found associated with favorable factors such as structure, lithology, and additional hydrothermal alteration, it is considered to be a possible guide to ore. They have found, too, that the chances of finding ore are very good if the alteration sequence is from limestone → dolomite → jasperoid → pyritic baritic jasperoid. Such zones were not observed in the East Traverse Mountains.

STRUCTURE

> ". . . and they are so amazingly complex that the writer, in his endeavors to interpret them, has proceeded only slowly from bewilderment to partial understanding." (L. F. Noble, 1941).

In the past the East Traverse Mountains have been described as an area of mature topography, void of outcrops and sculptured from bedrock composed of homogeneous lithology highly brecciated by faulting and jointing. At present the East Traverse Mountains are considered to be a fault block spur, inseparably related to the evolution of Wasatch faulting, acting as a unit, yet expressing extensive internal adjustment along zones of previously developed weakness. Section A-A' shown on Plate VIII taken along the general axial trend of the East Traverse Mountains, shows a simplified interpretation of the apparent structure. Plate V shows a cross section perpendicular to the trend of the range.

Previous Work

Emmons (1876, p. 439) briefly describes the East Traverse Mountains as follows:

> "These hills show but few good exposures of the rocks which composed them, their slopes being generally covered with gravel and detrital material . . . their structure lines were too much obscured to afford indication of their stratigraphic grounds."

By the early nineteen hundreds, emphasis of regional trends had developed within the area. Butler's work regarding the ore deposits of Utah, published in 1920, set a pattern which was to influence the work of later geologists. In this report, Butler (1920, p. 100) writes that broad uplifts and anticlinal folding or doming of rocks was of prime importance, some of which show a distinct trend, and of these he writes:

> "Among these with a distinct trend are the great east-west Uinta uplift and its westward extension through the Wasatch and Oquirrh ranges . . ."

This concept is distinctly illustrated in Plate XI of that report.

Later Beeson (1925, p. 14), in describing the trend of the Uinta Mountains, extended their regional trends through the Wasatch Mountains, the Oquirrh Mountains, in the vicinity of Bingham and to the Stansbury Range.

Gilbert (1928, p. 27) discussed the East Traverse Mountains and designated them the "Traverse Spur"; and of the range he wrote:

> "The age and structure of the sedimentary rocks have not been determined, but there can be little question that the formations are Paleozoic and that they have shared in the early diastrophic changes of the rocks of that range."

From the current interpretation regarding the evolution of the East Traverse Mountains as a fault spur, the presence of fault scarps and fault line scarps would be expected. Although Gilbert was cognizant of this, the exaggerated influence of Lake Bonneville to produce sea cliffs and erosional shore line features prevented him from recognizing such fault structures. This fact is apparent as he (1928, pp. 27-29) wrote:

> "Post-Bonneville scarps of the usual type follow the base of the range on both sides of the spur and disappear at the junction of the spur and range. A careful scrutiny of the alluvial apron of the spur discovered no similar scarp . . .

> "Definite evidence of faulting was not found along the outer margin of the spur . . . Perhaps the best indication of the position of the hypothetic fault is given by a group of warm springs about half a mile northwest of the tract in which the foundation rocks are exposed."

Marsell (1932, pp. 85-86) preferred to interpret the structure in the East Traverse Mountains as "a steeply pitching anticlinal nose, which, in the vicinity of the Jordan Narrows, appears to merge with the homocline of the West Traverse Mass." Concerning faulting Marsell (1932, p. 91) writes:

> ". . . the findings, after a most careful investigation, failed completely to support the hypothesis that Basin-Range faults exist in the Traverse Mountains or bound them, except for the Wasatch fault which separates the East Traverse mass from the Wasatch Mountains. No fresh scarps are present. The mountains do not have a linear base, their outline is patchy and sprawling, with long, gently sloping spurs that gradually disappear beneath the alluvium of the bordering valleys. Faceted spurs are common but they are the result of wave erosion and not faulting."

Eardley (1933, p. 254) effectively demonstrated that this area expressed strong topographical relief prior to Wasatch faulting.

Recently the concept regarding the westward extension of the Uinta arch was again expressed by Crittenden (1952, p. 1):

> "The segment of the Wasatch Range to the described here lies just north of its intersection with the westward continuation of the Uinta Range (Plate 1). Its structure therefore, includes the westward prolongation of the Uinta arch which crosses the range near Alta, and an equally large and important syncline which crosses the range near Parley's Canyon."

However, he does not include the East Traverse Mountains as part of this structure.

Dolan (1956, p. 13) relies upon the structural interpretation of Marsell and reflects a more current belief regarding the structure of the East Traverse Mountains as follows:

> "Marsell explains it (structure of the Range) by deducing, from material found in some pebble dikes on the north side of the range and from the anticlinal appearance of the range (east-west axis), that the range probably has the following structure: (1) the range is probably underlain by a granitic intrusive body, similar and conceivably related to the Little Cottonwood Stock in the Wasatch Mountains immediately to the east, (2) as a result it has its anticlinal structure, and (3) it emerged from the structural evolution of the Wasatch as a faulted spur."

A regional gravity survey, not yet published, was made by Cook and Berg of the University of Utah. The results of their work were presented and abstracted for the A. A. P. G. meetings held in Salt Lake City during February, 1957; the program states the following:

> "The gravity data give no evidence that the Uinta arch extends west of the Wasatch front. Steep gravity gradients corresponding with Basin and Range faults occur along (1) parts of the Wasatch fault zone; (2) a continuous fault zone 60 miles in length along the west margin of the Oquirrh, Boulter and East Tintic Mountains; and (3) the Utah Lake fault zone east of Lake Mountain and West Mountain. A gravity high corresponding to the great fault block comprising the Oquirrh,

Boulter, and the northern part of the East Tintic Mountains. The gravity data indicate that in the valley areas between this fault block and the Wasatch fault block, a great intermont trough more than 100 miles long comprises a great belt of graben and smaller fault blocks of varied dislocations. Several large fragments lying immediately west of the Wasatch block have apparently dropped deeper than the other fragments as if slipping into a great crevasse."

Glenn Thomas (personal communication), who has had occasion to review magnetic survey maps of this general area, has never observed magnetometer or gravitational indications of unexposed igneous intrusives of any size in this area. The Little Cottonwood stock is confined generally to the area of exposure.

The following summary of tectonic events affecting the geology of this immediate area is taken from Eardley (1951, pp. 325-336) and Crittenden (1952, pp. 33-37).

Eastward thrusting associated with the Cedar Hills orogeny began somewhere near Middle Cretaceous time. Following this disturbance the Laramide orogeny was initiated during early-late Montanan time with compressional forces which gave rise to the east-west folds occurring east of Salt Lake City. These folds are referred to as "wrinkles" which developed as folds superimposed on a large syncline developed between the Cottonwood uplift and the Utah uplift elevated during early-late Montanan time. Late Cretaceous thrusting towards the east followed the east-west folding; the folding and faulting of the Oquirrh Range also occurred about this time. During Paleocene time, the Uinta arch was also initially elevated.

The middle Laramide orogeny was recorded by an angular unconformity within the Wasatch conglomerate during Paleocene time. Late Laramide forces developed during middle or late Eocene are recorded in the broad, gentle folds which were superimposed upon the older structures, thus defining the modern ranges for the first time; and the Uintas were again more fully defined.

At the close of Eocene time, a number of orogenic events occurred which are considered to be post-Laramide: (1) volcanic conglomerates, sands, tuffs, and volcanic flows occurred in the Park City volcanic area associated with the intrusion of the Clayton, Alta, and Little Cottonwood intrusive; and (2) the Uinta arch was finally completely defined.

Oligocene time was punctuated by the Absorokan orogeny, characterized mainly by volcanism, some folding, erosion that continued

through middle or late Miocene time, and minor normal faulting was also recorded.

Periodical Basin and Range faulting, beginning in late middle or early late Miocene time, is believed to have been more or less continuous up to the present time (Eardley, 1951, p. 481). The major movement along the Wasatch fault, however, is believed to have started in late Pliocene time with most of the displacement occurring during early Pleistocene time.

Faults

Pre-Wasatch Faulting - Observations Related to Post-Intrusive Thrusting

Effects of post-intrusive thrusting have been observed along the lower margins of the Cottonwood intrusive since the 40th Parallel Survey, and yet, the time of thrusting associated with the mylonite in this area is not well understood by geologists today.

Recorded in the 40th Parallel Exploration report (1877, pp. 139-140) a mylonite zone was described:

> "Near the point of contact with the granite mass of Lone Peak, there is found a greenish-white earthy, decomposed rock, in which the only traces of crystallization left are white irregular spots of partially kaolinized feldspar."

At that time the Cottonwood stock was considered to be Archaean in age, but there is no evidence to indicate that the greenish material was associated with shearing.

Cretaceous thrusting has been suspected in the Wasatch Range since the turn of the century as expressed by Butler (1920, p. 101):

> "The reverse and overthrust faults are largely confined to the areas of rather close folding and to areas adjacent to igneous intrusions . . . Little detailed geologic work has been done in the Wasatch Range and there is little doubt that overthrust faults are more abundant there than is at present known."

Beeson (1925, pp. 763-767) echoes an awareness of overthrusts by stating:

> "A chain of great overthrust faults extend from

southeastern Nevada to the Canadian boundary, as shown in Fig. 1."

This was followed by a list of 22 faults including the Mt. Nebo, Willard, and Bannock overthrusts.

While mapping the Wasatch fault, Gilbert (1928, pp. 14-15) was aware of the mylonite outcrops along the southwestern margin of the Cottonwood intrusive, of which he remarks:

"In an outer zone the granite is sheared and close to its outer surface is foliated, the foliation being parallel to the slope, which is at an angle of 29°. No slipping surfaces were discovered. The depth of the modified zone can not be stated, as the unmodified granite was not there seen in place, but the amount of change, as expressed by the development of parallel structure, was seen to diminish with distance from the outer face. Specimens were examined by Mr. Adolph Knopf, who characterized the less foliated rock as 'a crushed granite consisting of microcline, quartz and chloritized biotite" and the more foliated as 'a green schistose rock composed of quartz, feldspar, and epidote.' Of the schistose rock he says: 'It is probably represented by the first-mentioned specimen."

A. A. Baker, whose work is not yet published, has recently mapped the area east and south of the Lehi quadrangle. In a preliminary report, Baker (1949, p. 1196) writes that the main thrust fault has been traced from east of Heber west where it has probably been involved with deformation associated with the intrusion of the Cottonwood stock. Of the westward trace of the fault he writes:

"The occurrence of the thick section of late Paleozoic rocks in the Oquirrh Mountains and of the thin section in the Cottonwood region of the Wasatch Mountains indicates that the trace of the thrust fault follows the intervening valley where it is concealed by the sediments of Lake Bonneville. Thrust faults farther north in the Promontory Range, near Willard, and elsewhere in north-central Utah may represent a continuation of the same zone of thrust faulting, but continuity can not now be demonstrated."

Eardley (1951, pp. 329-330, Fig. 189) has correlated the late Cretaceous thrusting, stating:

". . . it seems to the writer that the Willard must be the same as the great thrust sheet that exists in the Provo section of the Wasatch. This is also probably the same as the Nebo thrust (Eardley, 1934), and the thrust in the Canyon Range (Christiansen, 1948)."

Christiansen (1950, p. 1450) suggests that evidence observed in the vicinity of Corner Creek Canyon may indicate post-intrusive thrusting. He writes:

"Evidence is accumulating which indicates that the scarp of the central Wasatch Mountains between Draper and Alpine and probably also north and south of this area is the stripped and slightly modified sole of a major thrust zone. Stripping and laying bare of the thrust surface was accomplished by late Tertiary erosion and probably by local normal faulting on the thrust surface in a reversed direction from the thrust movement. The following is a summary of the evidence supporting this conclusion:

"(1) Radical facies difference of contemporaneous strata . . .

"(2) Presence of a thick zone (300 feet) of mylonite . . .

"(3) Presence of a slice of Carboniferous (?) crinoidal limestone, on pre-Cambrian quartzites . . .

"(4) The relatively low (15° - 20°) essentially unbroken, slightly convex profile of the Wasatch frontal slope . . . "

To complete the discussion of the complexity of this fault zone, Crittenden (1952, pp. 29-30) notes the offset around the Cottonwood intrusive between Draper and Alpine is near the point of intersection of the Charleston, Deer Creek, and the Wasatch faults.

The presence of the Oquirrh formation in fault contact with the Cottonwood intrusive is substantial evidence indicating that the Charleston fault probably developed a re-entrant flanking the Cottonwood uplift, then extends northward through the Salt Lake Valley. The age of this thrusting has been demonstrated to be late Cretaceous.

Along the south face of the intrusive, shear zones are impressive. Between School House Springs and Jacob's Ladder, the intrusive contact is not well defined. Granite outcrops occur near the fault contact where Fort Creek leaves the intrusive and enters the Canyon. At this point the outer portion of the granite is capped with a foliated zone which parallels the slope of the intrusive; this mylonite is composed of crushed granite, dark green to black in color; and the femic minerals are weathered to chlorite and epidote, or they are absent entirely.

An exposure observed structurally above the foliated zone and below the alluvium showed samples of highly crushed quartz-monzonite rock which is vitreous and fleshy pink to white; the femic minerals are completely leached from the zone. Approximately 300 feet directly south from this exposure another outcrop recently exposed by stream erosion shows 75 feet to 100 feet of crushed granite which resembles a highly weathered decomposed granite. Fault planes coated with epidote occur within the exposure. This type of crushed granite is the same as that which occurs on the prospect dump southwest of Nephs Lake. The zone can be extended to the south, showing a zone of approximately 700 feet or more of shearing. School House Springs are located in this zone.

At the summit, on the contact of the intrusive below Jacob's Ladder, a green recemented, quartz-monzonite mylonite occurs. In thin section the rock shows crushed fragments of quartz-monzonite up to 6 mm. in diameter, containing quartz, feldspar and partially chloritized biotite firmly cemented in a green matrix, composed of very fine crystalline quartz, showing strain structure, epidote and opal. The extent of this zone is not well exposed, and the degree of cataclastic alteration varies greatly within small areas.

In the bottom of Corner Creek Canyon on the intrusive between the 5200 foot and the 5300 foot contour there occurs a two to four-foot zone of foliated rock composed of light green bands in a matrix of coarser, dark green to black schistic mylonite (Plate VI, figure 1). From several good exposures located near the bottom of Corner Creek Canyon, a sequence showing fresh granite, slightly crushed quartz-monzonite and covered by foliated zones of quartz-monzonite mylonites is leached of all its feldspars and femic minerals. It is laminated with a light greenish opal, which occurs in bands up to three and four inches thick. The opal is believed to have been deposited by circulating ground water which probably obtained much of its SiO_2 from the crushed mylonite carrying it in colloidal form, until it was precipitated. The foliated layer conforms to the contour of the intrusive dipping 18° to 20° toward the west.

Plate VI, figure 3, located at the bottom of the upper stranded channel of Corner Creek, shows a section of the shear zone. Fresh granite exposed in the bottom of the cut, becomes increasingly fractured, grading into a two to three-foot zone of black schistic mylonite which is firmly cemented with opal. The schistose material engulfs a mass of only slightly fractured quartz-monzonite, three to four feet in diameter; above the unfractured material the schistose mylonite grades back into a highly fractured quartz-monzonite which has been recently cut by erosion. West of this area and near the 5300 foot contour strongly foliated material caps the intrusive.

Extensive zones of mylonite, described above, indicate post-intrusive thrusting. To date, conclusive evidence indicating post-Eocene thrusting is lacking.

Butler (1943, pp. 51-60) confronted with this same problem, believed that the emplacement of the intrusives was contemporaneous with the uplift of the Uintas, and he states that "all the stocks obviously were intruded later than most of the thrust faulting." This conclusion is supported by observations which show the Alta stock (which is believed to be older than the more siliceous Cottonwood stock) cutting the Grizzly overthrust, and ore-bearing fissures cutting overthrust sheets acting as feeders of ore deposits that extend along the thrust contact. Later he writes:

> "The pushing that first produced the eastward overthrusts and later tilted them eastward may, however, have been renewed after the Uinta uplift had been established and the stocks, or some of them, had been intruded."

Eardley (1951, pp. 335-336) suggests an alternative that would explain the age and origin of the mylonite by stating:

> "These intrusive bodies may be as old as the Cottonwood uplift, but it is known that the intrusive stocks and the emplacement of the ores in the nearby mining district of Bingham, Ophir, Gold Hills, and Eureka, Utah, occurred after folding and thrusting; and students of the ore deposits in these districts are coming to view igneous activity in central and western Utah as of the same age as the extrusive activities of the Park City district, viz., late Eocene (Personal Communication, T. S. Lovering)."

A late Cretaceous age for the emplacement of the Cottonwood stock is in conflict with the Eocene age as determined by Larson's (Crittenden, 1952, p. 18) radioactive dating, and the work of others; but the shear zone along the southern margins of the intrusive can conveniently be accounted for, if the intrusive pre-dates the late Cretaceous thrusting.

Post-Intrusive Mylonite Summary

(1) An extensive mylonite zone occurring about the lower margins of the Cottonwood intrusive is definite evidence of shearing.

Plate VI

Figure 1

This picture was taken on the southwest flank of the Cottonwood stock. It shows a foliated zone of ultramylonite and mylonite with bands of opal separating the quartz-monzonite mylonite. The outcrop follows the general topography of the intrusive.

Figure 2

South flank of the Cottonwood stock taken from the west side of Fort Canyon. At least three erosional surfaces developed during Wasatch faulting are readily observed. Aretes developed during Pleistocene glaciation are present in the upper part of the Cottonwood stock.

Figure 3

A recent cut in the outer, highly fractured, zone of the intrusive is shown near the mouth of the upper stranded canyon where it enters Corner Creek Canyon.

Figure 4

This picture was taken near the summit west of Jacob's Ladder. It shows the Wasatch fault zone between the cottonwood stock and the lower Traverse Mountain spur. Four stranded channels may be seen on the intrusive; these have been described by Gilbert as once representing Corner Creek Canyon; subsequent faulting has elevated the channels.

Figure 5

A close-up of Figure 3 shows a light mass of relatively uncrushed quartz-monzonite which is surrounded by a highly fractured and crushed quartz-monzonite. The black zone located immediately below the unaltered mass is a schistic-appearing quartz-monzonite mylonite which overlies fresh quartz-monzonite.

Figure 6

This picture was taken northwest of American Fork. It shows the junction between the East Traverse Mountains and the Cottonwood stock. The low central zone shows the volcanic belt; the foreground shows the characteristic Pleistocene lake topography.

Plate IV

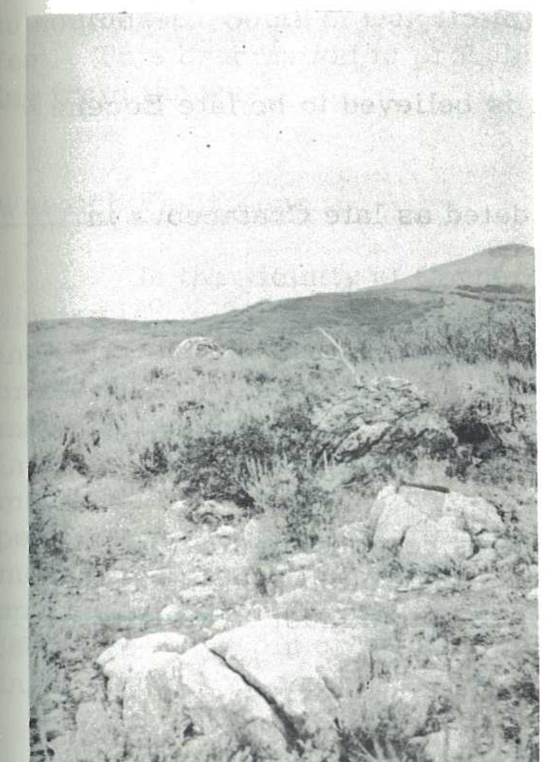


Fig. 1

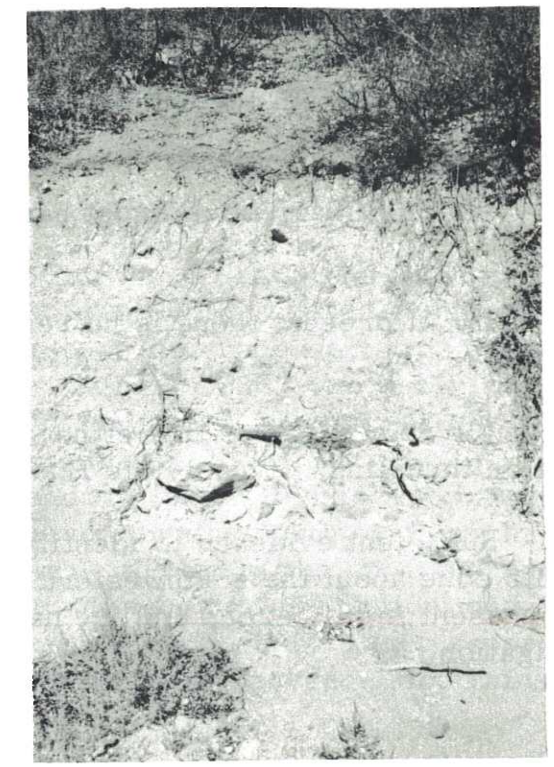


Fig. 2

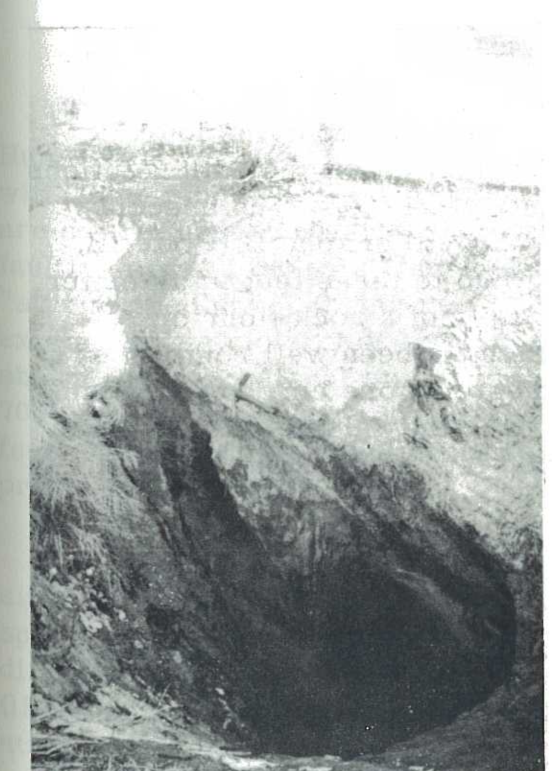


Fig. 3

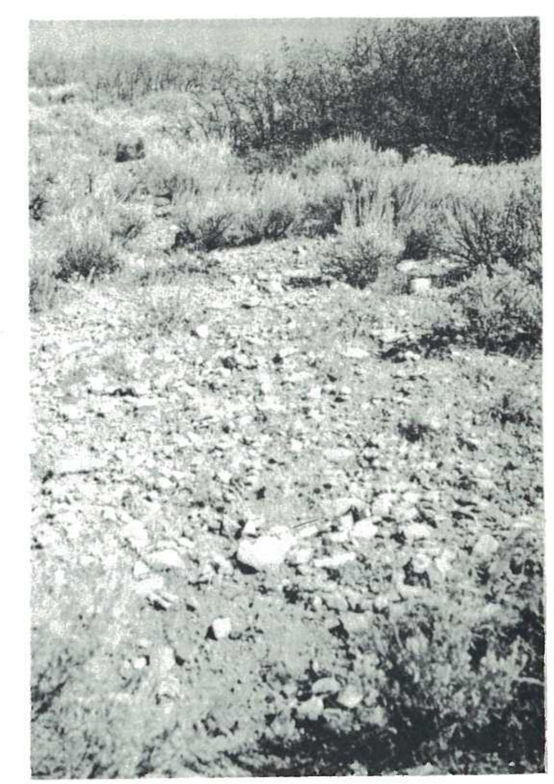


Fig. 4

(2) Mylonite is generally considered to develop only through intensive compressional forces; this would suggest post-intrusive thrusting.

(3) At present the Cottonwood stock is believed to be late Eocene in age.

(4) The Charleston thrust has been dated as late Cretaceous in age.

(5) At present there is no regional evidence of post-Eocene thrusting.

(6) This suggests that either the intrusion is older than early Laramide thrusting, or post-late Eocene thrusting has taken place.

Sufficient evidence to identify the forces responsible for the mylonite zone about the southwestern margin of the Cottonwood intrusive is not present in this area, and the nature of its origin must await further investigation.

Fault Breccia

Fault breccias, with quartzite "rock flour" and limonite-stained siliceous cement, occur frequently on the fault line scarp along the north flank of the East Traverse Mountains. In the vicinity of Red Rock, this cataclastic material is extensively developed and well exposed (Plate III, figure 2). Figure 4, plate III, shows an outcrop which contains four distinct fracture zones that have been subsequently cemented with solutions heavily charged with SiO_2 and varying amounts of Fe_2O_3. The breccia zones strike N. 45° to 47° W. and dip 35° NE. Within zone B (Plate III, figures 4 and 5) there are quartzite fragments up to three feet in diameter. Zone A (Plate III, figures 4 and 6) consist mainly of a rock flour or mylonite with larger breccia fragments which have been well rounded by friction. The rounded pebbles range from less than one cm. to three cm. in diameter. The breccia fragments do not have the varied lithology seen in the pebble dikes located approximately 2000 feet to the south on the same ridge.

An extensive breccia zone occurs in the NE 1/4, Sec. 30, T. 4 S., R. 1 E. on the south side of the East Traverse Mountains. A description of the breccia is given on previous pages. Approximately a thousand feet of breccia is in contact with a fault line scarp to the north. The breccia is separated by nearly 800 feet of Atokan sediments on the south from another breccia zone, which is also nearly a thousand feet in extent. The breccia zone strikes in an easterly direction along the south flank of the

range. Marsell (1932) has described a similar breccia zone which occurs near the west end of Steep Mountain, crossing the range from the northwest to southeast. South of Oak Hollow the zone expands to approximately 2000 feet. This brecciation is probably associated with late Cretaceous thrusting from the west.

Wasatch Fault Zone

In the vicinity of Corner Creek Canyon, a gently convexed surface dipping 18° to 20° west marks the contact between the Little Cottonwood intrusive and the East Traverse Mountains; it also represents the footwall or the Wasatch Fault scarp in this area. Gilbert (1928, pp. 14-15), while mapping the Wasatch Fault, notes that the fault zone trending N. 10° W. in the vicinity of American Fork Canyon, swings N. 80° W. near the mouth of Alpine Canyon, holding this trend for four miles as it skirts the periphery of the Little Cottonwood intrusive, turning north again at the mouth of Corner Creek Canyon. In general, the dip of the fault averages approximately 33.4°, except on the western margin of the Cottonwood intrusive. A groin, or saddle, has developed along the fault zone, separating the intrusive and the lower foothills of the East Traverse Mountains.

Hunt (1953, p. 38) comments:

> "There is no single Wasatch fault. There is, rather, a wide complex fault zone in which the greatest displacements seem to be in that part of the zone bordering the Mountain front."

Hunt (1953) remarks that A. A. Baker has mapped parallel faults deep within the mountains. Along the Wasatch front, most of the fault blocks are down-dropped to the west, and it is believed that similar block faulting occurs beneath Utah Valley. Eardley (1933) demonstrated that "strong preblock-faulting relief" of perhaps 3000 feet of topographic relief existed in the vicinity of the Little Cottonwood stock. Plate VI, Fig. 2, shows three erosional surfaces developed during Wasatch faulting. Where 7000 feet throw is expected in the vicinity of Timpanogas, possible 5000 feet throw along the fault front in this area would be sufficient to give the present topographic relief.

Plate VI, figure 4, shows the head of Corner Creek Canyon situated in the groin developed between the intrusive and the lower Traverse spur. Four channels may be seen dissecting the intrusive in a westerly direction, parallel to the channel of the present creek profile. Gilbert (1928, pp. 27-29) described them as ancient channels of Corner Creek, stranded on the face of the intrusive. Regarding them he remarks:

"The stranding of the creek channel is evidently a result of the shifting of contact between the granite and the rock of the spur . . . In intervals between fault slippings the creek has corraded the granite, and occasionally, during a long interval, it has corraded so deeply as to become entrenched."

South of the highest channel at an elevation near 5900 feet, large boulders composed of quartzite breccia and volcanic flow rocks, were found in abundance, thus marking the erosional surface once traversed by Corner Creek. As the author traversed the various channels, much of the drainage was observed to be controlled by joints trending in a westerly direction. The joint pattern and the trend of the channels closely conforms to the system recognized by Beeson (1925, p. 781) as being developed in the northeast quadrant with the major fissures striking about N. 65°E., and the minor fissures striking N. 35° E. (Plate VII).

Though the stranded channels may have been initially developed by the corrading contact between the intrusive and the sedimentary and volcanic rocks of the Traverse spur, the joint pattern appears to be a controlling factor.

Corner Creek is observed to cut fresh granite just below the upper switchback of the road that traverses the range. Here the unweathered granite is cleanly fractured into large blocks, and the stream, controlled by joints, is cutting its course through the intrusive. The fault zone in this area is covered by alluvium for the most part.

North Flank Fault

This fault scarp has been referred to by Gilbert (1890, p. 107) as a great sea cliff cut by Lake Bonneville currents and wave action which developed maximum forces while traveling the full length of the lake. The material derived from this area was transported to the Jordan Narrows area, where large spits were developed. Marsell (1932) followed the influence of this great geologist and called Steep Mountain scarp a sea cliff, but recent work done in the area by Dolan (1957) reflecting the current concept of Marsell, shows the north face of Steep Mountain as an inferred fault scarp. Large slump fans occurring along the base of the scarp and the linear occurrence of Potatoe Hill and Red Rock Hill, located east and on strike with the north face of Steep Mountain, also strongly suggests faulting. Other evidence which supports this conclusion is as follows: (1) a sudden drop in the drainage profile which has developed sharp "V" gullies, thus dissecting an ancient erosional surface (Plate III, figure 4), (2) intense brecciation and silicification occurs along the trend of the scarp, (3) two highly brecciated orthoquartzite deposits occur on strike

east of Potatoe Hill; these breccias may be reduced to a rock flour with slight pressure between the fingers, and (4) zones of silicification and kaolinization occur along the scarp.

North of the Steep Mountain scarp near the 4800 foot contour, there occurs a fault line scarp 15 to 20 feet high. Coarse volcanic boulders occur above and below the scarp which has since been covered by Lake Bonneville sediments. In the main wash that drains the area between Red Rock to Potatoe Hill, this scarp is exposed, showing an abrupt ledge which has been silicified and highly stained with iron-bearing solutions. Patches of andesite flow rocks are exposed above and along the strike of this scarp.

Other scarps may be present along the north flank of the East Traverse Mountains, but they are covered by Pleistocene Lake sediments.

South Flank Fault

Hunt (1953, p. 38) mapped and briefly described a fault along the south flank of the East Traverse Mountains. The fault displaces Pennsylvanian-Oquirrh quartzites, Tertiary volcanics and Pleistocene fanglomerate, raising them a few hundred feet, and subsequent erosion has deeply dissected them.

Towards the west end of the fault, the scarp is frequently marked by a dark red, weathered breccia. Silicification is also common along its trend.

Minor Faults

Maple Hollow Fault

Extensive breccia outcrops and the divergent attitude of bedding strongly support faulting through this Hollow. A zone of extensive silicification and hydrothermal alteration of the volcanics also demonstrates deep fissures. The thick section of volcanic flow rocks on the east wall of the canyon without any counter part to the west, suggests the volcanics on the west may have been faulted up and later eroded away.

Faults Encountered in the Draper-Alpine Tunnel

Murdock (1941) writes concerning the faulting encountered in the draper-Alpine tunnel as follows:

"Associated with the large Wasatch fault to the east, but secondary to it, are step faults, parallel faults and cross faults. Members of this group caused much of the construction difficulties involved in boring the Alpine-Draper tunnel."

To complete the section on faulting, a reproduction of the description of the faults encountered while boring the tunnel for the Salt Lake City aqueduct may prove valuable. The station numbers may be correlated with Plate V. Murdock (1941) writes:

"Fault at Station 1300+20

"This fault was striking 45 degrees west of the tunnel line and dipping about 45 degrees toward the Alpine portal. The fault plane was very evident by a two-feet layer of light colored clay 'gouge' bordered on both sides by crushed and broken breccia of red andesite porphyry. The impervious nature of the gouge had accumulated a flow of water along its upper contact so that a large flow (100 g. p. m.) was developed.

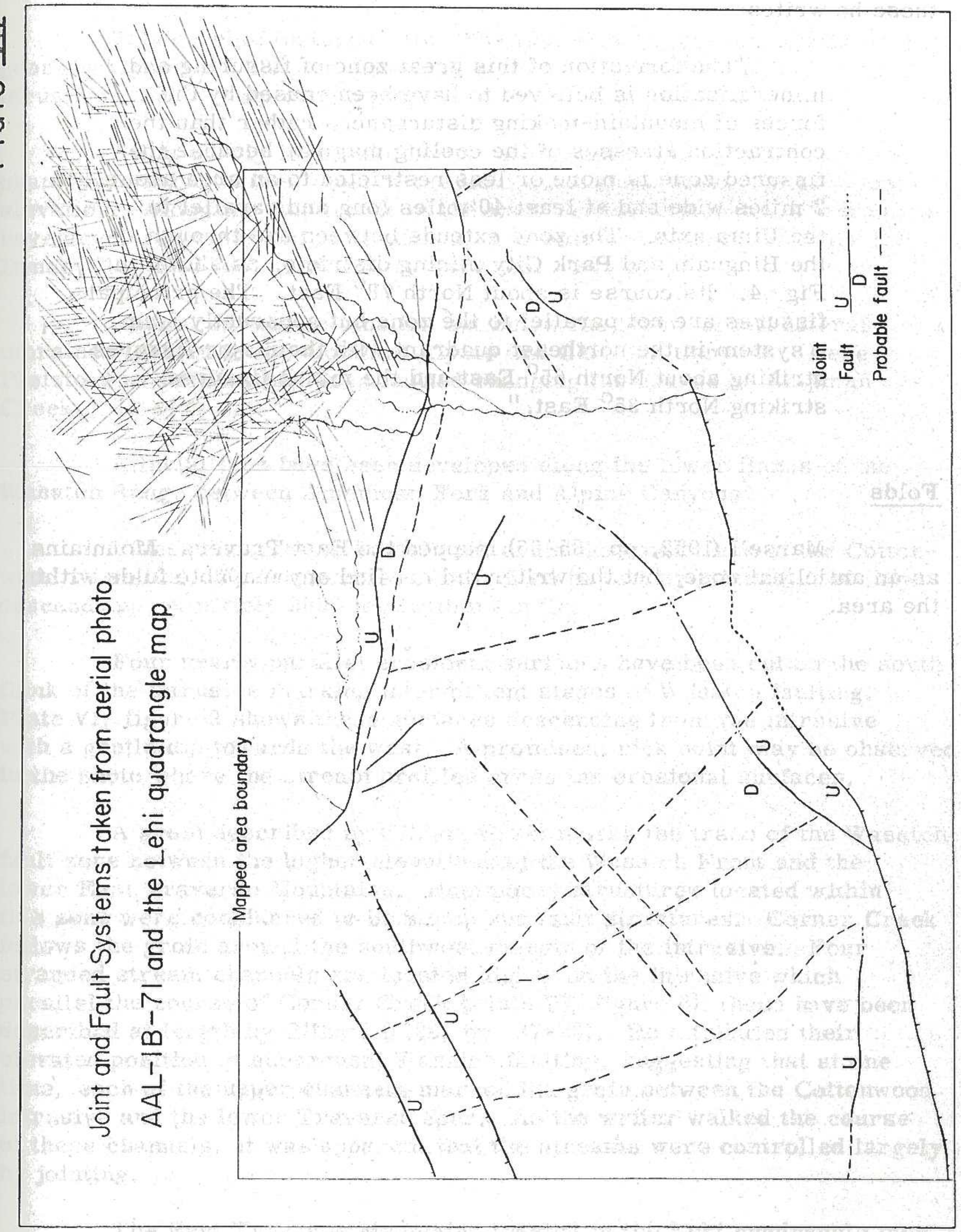
"Fault at Station 1323+50

"This fault like the one at Station 1300+20 was especially hazardous because of the water coming out along the fault plane. This fault was striking roughly parallel to the tunnel line and following along from nothing to ten feet to the west of the tunnel from about Station 1333 to the point where it crossed at Station 1323+50. It was dipping about 60 degrees to the west and at the point of crossing it repeated the quartzite 1 (see tunnel section) for a short distance and then the quartzite was faulted out. This section was all 'heavy' ground and at Station 1223+50 a drain tunnel was driven parallel to the main heading to drain the water before progress could be made."

Joints

Jointing has played an important part in the fracturing of the Cottonwood stock, and at least part of the fracturing of the East Traverse Mountains appears to have similar trends. The joint pattern of the Cottonwood stock as shown on aerial photo AAL-1B - 71 is illustrated on Plate VII.

Plate VII



Joint and Fault Systems taken from aerial photo AAL-1B-71 and the Lehi quadrangle map

Beeson (1925, pp. 780-781) described zones of fissuring which he associated with mild tectonic facies following the intrusive activities; of these he writes:

> "The formation of this great zone of fissuring and mineralization is believed to have been caused by the forces of mountain-making disturbances rather than the contraction stresses of the cooling magma, because the fissured zone is more or less restricted to an area about 2 miles wide and at least 40 miles long and parallel to the Uinta axis. The zone extends between and through the Bingham and Park City mining districts, as shown in Fig. 4. Its course is about North 78^{o} East. The principal fissures are not parallel to the zone but apparently form a system in the northeast quadrant with the major fissures striking about North 65^{o} East and the minor fissures striking North 35^{o} East."

Folds

Marsell (1952, pp. 85-86) mapped the East Traverse Mountains as an anticlinal nose, but the writer did not find any mapable folds within the area.

GEOMORPHOLOGY

Topographic features within the Lehi quadrangle include several geomorphic units. They include land form sculptured by glaciation, lacustrian and stream erosion and deposition, slumping and faulting.

A flat nearly level lake bottom topography, cut by a few stream channels, characterizes most of the Lehi quadrangle below the 4800 foot elevation. Along the North side of the East Traverse Mountains sea cliffs have developed along old fault scarps, and wide beach terraces mark the Bonneville, 5135 foot, and Provo, 4800 foot, levels.

Glacial outwash plains fan out below the terminal and lateral moraines located in the mouth of Alpine and Chipman Canyons. Here a Pleistocene moraine has been faulted changing the course of Chipman Creek.

Alluvial fans have been developed along the lower flanks of the Wasatch Range between American Fork and Alpine Canyons.

Five tributaries to Fort Creek drain the south flank of the Cottonwood intrusive. The streams are controlled in part by jointing, and they descend approximately 2000 feet within a mile.

Four nearly parallel erosional surfaces have been cut on the south flank of the intrusive marking intermittent stages of Wasatch faulting. Plate VI, figure 2 shows these surfaces descending from the intrusive with a gentle dip towards the west. A prominent nick point may be observed in the photo where the stream profiles cross the erosional surfaces.

A groin described by Gilbert (1928) marks the trace of the Wasatch fault zone between the higher elevations of the Wasatch Front and the lower East Traverse Mountains. Hummocky structures located within this zone were considered to be slump and fault structures. Corner Creek follows the groin around the southwest margin of the intrusive. Four stranded stream channels are located higher on the intrusive which parallel the course of Corner Creek (Plate VI, figure 4); these have been described at length by Gilbert (1928, pp. 27-29). He attributes their elevated position to subsequent Wasatch faulting, suggesting that at one time, each of the upper channels marked the groin between the Cottonwood intrusive and the lower Traverse Spur. As the writer walked the course of these channels, it was apparent that the streams were controlled largely by jointing.

The East Traverse Mountains located in the Lehi quadrangle may be divided geomorphically into three units. East of Mercer Hollow the topography resembles a huge dissected alluvial fan that dips toward the southwest with its apex located near Jacob's Ladder. In this area bed rock is seldom observed. The central portion of the range is low and rolling, characterizing the narrow belt of volcanic flow rocks that crop out in that vicinity. West of Maple Hollow the topography is higher and steeper reflecting the highly fractured and faulted Pennsylvanian orthoquartzites. Here the East Traverse Mountains reach their highest elevation of 6682 feet, and the canyon slopes are frequently 35° or more.

Three old erosion surfaces were observed and described by Marsell (1932, p. 99), the levels occurring at 6200, 5600, and 5250 feet in elevation. The 5600 foot elevation is very conspicuous in the East Traverse Mountains; the 6200 foot elevation marks the summit throughout the central part of the range. These surfaces were probably formed during early periods of Wasatch faulting. The writer believes that they may represent old valley base levels developed during intermittent stages of faulting.

Evidence shows that older erosion surfaces are present in the East Traverse Mountains. Plate IV, figure 3 shows a prospect which dips 36° away from the present drainage pattern. The prospect follows an old erosional surface and soil profile for approximately a hundred feet. Alluvial fan material has buried the old topography which is marked elsewhere by outcrops of volcanic ash. This suggests that during early to middle Tertiary time, pyroclastics were deposited on an old topography that has subsequently been rejuvenated by Basin and Range faulting.

Corner Creek and Fort Creek are the only permanent streams traversing the East Traverse Mountains. The most prominent drainage pattern is strikingly parallel, running perpendicular to the general trend of the range. From observations of aerial photos and field work the drainage pattern of the Traverse Spur seems to be controlled by zones of weakness that may have been caused by jointing and fault movements.

Fault scarps and fault line scarps flank the margins of the East Traverse Mountains, and in most places they have been modified to form sea cliffs.

GEOLOGIC SUMMARY

The tectonics critical to the East Traverse Range probably begin with the late Cretaceous Cottonwood uplift. Following the elevation of the Cottonwood uplift, a great allochthon was thrust from the west bringing the thick miogeosynclinal section of the Oquirrh Basin, composed primarily of Pennsylvanian Oquirrh sediments, into fault contact with the thin-shelf section of this area. Intense brecciation throughout the Oquirrh formation in this area suggests to the writer that the Cottonwood uplift may have acted as a buttress against which the near surface Oquirrh sediments were thrust, thus developing the extensive breccia zones that occur throughout the area. This early period of brecciation is supported by the fact that the volcanics, although highly jointed and fractured in most cases, still occur in massive units. Late Cretaceous thrusting was then followed by the intrusion of the Cottonwood stocks during late Eocene time. Mylonite along outer margins of the stock denotes post-intrusive thrusting, or possibly upthrusting of the footwall block, thus producing mylonite.

Volcanism and erosion probably dominated geologic events until late Pliocene time, when Basin and Range faulting was definitely expressed along the Wasatch fault; thus, initiating a period of interrupted adjustment that has continued until the present time. Along both flanks of the range volcanic flow rocks were faulted and highly silicified by hydrothermal solutions.

Following the deposition and the faulting of Pleistocene fanglomerates, glaciation was initiated by a colder and more moist climatical cycle in the Wasatch mountain range. Morainal material and Lake Bonneville sediments record Wisconsin glaciation. During recent time alluvial fan material, etc., have been deposited by the present drainage.

Throughout the range, the unrelated attitude of the beds, and the chaotic occurrence of breccia outcrops suggests that the present East Traverse Mountains originated as a fault block spur involving rocks associated with the Charleston thrust sheet. In response to the evolution of Wasatch faulting extensive internal adjustment has occurred between individual blocks and along zones of weakness developed during previous periods of thrusting, intrusion and normal faulting.

Ground water reservoirs located beneath the Lehi quadrangle in the form of coarse fanglomerates, alluvial fans, and coarse fluviatile and lacustrian gravels and sands represent, perhaps, the greatest potential economic resource in the area. With an ever increasing population and growing industrialization of the area, there is a growing demand for water. The proper utilization of ground water reservoirs may ultimately bring thousands of acre feet of water to beneficial use, which otherwise is now lost to surface evaporation and transpiration around Utah Lake.

Gravel pits are currently being operated throughout the area, but the better deposits used for concrete aggregate are located along the American Fork River.

The area has been extensively prospected, but with the general lack of favorable structure and lithology, it is very unlikely that any mineralization of any size or importance will be located in this area. The silicified zones within the andesite flow area are not extensive enough to encourage further development.

The highly fractured mylonite-breccia deposits developed in the Oquirrh quartzites are presently being quarried approximately a mile southeast of the Utah State Prison, and two similar pits have been quarried in the vicinity of the Draper portal of the Salt Lake aqueduct.

Rich fertile soil derived from weathered volcanics and oak brush is currently being stripped from the summit of the range and trucked to the valleys.

Hunt (1953, pp. 58-59) suggests that clay developed on ancient soils within the volcanic flow area of the East Traverse Mountains may prove to be a useful source of material for brick and structural clay products.

BIBLIOGRAPHY

Baker, A. A. (1947) Stratigraphy of the Wasatch Mountains in the Vicinity of Provo, Utah: U. S. Geol. Survey Oil and Gas Invest. Prelim. Chart 30

_____, J. W. Huddle, and D. M. Kinney (1949) Paleozoic Geology of North and West Sides of Uinta Basin, Utah: Bull. of Amer. Assoc. Petroleum Geologists, Vol. 33, No. 7

Beeson, J. J. (1927) Mining Districts and Their Relation to Structural Geology: American Institute of Mining and Metallurgical Engineers Transactions, Vol. LXXV, p. 757-796

Bissell, H. J. (1936) Pennsylvanian Stratigraphy in the Southern Wasatch Mountains: Iowa Acad. Sc. Proc. 43, p. 239-243

_____ (1939) Fusulinids as as Aid in Zoning the Oquirrh Series of Utah: Utah Acad. Sc. Proc. 16, p. 87-89

_____ (1952) Stratigraphy of Lake Bonneville and Associated Quaternary Deposits in Utah Valley, Utah: Geol. Soc. America, Bull. 7, Vol. 63, p. 1358

_____ (1952) Stratigraphy and Structure of the Northeast Strawberry Valley Quadrangle, Utah: Amer. Assoc. Petrol. Geol. Bull., Vol. 36

_____ (1953) Summary of Structural Evolution of the Utah Lake Basin, Central Utah: Compass of Sigma Gamma Epsilon, Vol. 31, p. 23-34

Butler, B. S., Loughlin, G. F., and Hikes, V. C. (1920) The Ore Deposits of Utah: U. S. Geol. Survey Prof. Paper 111

_____, and Calkins, F. C. (1943) Geology and Ore Deposits of the Cottonwood-American Fork Area, Utah: U. S. Geol. Survey Prof. Paper 201

Cook, K. L., and Berg, J. W., Jr. (1957) Regional Gravity Survey in Salt Lake and Utah Counties, Utah: Program: Rocky Mountain Section, Amer. Assoc. Petroleum Geologists, Salt Lake City, Utah, February 26

Christiansen, F. W. (1950) Thrust Surfaces on the Front of the Central Wasatch Mountains, Utah: Geol. Soc. America Bull., Vol. 61, p. 1450

Crittenden, M., Sharp, B. J., and Calkins, F. C. (1952) Geology of the Wasatch Mountains East of Salt Lake City: Utah Geol. Soc. Guidebook 8, p. 1-37

Dolan, W. M. (1957) Location of Geologic Features by Radio Ground Wave Measurements in Mountainous Terrain: Unpublished Master's Thesis, Univ. of Utah

Eardley, Armand J. (1933) Strong Relief Before Block Faulting: Journ. of Geol., Vol. 41, p. 254-255

_____ (1951) Structural Geology of North America: Harper and Brothers, New York City

_____ (1957) The Changing Story of Great Salt Lake: The Utah Alumnus, Vol. 33, No. 3, Jan.-Feb.

Gilbert, Grove Karl (1890) Lake Bonneville: Monographs of the U. S. Geol. Survey, Vol. 1, Washington

_____ (1928) Studies of Basin and Range Structure: U. S. Geol. Survey Prof. Paper 153

Gilluly, James (1932) Geology and Ore Deposits of the Stockton and Fairfield Quadrangles, Utah: U. S. Geol. Survey Prof. Paper 173

Hague, Arnold, and Emmons, S. F. (1876) Descriptive Geology: U. S. Geol. Expl. 40th Par., Vol. 2, p. 439-441

Howd, Frank H. (1957) Hydrothermal Alteration in the East Tintic Mining District: Guidebook to the Geology of Utah, No. 12, p. 124-134

Hunt, C. B. (1953) Lake Bonneville: Geology of Northern Utah Valley, Utah: U. S. Geol. Survey Prof. Paper 257-A, Plate 1

Johannsen, Albert (1937) A Descriptive Petrography of the Igneous Rocks, Vol. 3, The Intermediate Rocks: The University of Chicago Press, Chicago, Illinois, p. 289

Marsell, R. A. (1932) Geology of the Jordan Narrows Region, Traverse Mountains, Utah: Unpublished Master's Thesis, Univ. of Utah, p. 88

_____ (1953) Wasatch Front: Compass of Sigma Gamma Epsilon, Vol. 31, p. 3-22

McFarland, Carl R. (1955) Geology of the West Canyon Area, Northwestern Utah County, Utah: Unpublished Master's Thesis, Brigham Young University

Morris, Hal T. (1957) General Geology of the East Tintic Mountains, Utah: Guidebook to the Geology of Utah, No. 12, p. 1-56

Murphy, D. R. (1954) Fauna of the Morrowan Rocks of Central Utah: Unpublished Master's Thesis, Brigham Young University

Murdock, J. Neil (1941) Geology of the Alpine-Draper Tunnel: U. S. Dept. of the Interior, Bureau of Reclamation

Nygreen, Paul W. (1958) The Oquirrh Formation, Stratigraphy of the Lower Portion in the Type Area and Near Logan, Utah: Utah Geol. and Mineralogical Survey, Bull. 61

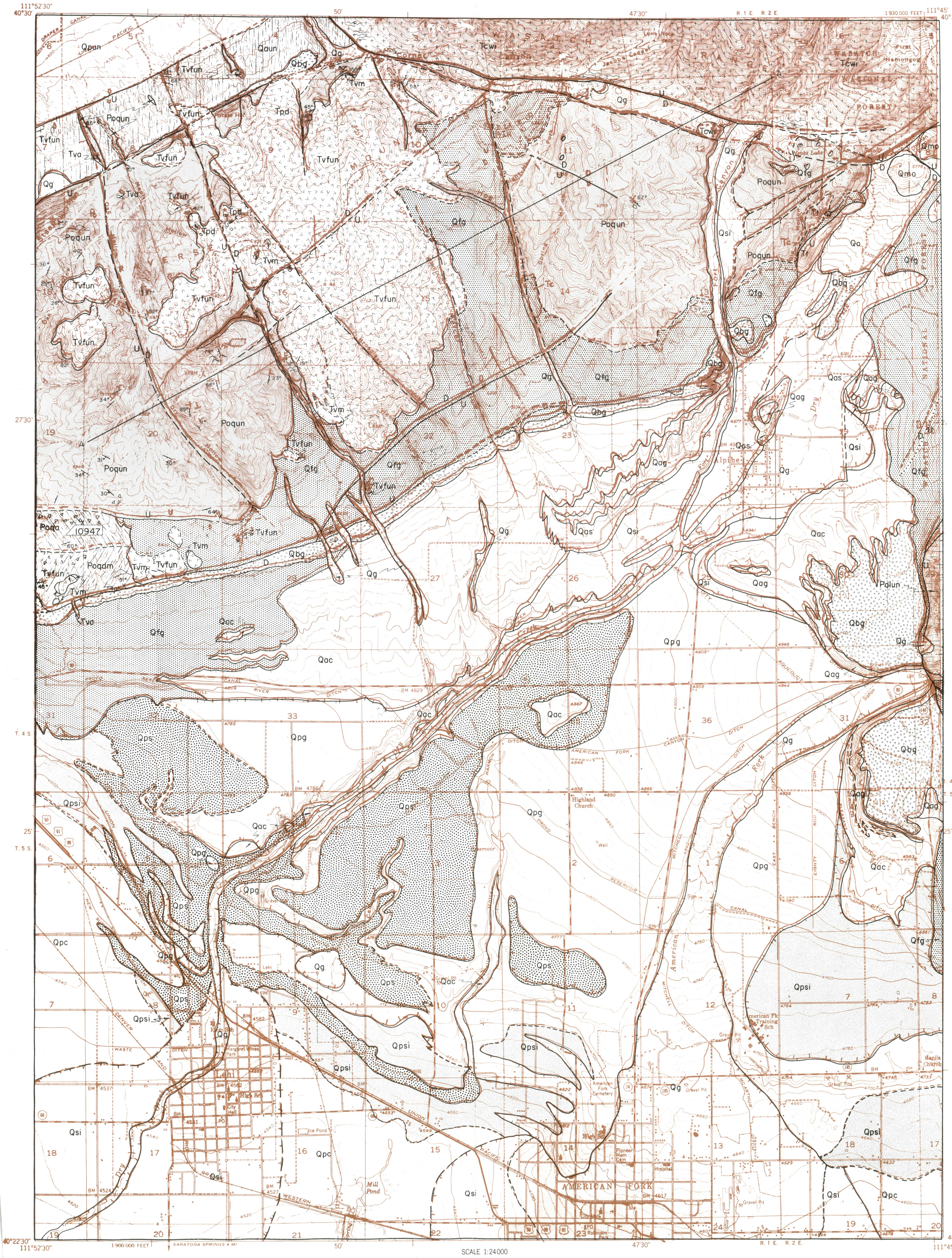
Pitcher, Grant G. (1957) Geology of the Jordan Narrows Quadrangle, Utah: Published Master's Thesis, Brigham Young University

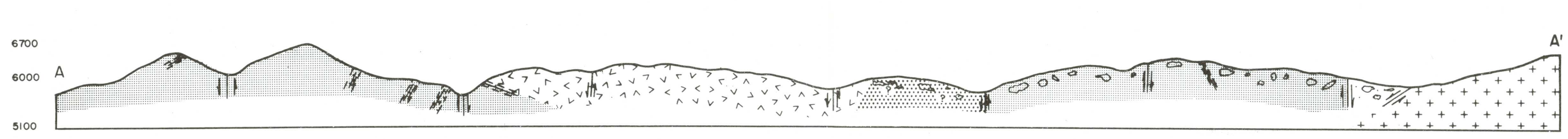
Slentz, L. W. (1955a) Tertiary Salt Lake Group in the Great Salt Lake Basin: Unpublished Ph. D. Thesis, University of Utah

_____ (1955b) Salt Lake Group in Lower Jordan Valley, Utah: Guidebook to the Geology of Utah, No. 10, p. 23-44

Stillman, F. B. (1928) A Reconnaissance of the Wasatch Front Between Alpine and American Fork Canyons, Utah: Journal of Geol., Vol. 36, p. 44-55

Wimber, Raymond (1931) A Study of the Igneous Rock of the Traverse Mountains, Utah: Unpublished Bachelor's Thesis, University of Utah (not available)





Legend

— Recent deposits —

Qg — Alluvial gravel

Qsi — Silt & clay

— Provo formation —

Qpg — Gravel, locally granitic, quartzites & limestone

Qps — Sand; clean quartz sand in bars, in places gravelly, silty & feldspathic

Qpsi — Silt

Qpc — Clay

Qpun — Provo formation undifferentiated

— Bonneville formation —

Qbg — Gravel

Qbs — Sand

— Glacial deposits —

Qo — Outwash from Wisconsin moraine

— Alpine formation —

Qag — Gravel

Qas — Sand

Qmy — Wisconsin moraine granitic boulders

Qac — Silt & clay well bedded

Qaun — Gravel, sand, silt & clay

Qfg — Fanglomerate, locally well cemented, faulted and deeply dissected

Qmo — Pre-Wisconsin moraine deeply weathered

(Cenozoic — Pleistocene — Lake Bonneville Group)

Poqun — Oquirrh formation, orthoquartzites calcilutites & quartzose sandstones undifferentiated

Poqa / Poqdm — Oquirrh formation Atokan & Desmoinesian orthoquartzite

(Paleozoic — Pennsylvanian)

Palun — Paleozoic undifferentiated consisting of Cambrian Tintic qtze. Ophir shale, Maxfield limestone, Mississippian Gardner formation, Deseret limestone, Humbug formation and Great Blue limestone

Igneous rocks / Metamorphic rocks

Tva — Volcanic ash & water laid tuff

Tvm — Volcanic flows generally andesites, locally hydrothermally altered

Tvfun — Volcanic flows undifferentiated

Tpd — Pebble dike

Tcwi — Cottonwood Intrusive quartz monzonite

Tt — Tactite zone

(Cenozoic — Tertiary — Mid Miocene; Late Eocene; Late Eocene)

— Symbols —

Formation contact

High angle fault

Doubtful or probable fault (dotted where concealed)

Hachures on a contact are on the side of the younger and overlapping deposits

Fault breccia

Mylonite or sheer zone

Prospect pit

Mine on large open pit

Fossil location B.Y.U.

Unnumbered fossil location

Outcrop

A Geologic Map of the Lehi Quadrangle, Utah.

by

R. L. Bullock

1958