TERTIARY SALT LAKE GROUP

IN

THE GREAT SALT LAKE BASIN

by

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ABSTRACT

The term Salt Lake group is here used to include all rocks that are post-Wasatch (Paleocene and Eocene) and pre-Pleistocene in age. On the basis of varied lithologies, soil profiles, erosional unconformities, and structural deformation, the Salt Lake group has been subdivided as follows; Traverse volcanics and Jordan Narrows units (oldest), Camp Williams unit, Travertine unit, and the Harkers fanglomerate unit (youngest). The commonest rock types in the Traverse volcanics are reddish to purple andesites and andesite breccias, augite and biotite-hornblende latites and latite flows, and lesser amounts of rhyolite and basalt. A white marlstone is the dominant lithologic type of the Jordan Narrows unit. In addition it contains oolitic, argillaceous, and cherty limestones, sandstones, clays, and rhyolitic tuffs. These are all fresh water lacustrine deposits and were derived from and deposited almost contemporaneously with the Traverse volcanics. The Camp Williams unit is composed of red to tan colored mudstones and siltstones and a basal conglomerate of igneous detritus. All are poorly consolidated. The Travertine unit consists of a white dense, massive, travertine which contains some small lens-like accumulations of manganese dioxide. The Harkers fanglomerate unit is a light colored, poorly consolidated, torrential stream deposit and is composed of Paleozoic quartzites and limestones with smaller amounts of igneous fragments. Several mud rock flows occur in the Salt Lake group.

Dips up to 30° are common and are most pronounced near demonstrable or inferred faults. Folding is possibly responsible for gentle regional dips. A fault mosaic has been mapped in the Jordan Narrows area.

A pediment along the east flank of the Oquirrh Mountains is bounded on the west by a normal fault and on the east by the Bonneville shoreline. The pediment was eroded across rocks chiefly of the Salt Lake group. Later erosion has produced one and possibly two lower surfaces.

The Tertiary geology of Tooele Valley and the Stansbury Mountains is slightly similar to that of lower Jordan Valley and the Oquirrh Mountains. (1) Stratigraphically the resemblance is limited to the thick volcanic sequence and fanglomerate unit of the Stansbury Mountains both of which might be correlated with the Traverse volcanics and Harkers fanglomerate, respectively, in the Oquirrh Mountains. No sedimentary deposits have been found in Tooele Valley that would correspond to the Jordan Narrows, Camp Williams, and Travertine units of Jordan Valley. (2) Remnants of an old pediment flank the Stansbury Mountains on the east, but this pediment is not as extensive or well-defined as the one comprising the Oquirrh Foothills. (3) Structurally Tooele Valley is depressed like the Jordan Valley block. Faulting has deformed the rocks of the Salt Lake group in the Stansbury Mountains and produced a regional dip eastward of 10° to 20°. The sedimentary units of the Salt Lake group are nearly horizontal in the Oquirrh Mountains.

The Rozel Hills are composed of interbedded basalt flows and lacustrine limestones of the Salt Lake group but differ from the Tertiary rocks of the Oquirrh and Stansbury Mountains in the following respects; the igneous rocks are limited to basalt flows; the limestones are the only sedimentary (Tertiary) rocks which crop out although marls, tuffs, and conglomerates occur in the subsurface; the rocks have a regional dip of 13° to the northeast.

In conclusion the writer finds that variation in the sedimentary rocks from one locality to the next is the normal rather than the exceptional condition. This is probably true for the Basin and Range province as a whole due to numerous lakes, isolated block fault mountains intermittently rejuvenated, and widespread, spasmodic volcanic activity. Fossils are scarce and correlation difficult.

An outline of the Tertiary geologic history of the Salt Lake group in Jordan Valley is proposed as follows: (1) Volcanism (early-Oligocene (?) to mid-Miocene (?)) accompanied by lacustrine sedimentation. This was the time of deposition of the Traverse volcanics and Jordan Narrows units. (2) Disappearance of the lake, some deformation and erosion, and deposition of the fluvial Camp Williams unit in late Miocene (?) time. (3) Significant block faulting along the east flank of the Oquirrh Mountains in early (?) Pliocene time and deposition of the Harkers fanglomerate. (4) Pedimentation of alluvial fans composed of Harkers fanglomerate culminating in late Pliocene. (5) Incision of the pediment during the Pleistocene.

INTRODUCTION

Purpose

This study was undertaken in an attempt to delineate more precisely the stratigraphic units of the Salt Lake group and their relationships within the Great Salt Lake Basin. The Salt Lake group has been a convenient designation for all Tertiary rocks that are post-Wasatch and pre-Pleistocene in age. It seems likely that over such a long time span, a varied history would have been recorded, at least partially, in the sediments. Such sediments are for the most part buried by the Quaternary alluvium, and although they do crop out to a limited extent, they have not been carefully studied previously.

The original intent of the writer was to make a stratigraphic and sedimentary investigation of the subsurface portions of the Salt Lake group. This proved infeasible because few wells drilled in the area ever penetrated Tertiary strata. Furthermore, few samples or cores were kept of the wells which penetrated the Tertiary deposits. During the first six months of 1955, however, exploration for both oil and water has resulted in several holes being drilled into and through Tertiary beds. The information gleaned from these was most welcome and has been incorporated in the text.

Location, Scope, and Accessibility

As defined in this paper, the Great Salt Lake Basin is an area approximately 50 miles wide and 100 miles long in north central Utah. The Wasatch Mountains lie along the east side of the basin. South Mountain and the Traverse Mountains constitute the southern boundary. The northern and western limits are somewhat arbitrary. See index map, Plate I. Within this area three localities were studied in detail.

Several paved highways cross the basin and many first class hard-top roads serve the suburban areas of Salt Lake City and outlying farm districts Most of the secondary roads giving access to the foothills are maintained by railroad and mining companies.

Geomorphology

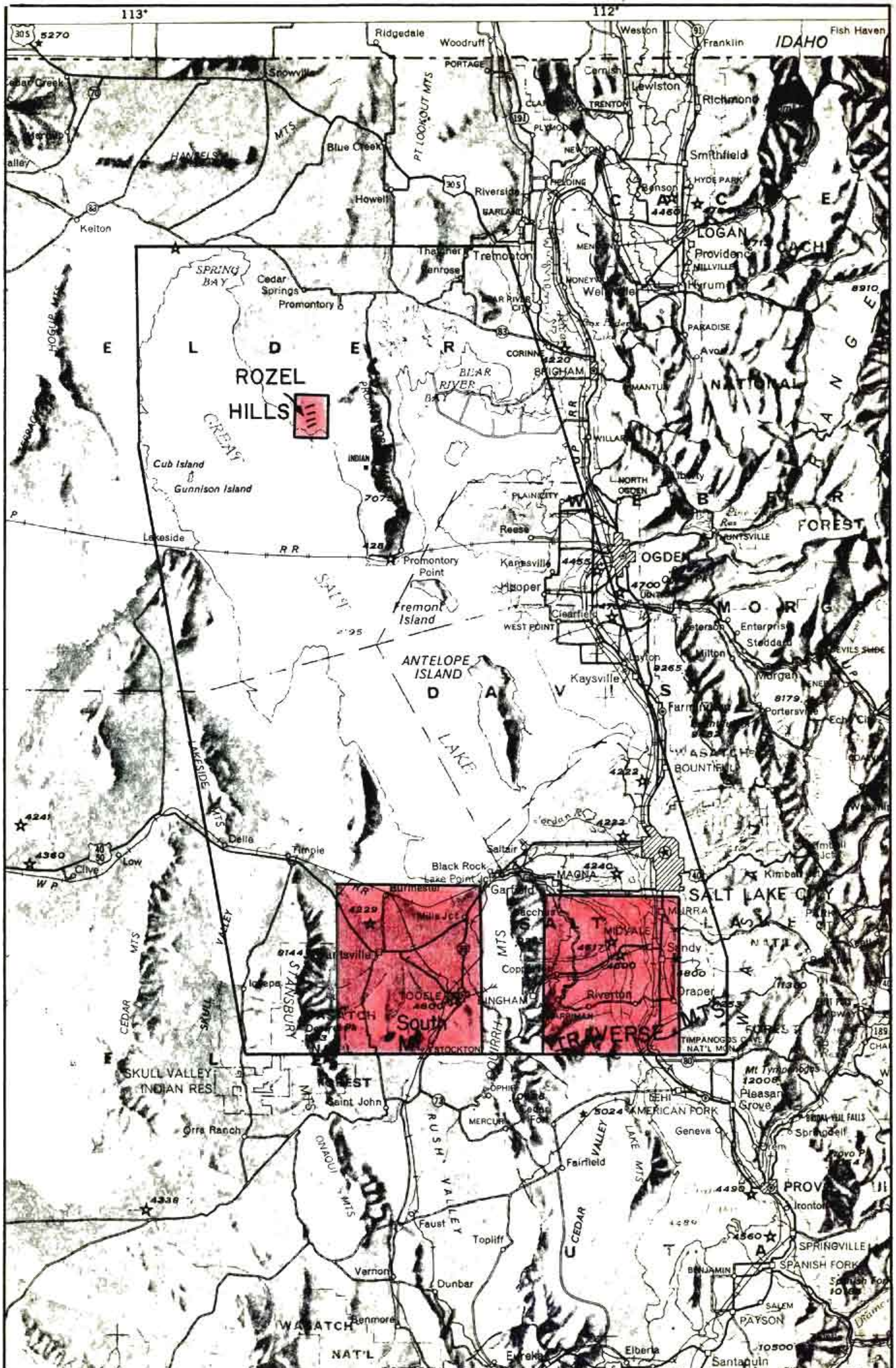
Great Salt Lake Basin is a portion of the Basin and Range physiographic province and contains a number of geomorphic units: these are Jordan, Tooele, and Skull valleys, the Traverse, Oquirrh, Stansbury, Lakeside, and South Promontory Mountains, along with Great Salt Lake and some of its associated salt flats. The general basin and valley floors have an elevation of about 4200 feet above sea level. The crest lines of the mountains lie 5000 to 6000 feet above the basin floor.

The Jordan, Weber, and Bear Rivers are the only major streams flowing into the basin. There is no drainage outlet.

Rock Units

Cenozoic rocks underlie most of the foothill belts, valleys, and basin floor. They fall into three categories.

1. Igneous, both extrusive and intrusive.
2. Lacustrine clastic and chemical sediments.
3. Fluvial deposits.



INDEX MAP OF
GREAT SALT LAKE BASIN

Scale
1 inch = 16 miles

The mountains are composed primarily of Paleozoic quartzite, limestone, sandstone, and shale, and secondarily of intrusive diorites and monzonites.

Field Work

Field work was accomplished during the summers of 1954 and 1955. Most of the time was devoted to preparing geologic maps, measuring sections, and collecting samples. The samples were examined for microfossils in the laboratory. The West Traverse Mountains and east flank of the Oquirrh Mountains were mapped (Plate XVII) using the Lark, Magna, and Jordan Narrows topographic quadrangle sheets of the U. S. Geological Survey (scale 1:24,000) for control. It proved necessary to examine and map an area of six square miles along the Jordan River in considerable detail. This will be referred to as the Jordan Narrows enlargement (Plate XVII). Construction of a map of the Rozel Hills (Plate XVIII) was undertaken using aerial photographs obtained from the Aerial Photographic and Engineering Laboratory of the U. S. Agricultural Department as a guide.

Previous Work

Hayden (1869, p. 92) applied the name Salt Lake group to the Tertiary marls, sands, and sandstones in Salt Lake and Weber Valleys. He assigned a late Tertiary age to the group and recorded a maximum thickness of 1,200 feet. Members of the Hayden survey regarded these beds as lacustrine in origin. Apparently, Peale (1879, pp. 588, 649) was responsible for extending the term Salt Lake group into Idaho. He assumed that the lacustrine deposits of southeastern Idaho were laid down in the same lake referred to by Hayden's group. Other early workers who further described and defined the Salt Lake group were Emmons (1875, p. 381), Gilbert (1890, pp. 980-101), and Mansfield (1920, pp. 399-406).

Paleontological investigations consist of studies of mollusks in the Salt Lake group by Yen (1946, 1947), of plant fragments from Cache Valley by Brown (1949), and of the microfossils by Swain (1947) and Edmisten (1952). The microfossils consist mainly of ostracodes and charophytes.

The most extensive work on the Salt Lake group of Great Salt Lake Basin is by R. E. Marsell (1932). In discussing the geology of the Jordan Narrows, Marsell (pp., 45-49) describes the lithologic units as marls, limestones, pumicites, oolitic limestones, sands, and clays all of fresh water origin. He observed that the white color of the marls and limestones is typical of the Salt Lake group. A Pliocene age was proposed for the exposed strata. He found vertebrate remains in a travertine deposit which were originally designated as Pleistocene. Stirton and Savage (1952, oral citation) later dated them as Blancan (late Pliocene). Marsell also prepared a topographic and geologic map of the entire Traverse Mountains and Jordan Narrows. Unfortunately there are no copies of the geologic map now available.

Eardley and Haas (1936, p. 67) in reviewing the oil and gas possibilities of Great Salt Lake Basin, refer to the Salt Lake group and describe the sediments as volcanic conglomerates and tuffs, clays, marls and marlstones, concretionary and oolitic limestones. These are classed as fluvial and lacustrine deposits. It was also indicated that the basalts and limestones at Rozel Point should be part of the Salt Lake group. They conclude (pp. 67-68) "that the Salt Lake formation has widespread occurrence. ... Most of the formation is now obscured by the overlying Recent alluvium of the valley fill."

A map of Tooele Valley was prepared by Thomas (1946) in connection with his study of the ground water in that area. He reports that (p., 116) "the Salt Lake group forms the foothill slopes above the highest shoreline of Lake Bonneville in discontinuous areas along the margin of Tooele Valley. In these exposures the formation is a typical fanglomerate."

Gvosdetsky and Hawkes (1953, pp. 15-16) refer to the well-stratified Salt Lake formation in the Bacchus Pit, a borrow pit, just southeast of Magna, Utah. In particular, Gvosdetsky studied the soil profiles developed on the eroded surface of the Salt Lake formation and concluded that they are pre-Pleistocene.

Other authors who have written on the Salt Lake group outside of Great Salt Lake Basin are Ludlum (1943), Keller (1952), Williams (1952), Smith (1953), Hunt (1953), Felts (1954), Adamson, Hardy and Williams (1955).

Acknowledgements

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Mr. R. E. Cohenour assisted the writer at times in the field and Dr. W. P. Johnston critically read the manuscript. Mr. E. J. Roscoe identified the microgastropods.

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GEOLOGY OF THE JORDAN NARROWS

Introduction

At no other place in the Great Salt Lake Basin is there a better or more complete exposure of Tertiary sediments than in the Jordan Narrows. In this area it has been possible to recognize the several units in the Salt Lake group and to work out their relationships to each other and to the younger Quaternary deposits, (Plate XVII).

The name Jordan Narrows is derived from a water gap in the Traverse Mountains through which the Jordan River flows northward on its way from Utah Lake to Great Salt Lake. The Traverse Mountains, an east-west range connecting the Wasatch and Oquirrh Mountains, are thus split by the Jordan Narrows into approximately equal parts. Camp Williams, a military reservation used by the National Guard Units in the summer, is located just to the west of the Narrows.

Various aspects of the Jordan Narrows and the rocks exposed there have been dealt with by Marsell (1932), Lofgren (1947), Edmisten (1952), and Hunt, Varnes, and Thomas (1953). Professor R. E. Marsell has been concerned with the problems of water supply for a number of years and has accumulated a large store of unpublished information relative to the geology of the area.

Geography and Geomorphology

The Jordan River is described by Marsell (1932, p. 15) as

> "the principal stream in the region. Throughout its entire course, this river is in the old age stage of the geographic cycle. This condition characterizes its valley throughout the entire distance down to Great Salt Lake. The explanation of this anomaly is found in the circumstance

that the river flows from source to mouth across the flat bottom of ancient Lake Bonneville, with a total fall of only 290 feet in a distance of about 45 miles."

Beef Hollow drains a portion of the Western Traverse Mountains adjacent to the Jordan Narrows and enters the Jordan River toward the north end of the water gap. It carries water only in the early spring from melting snows, or from occassional cloudbursts.

The Jordan Narrows has an overall length of 3/4 of a mile and is 1/4 mile wide. Total relief from the river bottom to the crest of the Traverse Mountains is about 1800 feet but only the lower portion has steep valley walls.

This break through the Traverse Mountains serves as a transportation funnel between Utah and Jordan Valleys (better designated as upper and lower Jordan Valleys) (Marsell, 1955, personal communication). It contains several major highways, railroad lines, and numerous irrigation canals. The latter stem from the dam on the Jordan River and assist in distributing the water throughout the lower Jordan Valley. One canal flows to Magna, Utah a distance of some 25 miles.

Marsell (1932, pp., 11-13) characterizes the Traverse Mountains as follows:

"When viewed from Salt Lake Valley, the Traverse Mountains appear to the south as a low, flat-topped mass of sprawling, rounded hills and ridges. .. The low, rounded summits and gentle, broadbacked ridges give them an appearance that contrasts markedly with the high, sharp peaks and serrate ridges of the neighboring Wasatch Mountains. In those parts of the Traverse Mountains that border the Jordan Narrows water gap the most conspicuous surface forms are those resulting from the work of Lake Bonneville, whose waters at the highest stages lapped well upon the flanks of the range."

Stratigraphy

Major divisions

Paleozoic rocks make up the core of the Traverse Mountains but are to a considerable extent buried under Tertiary extrusive flows that extend well into Jordan Valley under the cover of younger sediments. No attempt has been made to map the formations of Paleozoic age. The Salt Lake group is excellently exposed in the Jordan Narrows, and is divided into three principal units. The varied lithologies, soil profiles, erosional unconformities, and structural deformation all point to a long, complicated, geologic history. It is hoped that the new units proposed herein will prove usable and serve as a guide for further Tertiary studies within the Great Salt Lake Basin.

Tertiary section

The Jordan Narrows section was compiled from rocks exposed along the west bank of the Jordan Narrows and in Beef Hollow. A channel section was obtained by removing the weathered surface material and collecting fresh rock. A sample was taken for each two-foot interval. These samples were later examined in the laboratory for microfossils and lithologic characteristics. No megafossils were discovered. The Quaternary sediments and youngest Tertiary fanglomerate were not sampled.

	Feet
Recent stream terrace gravels and sediments of Lake Bonneville. For the most part they are poorly consolidated, well stratified, and horizontal.	0-100

— Unconformity —

	Feet
Harkers fanglomerate (new name)	
Fanglomerate, tan, very poorly cemented, subrounded pebbles to boulders in a silty, sandy matrix. Quartzites and limestones predominate with lesser amounts of volcanic rocks. These latter are usually badly weathered and disintegrate readily. A few lenses of reddish brown silt are present.	50
The type section of this formation is in Harkers Canyon in Section 19, T. 2 S., R. 2 W., and will be described fully under a later heading.	
— Fault —	
Camp Williams unit (new name)	
Mudstone, light red to light brown, sandy, with $CaCO_3$ present in sufficient amounts locally to yield hard, white, nodules. Weathers to blocks with conchoidal fracture. Sand is composed of quartz, mica, hornblende, gypsum, and calcite, with aggregates of silt composed of the same minerals.	45
Same as above but is shaly and contains fragments of rhyolitic tuff plus abundant volcanic detritus.	3
Mudstone or siltstone, light to dark reddish brown with fragments of light tan clay which are hard and calcareous. Sand very minor. Weathered surface is massive and blocky.	15
Same but with shaly streaks and sandy lenses. Color also becomes lighter because of larger amounts of $CaCO_3$.	17
Siltstone, light tan to pink, silty, good to poorly cemented by $CaCO_3$. Some particles range in size from pebbles to lutite. The sand is composed of quartz, mica, feldspars, clay minerals, and small amounts of the dark ferro-magnesium minerals.	5
Mudstone, gray to pink, shaly, alternating with gray to reddish fine grained sandstone that is well indurated. This interval shows some bedding.	11

	Feet
Sand, gray, grading into a conglomerate composed of boulders several feet across, gravels, and poorly stratified sands. Lenses cemented with $CaCO_3$ occur. Larger fragments are somewhat rounded and primarily of volcanic origin with lesser amounts of quartzite and limestone.	13
Total thickness	112

— marked erosional unconformity —

Jordan Narrows unit (new name)

Marlstone, white to light gray, very hard and dense especially in the weathered surface, blocky fractures, contains streaks that are higher in clay minerals and the streaks have a yellowish tint. Sand and silt are scarce and composed of well rounded quartz, feldspar, and calcite fragments with small amounts of magnetite, mica, and hornblende. Ostracodes and charophytes are present but very scarce. Manganese dioxide stains and dendrites are a very characteristic feature of the marlstone. Bedding is lacking but certain strata contain higher amounts of calcium carbonate and stand out as ledges along the face of the outcrop.	26
(Marlstone as defined in this paper is a rock containing 25 to 75 percent $CaCO_3$ with the remainder primarily of clay.)	
Sandstone, tan, coarse, poorly consolidated, and contains mud and clay galls. The sand grains are angular to sub-rounded and consist of quartz, feldspar, gypsum, hornblende, and mica, which indicates an igneous source rock.	4
Marlstone, as above, ranging from a nearly pure limestone to a slightly calcareous clay with ostracode and charophyte remains more abundant than higher in the section.	33
Sandstone, tan, with aggregates of marlstone and some clay galls.	4
Marlstone, somewhat oolitic and tuffaceous and containing more crystaline calcite.	37
Tuff, gray, rhyolitic, poorly consolidated, porous, and composed predominantly of glass shards.	3
Clay, pink, calcareous, silty.	5

	Feet
Sandstone, light tan, silty, poorly consolidated, contains several lenses of pebble conglomerate. Derived apparently from volcanic rocks. More magnetite present than higher in the section. Ostracodes and a few charophyte stems recorded.	3
Marlstone, as before, but rather silty. Contains abundant calcareous tubes that are casts of plant stems and roots.	3
Covered by slump.	20-30
Siltstone, light gray, loosely cemented by $CaCO_3$ and composed primarily of igneous clastics with quartz abundant, no laminations or bedding.	4
Limestone, white, very hard and dense, stained with MnO_2 dendrites. It contains many calcareous rods that represent root replacements, and has streaks of yellow chert. Calcite crystals very fine.	8
Same but more silty and very porous, with the silt being derived from igneous rocks.	12
Marlstone, white, slightly oolitic, alternating with buff colored clays containing carbonaceous fragments.	14
Sandstone, gray to buff, dirty, some gravel, poorly consolidated. Clays are slightly bentonitic and the sand is composed of igneous detritus.	15
Limestone, white, as above.	8
Marlstone, white, porous, interbedded with tan to yellow clays that are shaly and somewhat silicious. Ostracodes and charophytes present but not abundant.	40-50
Limestone, white, argillaceous and tuffaceous, stained with MnO_2.	25
Marlstone, pink, silty, and oolitic. Cherty streaks.	5
Shale, gray, calcareous, grading into a porous marlstone having a vesicular appearance. The openings are filled with what appears to be clay galls or tiny concretions. Base not exposed.	7

	Feet
(Moved to Beef Hollow, interval missing)	20 ?
Limestone, tan to pink, very hard, porous, massive, ledge former, blocky fracture, silty streaks and vuggy, vugs filled with crystalline calcite. There are a few sand grains of quartz, feldspar, mica, hornblende, and magnetite.	9
Mudstone, red to brown, calcareous, soft.	3
Limestone, pink to tan, argillaceous, very hard and much as above. Massive and forms ledges.	13
Limestone same as above alternating with a marlstone having blocky, conchoidal fracture. Base not exposed.	35
Total thickness	340-370

Problem of nomenclature

The terms Salt Lake group and Salt Lake formation are both used in the literature. Wilmarth (1938, p. 1897) followed Mansfield (1927, p. 110) and used the term Salt Lake formation. Eardley (1944, pp. 845-846) used the term Salt Lake group and placed the Norwood tuff (Oligocene) at the base. He writes, "When the intermontane valleys west of the Wasatch become better known stratigraphically, the Salt Lake group may be found to include several formations, perhaps separated by considerable parts of the Tertiary. This possibility emphasizes the necessity of a new formational name." Williams (1952) in Smith (1933, pp. 73-75) proposed three formations within the Salt Lake group. These are, from oldest to youngest, the Collinston conglomerate, West Springs formation, and Cache Valley formation. Keller (1952) also working in northern Utah and southeastern Idaho introduced the Mink Creek conglomerate which Adamson, Hardy, and Williams (1955) have incorporated into the Salt Lake group.

It thus seems apparent that the various rock units throughout northern Utah and southeastern Idaho identified as belonging to the middle and late Tertiary can not be placed in one formation. There is as yet little fossil evidence or subsurface data, however, to establish time equivalence of these deposits to those in the Great Salt Lake Basin.

Most of the Tertiary rocks of the Great Salt Lake Basin are probably local and discontinuous. They do not extend from one locality to another over a distance of 100 or 200 miles and for this reason some stratigraphers would hesitate to accord the local deposits the rank of formations. However, it may be seen in the above references that this has been done. The deposits can not be designated as members, tongues, lenses, or channels of thick or extensive formations, since this is not their true nature. If these deposits are named by their dominant lithology, then according to existing rules of stratigraphic nomenclature they are classed as formations. In application to the deposits of the Great Basin this is unfortunate, because nothing is more characteristic of some of them than their lithologies, viz; fanglomerate, agglomerate, or tuff, yet we hesitate to call them by these lithologies since in doing so we would indicate them as true formations, when perhaps some of them should not be so dignified.

The deposits are extremely significant, however, in constructing the orogenic, erosional, sedimentary, and life record of the Tertiary in the Basin and Range region and deserve recognition. Professor Stokes and Eardley believe that they should be called groups or formations, but until the problem can be brought to the attention of the geological profession, the divisions of the Tertiary here recognized will be called units. Thus as a precautionary measure the difficulty is circumvented but not solved.

Jordan Narrows unit

A white marlstone is the most common rock in the Jordan Narrows unit but in addition it contains oolitic, argillaceous, and cherty limestones, sandstones, clays and rhyolitic tuffs. These are all fresh water lacustrine deposits. The marlstones and limestones weather out as blocks and are good ledge formers. The generally white color of the outcrops is a distinct mark of the unit in the Great Salt Lake Basin. Its total thickness is unknown but exceeds 300 feet (this paper, p. 13), and perhaps 2,000 feet.

The discordance of dips and erosional unconformity at the top of the Jordan Narrows unit indicates that its deposition was followed by a time lapse accompanied by faulting and folding. A general southeasterly dip of approximately 15° is common but by no means consistent. Examination of the Jordan Narrows enlargement (Plate XVII) will show its fault block nature.

The areal extent of this unit is not definitely known, but there is some suggestion that it underlies the entire Jordan Valley. Eardley and Haas (1936, pp. 73-74) mention marls and tuffs drilled into at 1300 feet in a well west of Salt Lake City. Hunt, Varnes, and Thomas (1953, p. 13) in Utah Valley (upper Jordan Valley) refer to white clays penetrated at a depth of 180 feet in a water well. The nearest outcrop is 16 miles to the northwest along the east flank of the Oquirrh Mountains and will be discussed later.

No fossil evidence is known by which a date can be assigned to this deposit. The ostracodes in it seem to indicate a Miocene-Pliocene age according to D. J. Jones (personal communication). Its lithology is similar to that of the Norwood tuff and like the Norwood is a facies of the andesitic volcanics of post-Laramide age. Dr. Eardley prefers to correlate it tentatively with the Norwood tuff of early Oligocene (Chadron) age and hesitates to accept the ostracode evidence as meaningful.

In order to allow sufficient time for the geologic events which followed deposition of the Jordan Narrows unit, the writer believes that an upper age limit of mid-Miocene must be postulated.

Camp Williams unit

The term Camp Williams is derived from the military area of the same name. The camp itself is bounded on the east by the Jordan River and on the north by Beef Hollow. Excellent exposures of the Camp Williams unit can be seen in both stream valleys.

The red to tan color of the Camp Williams unit is perhaps its outstanding characteristic. Lithologically it is composed mostly of mudstones and siltstones that are poorly consolidated and lesser amounts of impure sandstone that commonly forms distinct ledges. A basal conglomerate primarily of igneous detritus is also present.

The unit measures at least 100 feet thick but for the most part is not completely exposed. Dips up to 20° have been observed.

This sedimentary unit apparently represents a fluvial environment with occasional flood-plain lakes in which some of the well-bedded strata could have collected. Its known areal extent is rather limited and confined to the Jordan Narrows and immediate vicinity. However, well cuttings from two water wells drilled near the Riverton Reservoir, 3 miles south of Riverton and about 1/2 mile north of the Traverse Mountains (Plate I) were examined.

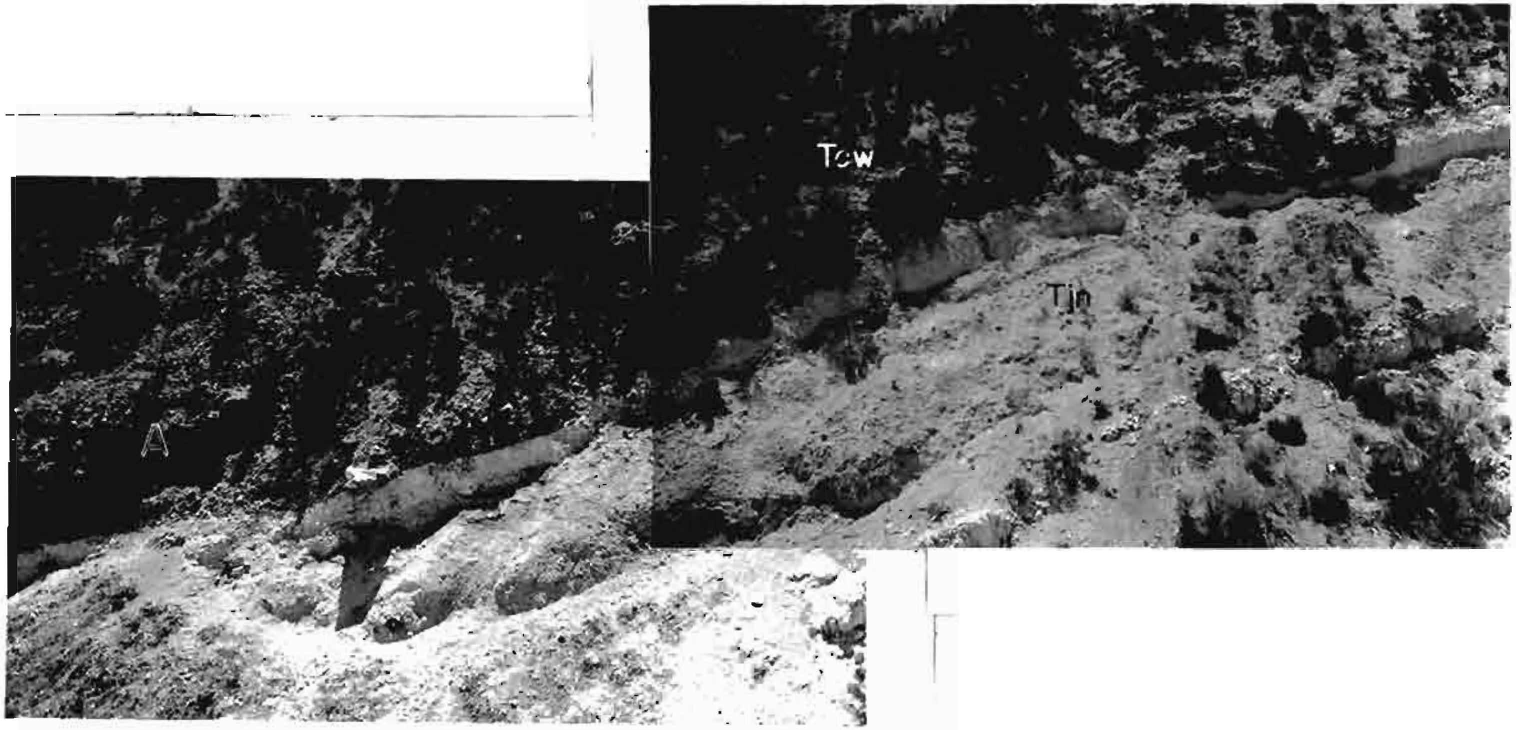
They proved to be composed of tan to pink silts, tan to light tan clays, and gravel consisting of igneous detritus. In general the sorting was poor and the sediments unconsolidated. Total depth reached was 676 feet. Except for the almost entire lack of consolidation in this subsurface material and the somewhat higher percentage of igneous clastics, it closely resembles the Camp Williams unit. An absolute correlation is impossible without further subsurface data.

An abrupt color change from the white marlstones of the Jordan Narrows unit to the red silts and sands of the Camp Williams unit can be seen from a distance and marks the unconformity between these two deposits. Closer examination shows the surface of the Jordan Narrows unit to be very rough and irregular and to have a relief of several feet (Plate II). The basal conglomerate of the Camp Williams unit further distinguishes the unconformity. In some places, boulders 2 to 4 feet across rest directly on the fine grained marlstones.

There is an angular discordance of at least 5^{o} between these two units where viewed in the Jordan Narrows.

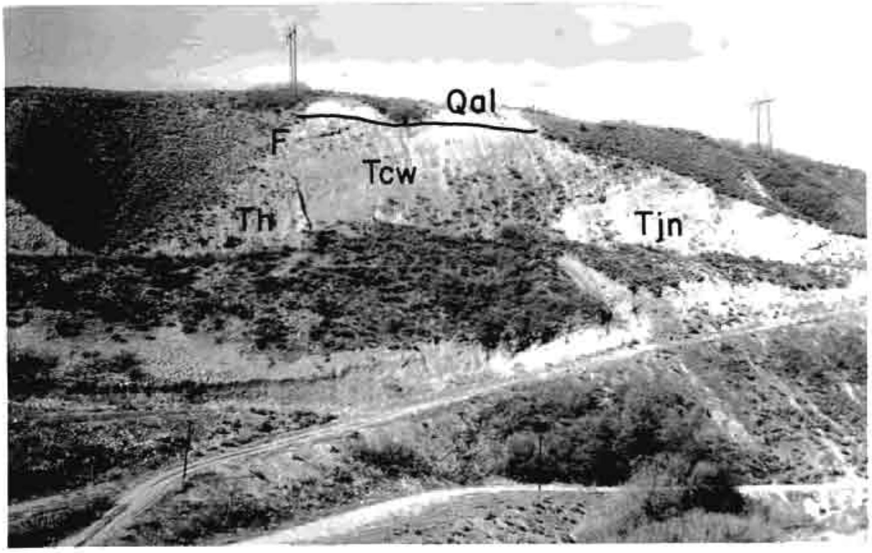
A deep soil was developed on the upper portion of the Camp Williams unit and is preserved in the outcrops north of the Jordan Narrows. The Harkers fanglomerate overlies the Camp Williams unit with a discordance of about 7^{o} or is in fault contact with it throughout the Jordan Narrows area (Plate III, figure A).

No fossils have been found in the Camp Williams unit. However, since it lies stratigraphically between the Jordan Narrows unit (early-Oligocene (?) to mid-Miocene (?)) and the Travertine unit (late Pliocene), it can be dated only as post-early Oligocene and pre-late Pliocene.



White marlstone of the Jordan Narrows unit overlain unconformably by the Camp Williams unit. Note basal conglomerate (A) of the Camp Williams unit. Beds are dipping to southeast.

LATE II



A. West wall of Jordan Narrows showing from right to left the Jordan Narrows unit, erosional unconformity, Camp Williams unit, fault, Harkers fanglomerate. Note angular discordance of dips in the Jordan Narrows and Camp Williams units.

B. To the south of view in Figure A. These are well bedded silts of the Provo formation and later gravels, both typical of the Pleistocene deposits.

Travertine unit

The Travertine deposits are rather limited in extent and thickness. Their location can be seen by examination of Plate XVII, particularly the map labeled Jordan Narrows enlargement.

Marsell (1932, p. 51) describes the deposits as follows;

> "The rock in hand specimens varies from dense, massive, flinty travertine to coarse, crustiform, or even cavernous, limestone, often resembling tufa. The color is white or pale cream. The rock is harder and resists weathering better than the Pliocene marlstones, which it superficially resembles. The hot springs which built up the travertine deposits also formed lens-like masses and veins of manganese ore."

The Travertine unit overlies both the Camp Williams and Jordan Narrows units. It ranges in thickness from 20 feet or greater to a very thin veneer.

The travertine deposits are of prime importance in that their age is well-established by fossil horse remains. Stirton and Savage (1952, oral communication) have identified a jaw and teeth as late Pliocene (Blancan). This fossil was found in the upper portion of the largest travertine outcrop by Marsell (1932) one mile northwest of Camp Williams. It is now preserved in the Geology Museum of the University of Utah.

The exact relationship of the Travertine unit to the Harkers fanglomerate is unknown but the author believes they may be contemporaneous. Reasons for proposing a Pliocene age for the Harkers fanglomerate will be presented in a later section on geomorphology.

Since faulting was pronounced in the Jordan Narrows in Pliocene time, the Travertine may have been a deposit from springs issuing along the faults during this time.

Harkers fanglomerate unit

Within the Jordan Narrows proper the Harkers fanglomerate is in fault contact with the Camp Williams unit (Plate III, figure A) but elsewhere overlies it unconformably (Plate IV) and dips more gently than either of the older deposits.

Since this is not the type locality of the Harkers fanglomerate, its detailed lithologic description will be reserved for discussion under the section entitled Oquirrh Foothills.

Lofgren (1948, p. 17) writes that "the fanglomerate (Harkers) exposure, in turn, is truncated and buried beneath the sediments of ancient Lake Bonneville and more recent stream gravels." Plate IV, figure B shows an outcrop of the typical gravels, sands, and silts.

One of the main problems encountered is the separation of late Pliocene from Pleistocene sediments. Fossil evidence is usually lacking and lithologies are too similar for useful field identification. The author however, found several criteria that proved satisfactory, at least within the Great Salt Lake Basin, for distinguishing between the Harkers fanglomerate and Quaternary deposits.

1. Deformation of the Pliocene beds gives them gentle but distinct dips. The Pleistocene strata are for the most part horizontal. Marsell (1948, p. 110) notes that the Quaternary rocks show little evidence of any tectonic movements except for minor dislocations near faults with recent movements.

2. In general the later Pleistocene materials are better sorted, more rounded, and less consolidated. It is true that the Harkers fanglomerate could not be classified as a well-indurated deposit, but it does in many localities have sufficient cement to allow the formation of distinct ledges along the canyon walls.

A. Fluvial Camp Williams unit in Jordan Valley north of Jordan Narrows. Beds dip to the south and are overlain unconformably by Quaternary river gravels.

B. View of Jordan Valley 2 miles north of the Jordan Narrows. The Red Camp Williams unit (Tcw) overlain unconformably by the Harkers fanglomerate (Th) which is well-consolidated in this area.

Although the Harkers fanglomerate is not without sorting, it is seen only in lenses and wedges of local extent. In the Quaternary deposits, however, beds of the Alpine and Provo clays 50 feet thick can be traced for several miles. They are well-stratified and represent lacustrine deposits in contrast to the alluvial fan origin of the fanglomerate.

3. The late Tertiary sediments are without geomorphic expression in contrast to the Quaternary deposits which are found and identified as spits, bars, alluvial fans, deltas, and river terraces. That is to say, although the materials in the Salt Lake group were laid down as lacustrine beds, alluvial fans, mud rock flows, etc., they can not be determined as such today from any geomorphic expression they now possess. Their original forms have been lost by burial and erosion during the Quaternary period.

4. Considering the overall picture the extent of the Tertiary deposits is greater than that of the Quaternary. This can be seen particularly on the fringes of the basin where the Tertiary deposits lap up the flanks of the mountains much farther. The Harkers fanglomerate is found up to elevations of 6000 feet or more but the Pleistocene sediments seem to lie mainly below the 5200 foot level.

Further discussion of the Quaternary deposits is not attempted. The reader is referred to a paper on the "Quaternary System in Utah", by R. E. Marsell (1948).

Paleontology

Detailed examination of the channel samples taken in the Jordan Narrows yielded few microfossils. For the most part they were persistant throughout the Jordan Narrows unit but very scarce. It often required several hours of searching in one 200 gram sample to find a single ostracode. The question, of course, arises as to the value of such an intensive search. First, the author attempted to determine if there were any definite fossil zones or fossiliferous strata that could be used for correlation, and second if there were any distinctive microfossils that might be helpful in dating the deposit more accurately. The answer was negative in both respects. Edmisten, however, (1952, p. 36) suggested that the Salt Lake group (Jordan Narrows unit) might be zoned on the basis of *Charaxis saltlakensis* although he admits that the fossils limited to only one zone are rare. He reported the following microfossils (1952, pp. 76-78).

Ostracoda	Charophyta
Candona candida	*Aclistochara lastitruncata*
Candona compressa	*Chara conica*
Cypridopsis saltlakensis	*Chara strobilocarpa*
Cyprois marginata	*Chara inconspicus*
Limnicythere lobata	*Chara subovalis*
Limnicythere lira	*Chara tornata*
Darwinula stevensoni	*Chara obovata*
Cypridopsis anterotumida	*Charaxis saltlakensis*

The author found many of these same specimens and has little to add except for two species of Candona not previously reported. These are *Candona kingsleyi* and *Candona candida* cf. *acuminata*. Further it should be noted that Edmisten's upper fossil zone (1953, p. 8) should be enlarged to include the upper 40 feet of the Jordan Narrows unit.

In following Yen (1947, p. 272) who assigned a Pliocene age to the exposure of the Salt Lake group near Logan, Utah, Edmisten suggests that the Jordan Narrows section of the Salt Lake group is approximately the same age but does not analyze the fossil evidence for his correlation.

Although a respectable number of species from the Jordan Narrows unit have been identified, there is little evidence on hand for even an approximate age determination within the Tertiary.

Mud rock flows

In or near the Jordan Narrows there exist several excellent exposures of ancient mud rock flows. One may be seen two miles south of Camp Williams in a road cut along Highway 68. A second is located in Beef Hollow about 1/4 of a mile west of the same highway where it crosses Beef Hollow, and a third along the Utah Copper Canal 1 1/2 miles north of the dam in the Jordan Narrows. These are not of the same age nor are they exactly similar in nature and it seems desirable to discuss them briefly. They are labeled on the map (Plate XVII) and referred to in the text as Mrf-1, Mrf-2, and Mrf-3.

Mrf-1 can be seen in a road cut along State Highway 68, two miles south of Camp Williams where it slices through a low hill composed of the Jordan Narrows unit, (Plate V, figures A and B).

From six to ten feet of hard marlstones lie at the base of the cut and are overlain by a mud rock flow of very irregular thickness. It is composed almost entirely of volcanic detritus ranging from fine sands to boulders several feet in diameter. The matrix is light colored, predominantly $CaCO_3$, and apparently derived from the underlying marlstones. Assuming the lake bottom at the time of origin of the flow was covered by soft limy muds, it is not difficult to envisage a plowing, churning mass of volcanic detritus which moved out over the floor and incorporated large quantities of these muds until it came to a final rest. Subsequent induration yielded a very well-consolidated body resting on equally hardened marls. Normal deposition then resumed, as evidenced by a two to four foot layer of even-bedded marlstone overlying the mud rock flow. This necessitates placing the flow within the Jordan Narrows unit.

A. View of mud rock flow (Mrf-1) along Highway 68 south of Camp Williams. White, blocky marlstones overlain by the flow, both belong to Jordan Narrows unit.

B. Detailed view of exposure shown in Figure A. Note the irregular contact between the flow and underlying marlstones.

Mrf-2. State Highway 68 crosses Beef Hollow at the northern edge of Camp Williams. A second mud rock flow may be observed about 1/4 of a mile west of the highway (Plate VI, figures A and B).

Again the composition of the flow is almost 100 percent volcanic sands, gravels, and boulders. The matrix is calcareous silt which serves as a weak cement for the coarser materials. In this respect it differs markedly from Mrf-1. Its relation to the Jordan Narrows unit is also different in that it is faulted up against the marlstones and separated from them by a reddish-brown, sticky, fault-gouge clay. Hence, it is older than the beds of the Jordan Narrows unit against which it has been faulted and may be an early incident in the volcanic activity of the area. Quaternary cut-and-fill activity has deposited stream sands and gravels unconformably over and against these much older units. A second fault is believed to separate the Paleozoic rocks, which crop out to the west, (Plate XVII) from this flow and the Jordan Narrows unit.

Mrf-3. The Utah Copper Distributing Canal flows northward from the Jordan Narrows along the west side of Jordan Valley. The canal banks offer good exposures of both Quaternary and Tertiary sediments. One and one half miles from the dam in the Narrows, along this canal, a third mud rock flow was studied (Plate VII).

From youngest to oldest the observed units are as follows;

1. A veneer of Recent stream gravels and soil a few feet thick.

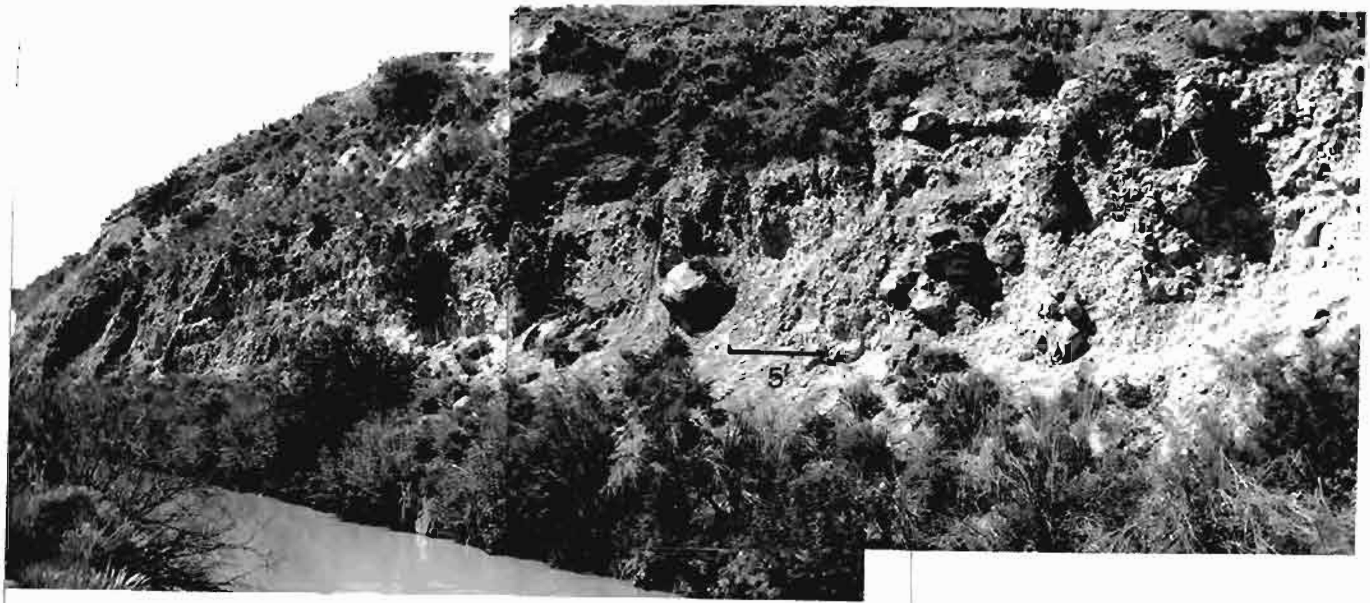
2. Blocky clays 20 to 25 feet thick that are probably Provo in age (Lofgren, 1947, pp. 17-18).

3. Red silts and calcareous mudstones belonging to the Camp Williams unit but covered too much by slump and wash to determine the thickness.

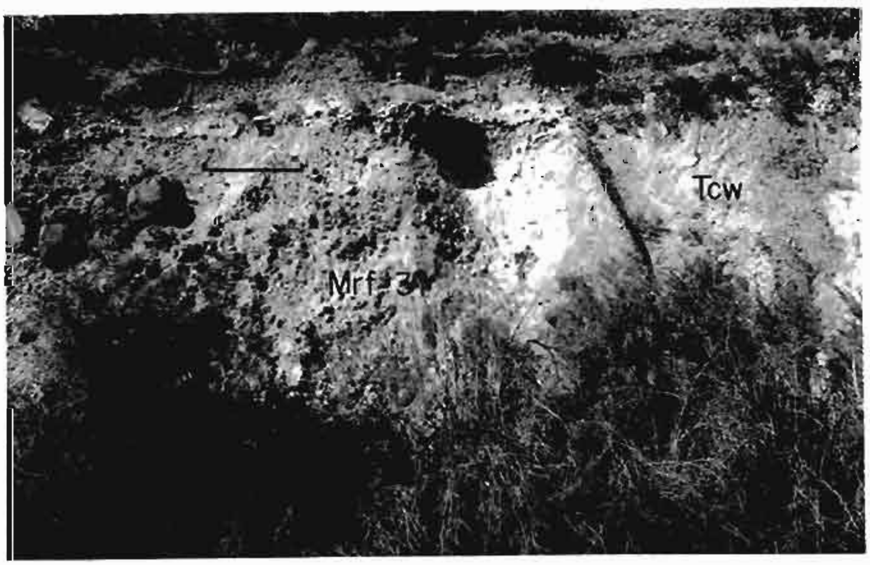
A.

B.

Views of the mud rock flow in Beef Hollow (Mrf-2). Looking from right to left in Figure A. note - white Jordan Narrows unit, (Tjn) fault, mud rock flow, (Mrf-2) and Recent stream gravels (Qal) unconformably against edge of the flow.



A. View of mud rock flow 1 1/2 miles north of the Jordan Narrows (Mrf-3). Flow composed of volcanic detritus.



B. Continuation of the view in Figure A, this picture adjoins the above sequence on the right. Note fault which places the Camp Williams unit against the mud rock flow.

4. Mud rock flow, gray color, predominantly volcanic detritus with boulders to 8 feet across. Poorly cemented with small amounts of $CaCO_3$. Rough alignment of the lava blocks produces a bedding that seems to terminate against a more typical mud rock flow mass showing no signs of sorting or stratification. Thickness of 20 feet or better can be measured but base of flow is not exposed.

The north end of the entire sequence is sharply interrupted by a fault which dropped the Camp Williams unit down against the mud rock flow.

Several interpretations can be made concerning the exact age of this flow. Since it seems to underlie the Camp Williams unit it might represent the basal part of this deposit. Another interpretation is that it is an early part of the Jordan Narrows unit. This view acquires some support from the observation that the Mrf-3 flow closely resembles the Mrf-2 flow in Beef Hollow, which seems to have occured early in the history of volcanism and the deposition of the Jordan Narrows sediments.

The contact between the flow and the Camp Williams unit is not clearly discernable. If it were, the age might be better determined.

Farther north along the same canal, a deposit overlying the Camp Williams unit exhibits definite mud rock flow structure, and the volcanic rocks are abundant but there is a noticeable increase in quartzite boulders. It is well-cemented with $CaCO_3$ and grades upward into the Harkers fanglomerate.

Thus it can be said that mud rock flows were formed throughout the late Tertiary (Oligocene-Pliocene). Their source was the volcanic terrain of the Traverse Mountains and it seems to the writer that this type of deposit would be expected along the flanks of a mountain mass covered by volcanic flows and subjected to erosion. Twenhofel (1950, pp. 266-268) points out that "volcanic ash is likely to produce mud flows if water accompanies the falls or later wets them." He also makes another point that fits in with the writer's concept of the climate at that time. "Not a great deal of water seems necessary to cause mud to flow, and mudflows are more prevalent in semiarid regions, or regions that for any reason are without cover of plant protection, than elsewhere."

Igneous Rocks

A detailed study of the igneous rocks was not made in view of the fact that Gilluly (1932) and Marsell (1932) have thorough descriptions of the various types present both in the Oquirrh and Traverse Mountains.

The commonest rock types are reddish to purple andesites and andesite breccias, augite and biotite-hornblende latites and latite flows, and lesser amounts of rhyolite and basalt. Gilluly (1932, p. 57) gives the following description.

> The commonest rock variety . . . is a medium-grained porphyry in which crystals of plagioclase, biotite, and pyroxene, rarely exceeding 1 mm in length are the only megascopically recognizable phenocrysts. . . In thin section phenocrysts of andesine ($Ab_{60}An_{40}$), augite, and biotite are seen to occur in a granitic groundmass of orthoclase, quartz, and plagioclase.

> Most abundant lava in Fairfield Quadrangle is biotite-hornblende latite. In thin section plagioclase is seen to be faintly zoned ($Ab_{70}An_{30}$). The principle mafic mineral is hornblende of basaltic variety. Most commonly the groundmass is hyalopilitic.

Marsell (1932, p. 63) reports similarly from the Traverse Mountains.

> In thin section the andesite is coarsely porphyritic. The chief mineral is oligoclase with a composition of $Ab_{72}An_{28}$. The feldspar shows prominent zonal growth. Biotite is the chief femic mineral accompanied by smaller amounts of hornblende and augite. All of the minerals have been considerably altered the ferro-magnesian in particular. The groundmass is largely composed of gray glass filled with abundant laths of felty microlites of feldspar.

The source of these extrusive rocks is believed to be the eruptive centers designated as Step Mountain and South Mountain in the western portion of the Traverse Mountains, near their junction with the Oquirrh Mountains. See Plate XVII.

Their exact age is unknown but Gilluly (1932, pp. 40, 65-66, 84-85) by comparing them with similar deposits in adjacent areas, believes that they should be dated as late Eocene and Oligocene. The volcanic activity must have been prolonged, for it seems certain that the entire Traverse Mountains and portions of the Wasatch and Oquirrh Mountains were buried by the extrusives. The outside age limits of the volcanics are latest Eocene and late Miocene judging from the presumed age of the Jordan Narrows unit with which the volcanics are approximately equivalent. The volcanic activity could have spanned this entire interval.

The writer attempted to correlate the volcanic glass from various areas in the basin by means of indices of refraction. Samples from the Jordan Narrows, Traverse Mountains, Oquirrh Mountains and Bacchus Pit all had indices of 1.505. According to Grout (1932, p. 114) this would indicate a very acid composition, with 70-72 percent silica. Thus it appears that the explosive eruptives were more acidic than the lava eruptives. The similarity of the indices also might be used as evidence to support the theory of a common source for the glass though not contemporaneity.

The igneous rocks still bury a great portion of the Traverse Mountains (Plate XVII) and constitute much of the foothill belt along the east flank of the Oquirrh Mountains.

Structure

Faults

Several faults displace and tilt the beds of the Salt Lake group conspicuously.

There is excellent topographic evidence for a major northeast-southwest fault along the north side of the East Traverse Mountains. This same fault appears to continue across the Jordan Valley but splits into at least three large branches and many minor faults as it intersects the Jordan Narrows. See Jordan Narrows enlargement on Plate XVII. A second major fault striking almost due north-south lies to the west of the Jordan Narrows along the edge of the water gap. The proof for the existance of this fault is manifest in the apparent sharp contact between the Paleozoic rocks and the Jordan Narrows unit and in the upturned nature of the marlstones in Beef Hollow near the contact. Alluvium and slope wash, however, prevent any direct observation of the actual contact.

Within the Jordan Narrows the major fault and branch faults displace all the beds of the Salt Lake group with the exception of the Travertine unit. The northern most branch fault is marked by the Camp Williams unit down-faulted on the north against the Jordan Narrows unit on the south. The displacement is approximately vertical and of small magnitude. Along the major north-south fault to the west of the Narrows the Jordan Narrows unit is faulted down against the Paleozoic rocks.

The faulting in the Jordan Narrows has produced a fault mosaic pattern, and it seems possible that the small blocks were rotated in the process of this faulting.

The exact age of the faulting is somewhat difficult to determine. Obviously it occurred after deposition of the Harkers fanglomerate and likewise must have originated much earlier since the tilted strata of the Camp Williams and Jordan Narrows units have an angular discordance with one another as well as with the Harkers fanglomerate. The Pleistocene beds, however, are undisturbed by the faulting. Thus the best estimate of the age would be post-middle Oligocene to pre-Pleistocene.

Marsell (1932, pp. 88-89) had this to say about the structure of the Traverse Mountains and its relation to the faulting recorded in the Salt Lake group.

> The present relief of the mountain mass and its external form are a direct expression of the earlier (Laramide) folding and not of the younger faulting. These faults, which today have no topographic expression . . . cross the range from southeast to northwest paralleling in general the axis of the folds in the Oquirrh Mountains. Their existence is revealed by dislocated strata or a resistant fault-breccia.

Folds

In the mapping done by the writer, only one possible fold was discovered. This is located to the north of the Jordan Narrows and is based on the change in dip of the Camp Williams unit from approximately 10° south to 15° north in a distance of 1/2 a mile.

Regional dips evidently not associated with faulting and of a more extensive occurrence seem to demand at least gentle folding.

GEOLOGY OF THE OQUIRRH FOOTHILLS

Geography

A belt of foothills 3 miles wide extends along the east flank of the Oquirrh Mountains for about 12 miles. The belt ends abruptly north of Coons Canyon where alluvium rests directly on the Paleozoic rocks. The belt can be traced southward to the junction of the Oquirrh and Traverse Mountains. At an elevation of approximately 6100 feet there is a sharp break in the slope where the gentle surfaces of the foothills abut against the more steeply inclined ridges of the mountain mass. The eastern edge is rather well defined by the Lake Bonneville shoreline at an elevation of 5180 feet.

From the air the foothills appear as an incised pediment. (See Plate VIII, figures A-D). Dry farm fields over most of the area accentuate the flat-topped ridges which are bounded by sharp V-shaped valleys (Plate X). These latter, for the most part, contain only intermittent streams.

An abandoned railroad bed plus mining and farm roads afford rather easy access. The many railroad cuts are invaluable in establishing stratigraphic relationships.

Mapping

The limited outcrops made mapping difficult. Slope wash, pediment gravels, vegetation, and recent alluvial deposits effectively mask the bedrock in the foothill belt. As a result, many of the contacts are uncertain since they were drawn without regard to the surface cover where it seemed thin. No attempt was made to delineate or distinguish the types of volcanic rocks.

Description of the Pediment

The dissected pediment which forms the Oquirrh Foothills has a gently sloping surface that is inclined about 3° to the east. This can best be seen on the ridges which flank Harkers Canyon. Here it is possible to trace continuously the oldest surface on an east-west line from an elevation of 6100 feet down to the Bonneville shoreline at 5180 feet.

The pediment gravel ranges in thickness from a thin scattering of a few cobbles to a cover several feet thick. It is composed of subrounded quartzite and limestone fragments with smaller amounts of volcanic detritus. A singular feature in the foothills are the larger residual boulders 4 to 6 feet across, that were probably left behind during the pedimentation or by later erosion. Many are blackened with desert varnish and so badly weathered that they disintegrate when struck with a hammer.

The rocks underlying the pediment veneer belong to the Salt Lake group except where headward erosion extended the surface a few hundred yards into the Paleozoic deposits. The Traverse volcanics and Harkers fanglomerate underly the bulk of the pediment. It seems probable that the pediment was sculptured on a series of coalescing alluvial fans (Harkers fanglomerate) but, no trace of the forms of the old fans can be seen today. If the Harkers fanglomerate is dated as late Pliocene (?) the pedimentation would fall in the latest Pliocene or early Pleistocene.

A. Looking southwest at north edge of pediment. Coons Canyon at extreme right and Harkers Canyon just left of center.

B. Looking northwest at pediment. Note flat topped ridges and different surface levels.

C. About same view as Figure B but a little further south and looking almost due west. Highest surface can be seen toward upper right corner of picture. Two long ridges there flank Harkers Canyon

D. View along eastern edge of pediment showing low rounded hills which are remnants of the pediment and were islands in Lake Bonneville.

Views Along East Flank of Oquirrh Mountains

Dissection of this late Pliocene pediment was a Pleistocene event and evidently not a continuous process. At least one and perhaps two lower and younger pediment surfaces can be seen on aerial photographs (Plate VIII, figures B and C) and on profiles from the topographic sheets (Plate IX, figures A and B). The profiles illustrate particularly well the various surfaces. They are numbered, from highest and oldest to lowest and youngest, 1, 2, and 3, and briefly discussed below.

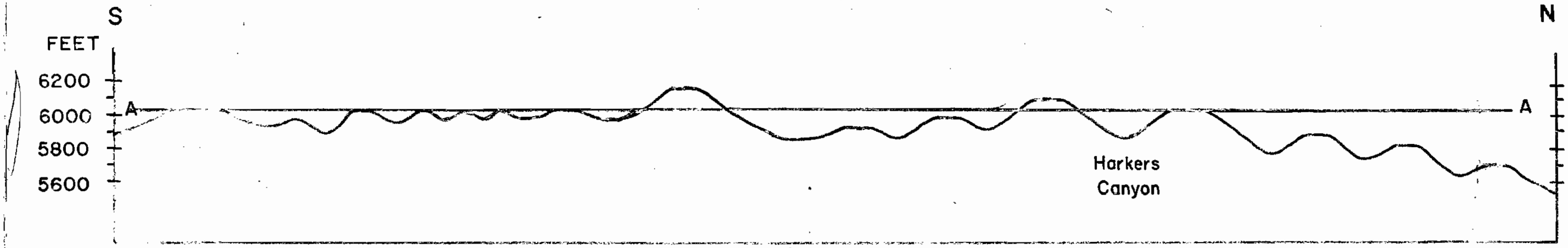
#1. Pediment number 1 is very distinct (Plate VIII, figure B) but is represented by only two or three prominent ridges. The best examples are those flanking Harkers Canyon. On a north-south line paralleling the Oquirrh Mountains and approximately 1/2 mile east, the surface of the pediment has an average elevation of 5900 feet.

#2. Pediment number 2 is far more extensive and averages 5700 feet along the north-south line described above. Its surface is the one so heavily cultivated for dry farming.

#3. The third pediment is more difficult to define. The writer feels that in part it is represented by broad stream terraces in Barneys Canyon and Barneys Wash and would tentatively place it at about 5400 feet. The adjustment of the streams to a base level controlled by Lake Bonneville seems a possible explanation for the development of this third pediment.

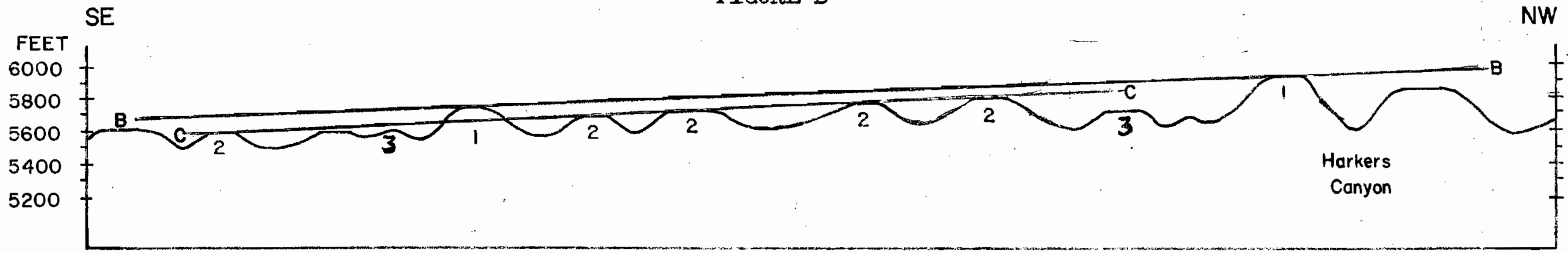
The most significant structural feature of the Oquirrh Foothills is a major north-south normal fault along the base of the Oquirrh Mountains. Examination of the cross sections along B-B and C-C on Plate XVII will show the Tertiary strata down faulted on the east. In part the fault is buried by the Harkers fanglomerate but elsewhere serves as a contact between the Paleozoic rocks and fanglomerate. The cross sections also show the oldest pediment, number 1, to have developed headward across the fault and in places extended a few hundred yards into the Paleozoic rocks.

FIGURE A



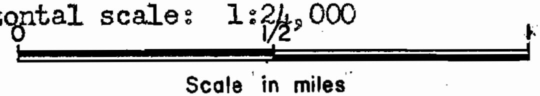
North-south profile across the Oquirrh Foothills. Drawn on a line 3/4 mile east of main mountain mass. Illustrates multiple erosion surfaces in pediment. It is impossible to adjust line A-A to lie in a plane common to all surfaces.

FIGURE B



Same profile as in Figure A, but on a northwest-southeast line. The numbers 1 and 2 represent erosion surfaces 1 and 2 respectively (see page 4). Line B-B lies in the plane of the oldest and highest pediment surface.

Vertical scale: Feet above sea level
Vertical exaggeration: 2.4
Horizontal scale: 1:24,000



PROFILES OF THE OQUIRRH FOOTHILLS

Taken from the Lark and Magna topographic quadrangle sheets.

PLATE IX

Thus the sequence of events associated with the pediment may be summarized as follows: (1) significant block faulting along the base of the Oquirrh Mountains in early Pliocene time, subsequent rejuvenation of mountain streams, and deposition of the Harkers fanglomerate as alluvial fans, (2) pedimentation of Harkers fanglomerate and Traverse volcanics culminating in late Pliocene time, (3) incision of pediment and development of younger pediments during the Pleistocene.

Stratigraphy

Major divisions

The oldest rocks and most prominent in outcrop are the volcanics (Plate XI, figures A and B). Due to their greater resistance to erosion, compared with the Tertiary sedimentary deposits, they stand above the general plane of the pediment as somewhat rounded, irregular hills (Plate X). The oldest sedimentary rocks are the lacustrine deposits correlated with the Jordan Narrows unit. Their exposures are quite limited. For the most part they appear in the stream bottoms or low on the flanks of ridges and hills. The Harkers fanglomerate overlies the Jordan Narrows unit unconformably and is the main constituent of the foothills. It crops out only in a few places because of its non-resistant nature. Detailed measured sections are limited to excavations such as gravel pits, road embankments, and railroad cuts.

Measured sections

The Bacchus Pit is an abandoned borrow pit and located 3/4 of a mile north of the Bacchus Powder Plant. A channel sample was obtained and the

Oquirrh Foothills looking southwest at Bingham Canyon and the town of Copperton. Note the very flat surfaces of the dissected pediment with rounded sprawling hill in rear standing above them. It is composed of volcanic rocks. Note also toward the lower central part of picture the stream terraces that are incised by modern streams.

A. Oquirrh Foothills. View of andesite agglomerate overlapped on flank by Harkers fanglomerate.

B. Oquirrh Foothills. View looking west. The prominent pinnacles are composed of tuffaceous agglomerates.

material examined in the laboratory under the microscope at a later time. Intervals of collections were 2 feet.

	Feet
Quaternary silts, sands and gravels.	20
— unconformity —	
Jordan Narrows unit	
Marlstone, white, hard, conchoidal fracture, interbedded with yellowish slightly bentonitic, shaly clay. Marlstone contains long prisms of calcite and lesser amounts of glass shards. Small amounts of mica, quartz, magnetite and feldspar occur as fine sand.	10
Sandstone, brown, fine grained, poorly consolidated, highly laminated, the lamination being caused by thin shale lenses. Sand composed of angular quartz and glass shards, aggregates of mica, calcite, hornblende, and magnetite with $CaCO_3$ as cement. Glass shards have an index of refraction of 1.505.	4
Mudstone, yellow, calcareous, conchoidal fracture, and contains very little sand.	2
Siltstone, gray to yellow, sandy, shaly, contains hard lumps of clay that are cherty in spots. Sand particles are composed of aggregates of quartz, mica, calcite, glass shards, magnetite, and stained by MnO_2. Cement is $CaCO_3$.	4
Marlstone as before but shaly strata are more predominant. Clay is bentonitic. Some of the strata are highly laminated.	25
Same but contains higher percentage of calcite crystals and shows a vugy-like structure. Vugs are hexagonal and many are filled with calcite.	3
Marlstone, white, hard, with conchoidal fracture, very fine grained except for a little crystalline calcite and small amounts of mica, magnetite, and quartz. Manganese dendrites are very common. This lithology alternates with gray to yellow strata much higher in the clay minerals (?) and is quite fissile.	8
Total thickness	56

#2. Approximately 3 miles south of the Bacchus Powder Plant a vertical channel section was taken in a railroad cut. Two foot intervals were collected in each sample (Plate XII, figure A).

	Feet
Harkers fanglomerate	
Fanglomerate with soil profile developed on it. On flanks of the hill this grades into a thick wedge of reddish brown silts and clays. No samples taken.	0 - 10
— unconformity —	
Jordan Narrows unit	
Marlstone, white, hard, blocky fracture, porous near top due to weathering; alternates with clay that is yellow, calcareous, and has shaly fracture. Ostracodes common. Small amounts of quartz, mica, feldspars and a few glass shards present.	17
Sandstone, yellow to brown, impure, poorly consolidated, fine grained. Composed of quartz, mica, feldspar, magnetite, chlorite, hornblende, and glass shards many of which are in form of small glass bubbles. Index of refraction is 1.505, for the glass shards.	2
Tuff, gray, glittering, porous, closely packed but only lightly cemented with $CaCO_3$. Has a little clay and small amounts of quartz and magnetite. Ostracodes present.	4
Same but has thin lenses of marl containing crystalline calcite.	2
Marlstone, gray to white, as above but distinct in that it forms a resistant ledge.	4
Tuff, white, rhyolitic, poorly consolidated, quite pure and highly laminated.	3
Same, but not as pure. Alternates with shaly white clays that are calcareous. Small amounts of mica, magnetite, and feldspar present. Festooned cross bedding prominent.	5
Siltstone, yellow to light tan, finely laminated, poorly consolidated, much contorted as though by contemporaneous deformation. Contains aggregates of glass shard, magnetite, mica and calcite.	4

	Feet
Shale, light tan, hard, fissile, makes up resistant ledges. Composed of aggregates of silt-sized particles. Small amounts of glass shards.	3
Same but interbedded with white, massive, marlstone, in which glass shards are more plentiful	6
Tuff, gray, well laminated, very loosely cemented with $CaCO_3$. Its consolidation seems to be due to interlocking of glass shards. Very pure with 95 percent glass shards and the remainder composed of mica, feldspar, chlorite, magnetite, hornblende, obsidian, and small fragments of marl. Carbonaceous fragments partially replaced by what seems to be iron carbonate and stained yellow as a result, are quite common.	22
Moved west approximately 150 yards	
Marlstones and siltstones interbedded as higher in the section. Base not exposed.	10
Total thickness	90

Jordan Narrows unit

Although it is impossible to trace continuously the typical white marlstones and limestones from the Jordan Narrows over to the foothill region of the Oquirrh Mountains, there is little doubt that the same unit is represented in both areas. The lithologies are quite similar but no one stratum can definitely be correlated except possibly for the tuff bed. This is much thicker along the flanks of the mountain mass than in the Narrows. As pointed out earlier in the text (page 26), the identical indices of refraction suggest the same source for the tuffs.

From the map (Plate XVII) it can be seen that the Jordan Narrows unit in this area is confined to the lower slopes and ridges or to the actual valley floor. The outcrops are more numerous in the vicinity of Clay Hollow and become scarce to the south, there being none south of Copperton. For the most part these strata are horizontal, with the exception of the

Bacchus Pit area, where they dip steeply, 31°, to the northwest (Plate XIII, figure B). A major fault has been suggested to pass just south of the Bacchus Pit along the base of an east-west salient which projects 3 to 4 miles out into the Jordan Valley (Plate XII, figure A). The author suggests for this projection the name Bacchus Salient. Warm water springs in the pit and the steep dips of the strata suggest the presence of branch faults from the major one mentioned above.

Harkers fanglomerate

Harkers Canyon cuts through the northern portion of the foothills (Plate XVII) and it is within this canyon that the Harkers fanglomerate is coherent enough to form ledges along the valley walls and floor the bottom of the valley. Thr railroad cuts offer the only other exposures of any magnitude (Plate XIV, figures A and B). However, as can be seen by an examination of the map (Plate XVII), the Harkers fanglomerate is the dominant rock on the Oquirrh Foothills. It undoubtedly extends out into the lower Jordan Valley under cover of the Lake Bonneville sediments, where it was originally deposited in the form of coalescing alluvial fans.

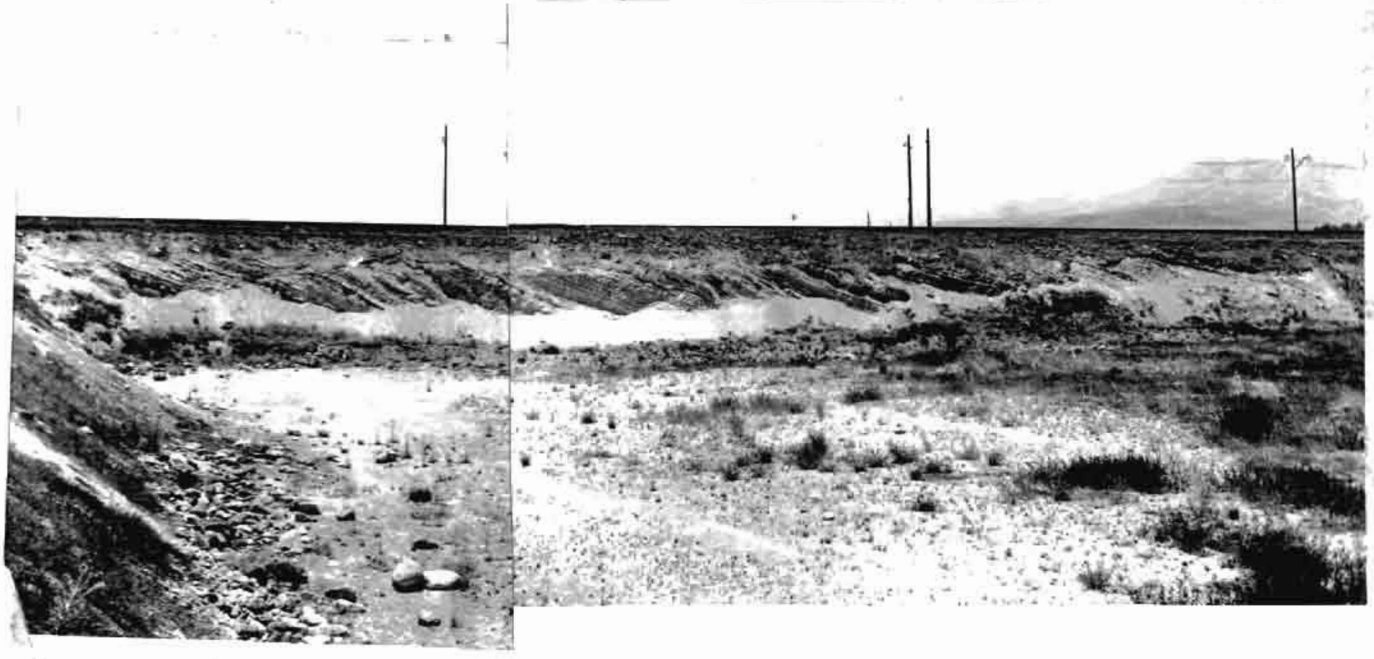
A description of the Harkers fanglomerate as it appears in Harkers Canyon and vicinity, which is designated as the type locality, follows.

> Fanglomerate, tan to gray, poorly consolidated except for local lenses and wedges which are almost white due to the $CaCO_3$ cement. The deposit as a whole is poorly sorted with occasional channels and lenses of reddish silts. Torrential bedding and cut-and-fill structure are common. The material is composed of angular to subrounded quartzites, sandstones, dark limestones, andesites and latites which range in size from silt particles to boulders 6 to 8 feet across. Normally, the quartzites and other Paleozoic rocks make up 80 percent of the unit but, lower in the section there occur wedges and channels that are 90 percent volcanic detritus. The overall color is

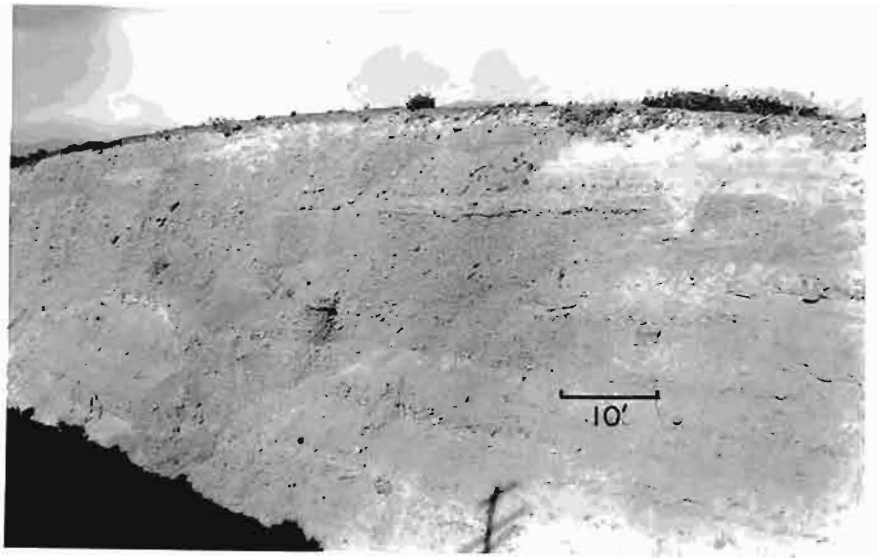
A. Railroad cut in Oquirrh Foothills showing white Jordan Narrows unit overlapped on flank by red silts which grade into the Harkers fanglomerate at top of ridge.

B. Bacchus Pit. View of Jordan Narrows unit overlain unconformably by Quaternary gravels. Note irregular erosion surface.

A. View looking south at Bacchus Salient. Edge of Oquirrh Mountains can be seen at far right.



B. Bacchus Pit, looking south at well stratified Jordan Narrows unit dipping approximately 30° to the northwest.



A. Railroad cut in Oquirrh Foothills. This cut is at right angles to the long ridges of the pediment and exposes the Harkers fanglomerate.

B. Same as Figure A. Note cut and fill structure.

> gray and the cement and matrix tuffaceous. Cobbles are the average particle size and there are fewer silt and clay lenses than higher in the section. The few thin strata of finer material are tuffaceous and calcareous.

The thickness of the fanglomerate unit is at least 300 feet in Harkers Canyon and was greater before pediment erosion.

The Harkers fanglomerate apparently originated as a number of coalescing alluvial fans deposited over a surface of moderate relief. The fans succeeded in burying the older topography possibly with the exception of some of the volcanic hill tops. Later pedimentation and erosion produced the present day distribution and outcrop pattern.

Paleontology

The microfossils found are very similar to those listed for the Jordan Narrows area. Ostracodes are fairly abundant but charophyte remains scarce. One new genus of ostracode and a species of *Candona* not previously reported were discovered. These were *Cyclocypris species* (?) and *Candona fabaeformis*. A few bone fragments were also seen but proved unidentifiable. The microfossils were found only in the Jordan Narrows unit.

Igneous Rocks

The volcanic rocks in the Oquirrh Foothills are similar to those previously discussed in the section on the Jordan Narrows. In this paper they are referred to as the Traverse volcanics.

As pointed out earlier (page 32), the volcanics usually appear as low, rounded hills and are more prevalent in the southern portion of the foothills. The area between Copperton and Butterfield Canyon is composed predominantly of volcanic rocks (Plate XVII).

TOOELE VALLEY

Introduction

The Stansbury Mountains to the west, South Mountain and Stockton Bar to the south, the Oquirrh Mountains to the east and Great Salt Lake to the north effectively bound Tooele Valley (Plate I). The valley is approximately 10 miles wide and 15 miles long, and represents a portion of the basin of ancient Lake Bonneville. The various lake terraces are well-preserved on the surrounding mountain flanks.

The principal streams draining into Tooele Valley are North Willow, South Willow, and Box Elder Creeks from the Stansbury Mountains and Settlement Creek, Middle Creek, and Pine Canyon Creek from the Oquirrh Mountains. All of the water discharged is utilized by the inhabitants of the valley for domestic use or irrigation. A report by Thomas (1946) should be referred to for additional information.

Geomorphology

In the vicinity of South Willow Creek on the east piedmont of the Stansbury Range a well developed pediment exists. The surface has been eroded across a fanglomerate which flanks the range and extends well into Tooele Valley. This pediment, as in Jordan Valley is dissected and at least two distinct surfaces can be observed along the ridges which bound South Willow Creek Canyon.

Stratigraphy

General statement

Rocks ranging in age from pre-Cambrian to Recent can be found within the Stansbury Mountains. Of more concern to this study are the Tertiary volcanics, conglomerates, and fanglomerates which make up the lower portions of the mountains and the dissected pediment that extends into the valley. Thomas (1946, pp. 109-110) gives the following general resumé for post-Laramide events.

> "Sediments of probable Eocene age, considered to be equivalent to the Wasatch formation elsewhere in Utah, were deposited along the east flank of the major anticlinal fold that now forms the Stansbury Range, and may have been distributed widely as fluviatile and perhaps lacustrine deposits in Tooele Valley. After the deposition of the Wasatch formation, volcanic eruptions on a moderate scale distributed latitic flows and breccias, and tuffs over the region. Basalt was erupted locally in the Stansbury Range as the last stage of volcanic activity in the area. These volcanic rocks have been extensively eroded from the highland areas and redeposited by streams at lower elevations.
>
> Block faulting typical of the Basin and Range province appears to have begun during the volcanic activity and continued intermittently to the present day."

The block faulting resulted in coarse clastics being shed into the graben valley to a thickness of several thousand feet.

South Willow Creek section

This section is generalized both with respect to description and thicknesses. See Plate XV for cross section.

Feet

Salt Lake group

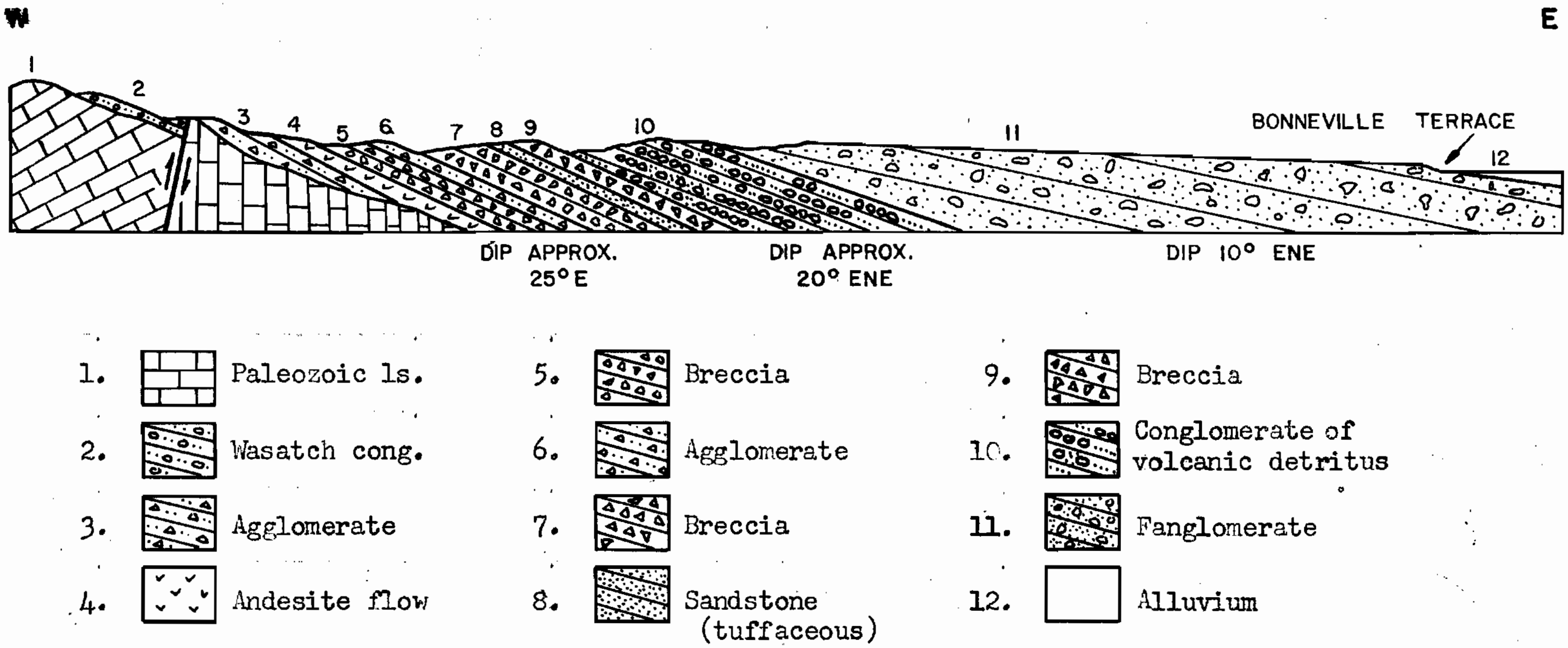
Fanglomerate, tan, very poorly sorted, unconsolidated to well consolidated with $CaCO_3$. composed primarily of Paleozoic black limestones and light colored quartzites with lesser amounts of green and brown shales, tan to

	Feet
dark brown sandstones and chert. Small amounts of volcanic fragments and red conglomeratic cobbles are present. Lower in the section the volcanic detritus increases considerably.	1500 - 2000
Conglomerate, white to tan, volcanic detritus, slightly calcareous except for two thin marl or chalk zones. Distinctively stratified but torrential in nature with individual strata ranging from several inches to 4 or 5 feet in thickness. Particle size ranges from clay to boulders 4 feet across. In general the matrix is a fine sand, poorly consolidated but resistant to erosion.	700 - 900
Breccia, red to brown, volcanic, coarse.	250 - 350
Sandstone, light gray, very tuffaceous, not well consolidated and contains some boulders. All material is volcanic. Seems to vary considerably in thickness.	50 - 200
Breccia, reddish-brown, volcanic, coarse, with local massive andesite bodies.	600 - 700
Agglomerate, gray, torrential, may represent a volcanic mudflow.	70 - 90
Breccia, volcanic, dark brown, very coarse.	75 - 125
Andesite, dark brown, massive, apparently represents a flow.	40 - 50
Agglomerate, gray, tuffaceous, shows some stratification and particles range from sand to boulders 4 to 6 feet across.	200 - 300

--- unconformity ---

Wasatch (?) formation (Paleocene to Eocene age)

Fanglomerate, red to orange, well indurated with coarse, sandy matrix and cement of red calcareous clay. Boulders consist mostly of dark gray to light gray limestone, silty sandstone, and red mottled, sandy, limestone. The boulders are slightly rounded. Shows crude stratification. Average size of the coarse detritus is 2 to 6 inches.	150



GENERALIZED CROSS SECTION ALONG SOUTH WILLOW CREEK CANYON

IN THE STANSBURY MOUNTAINS

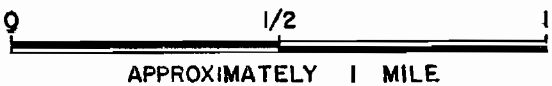


PLATE XV

	Feet
--- angular unconformity ---	
Paleozoic limestones	?

Davenport Canyon section

A section measured in Davenport Canyon about 2 1/2 miles north of South Willow Creek Canyon was similar with the addition of a 400 foot bed of limestone.

	Feet
Salt Lake group	
Breccia, reddish brown, volcanic, coarse.	600 - 800
Sandstones and silts, gray, tuffaceous, somewhat conglomeratic.	300 - 400
Breccia, dark brown, coarse.	40 - 50
Sandstone, gray, tuffaceous, contains isolated large volcanic boulders.	300 - 400
Limestone, tan to yellow, dense, crystalline.	300 - 400
Sandstone, light gray, tuffaceous.	400 - 500
Andesite, dark brown, massive, represents flows.	100 - 200
--- unconformity ---	
Paleozoic limestones.	?

Wasatch (?) formation

Rocks called Wasatch (?) formation in the measured section have a very limited extent on the east slopes of the Stansbury Mountains. The only exposure is a coarse fanglomerate that lies just above the first and oldest volcanics. It is plastered on the Paleozoic limestones and dips steeply to the east. A portion of the outcrop can be seen several hundred yards above the ranger station in South Willow Creek Canyon. A north-south fault apparently lies between the Wasatch (?) formation and the thick volcanic sequence.

Reasons for calling it the Wasatch (?) formation are as follows:

1. It is well cemented, and unlike the fanglomerates above the volcanics which are poorly cemented.

2. It has an abundant sandy, shaly, and limy matrix like parts of the Wasatch group east of Salt Lake City.

No fossils were found in it, and it lies apart from the volcanics so that stratigraphic relations cannot be demonstrated. The correlation must therefore be considered very poorly established.

Salt Lake group

Thomas (1946, pp. 113-114) places only the youngest fanglomerate (Plate XV, unit 3) in the Salt Lake group. In this paper all the Tertiary, post-Wasatch (?) deposits (Plate XV, units 3 through 11) are included within the Salt Lake group.

The volcanic agglomerates, breccias, and tuffs (Plate XV, units 3-9) are distinctly stratified and attain a thickness of 1500 to 2000 feet. They lie in a belt along the east flank of the Stansbury Mountains from Box Elder Canyon to Davenport Canyon and dip eastward about 20°.

Several thin sections were made in an effort to recognize any similarities of the volcanic rocks to those in the Oquirrh and Traverse Mountains. They were examined and reported on by Professor Max Erickson of the Mineralogy Department of the University of Utah as follows;

No. 1. Andesite from Davenport Canyon.

In thin section this rock has a hyalopilitic texture. Its average composition runs 70 percent andesine, 10 percent augite, 10 percent biotite, and 10 percent glass. The andesine is present in microlites not phenocrysts. The augite is mostly phenocrystalline.

No. 2. Andesite from South Willow Creek.

In thin section this rock shows a pilotaxitic texture with some preferred orientation that may be the result of flowage. Andesine makes up 75 percent of the rock and appears both as zoned phenocrysts and as microlites. In the phenocrysts the average composition is $Ab_{56}An_{44}$. Hornblende is present as about 15 percent of the rock and shows magnetite rims. The other 10 percent is predominantly augite.

As a result it may be concluded that general similarities exist between the Oquirrh-Traverse volcanics and those in the Stansbury Mountains. They have the same tectonic setting and are probably of the same age.

The conglomerate (Plate XV, unit 10), composed almost entirely of volcanic material, represents erosion from a volcanic terrain and redeposition at a lower elevation (Plate XVI, figure A and B). The lack of any Paleozoic rocks in this conglomerate would indicate that the volcanic accumulations effectively deflected drainage from the Stansbury Mountains at this place and no Paleozoics were washed in.

The youngest fanglomerate (Plate XV, unit 11) is similar to the Harkers fanglomerate. Lambert (1941, pp. 23-24) named this unit the Stansbury conglomerate and agglomerate. It has an angular discordance of about 5° with unit 10 but no unconformable contact was seen. Faulting, as proposed for the origin of the Harkers fanglomerate, also seems to be the best explanation for the fanglomerate flanking Tooele Valley. The definite decrease in volcanic detritus and increase in Cambrian shales and quartzites in the upper part of the unit indicates the increased development of drainage from the high Paleozoic rocks to the west across the volcanic area. The change

A. North side of South Willow Creek Canyon in the Stansbury Mountains. View of tuffaceous agglomerate dipping approximately 25° to the east.

B. South side of South Willow Creek Canyon. View of volcanic conglomerate, about 800 feet exposed in this cliff.

may have been due to renewed uplift of the range by faulting. Thomas (1946, p. 113) suggested a late Pliocene age for the renewed uplift which corresponds well with the writer's tentative dating of the Harkers fanglomerate.

Along the west flank of the Oquirrh Mountains there are limited outcrops of the same fanglomerate but the constituent particles are much coarser, as might be expected from the steep Oquirrh front. Thomas (1946, p. 117) points out that the beds of the formation along the Oquirrh Mountains now dip valleyward at angles prevailingly less than the inclination of beds along the Stansbury Mountains, presumably because of eastward tilting by later block faulting.

Hickey-Cassity No. 1 well

The recent drilling of a test oil well about 3 miles northeast of Grantsville, Utah at the north end of Tooele Valley has provided an excellent opportunity to learn something of the subsurface Cenozoic sediments within the Great Salt Lake Basin. This is one of the few deep wells in the area for which samples are available. It is described as follows:

Tooele County, Hickey Oil Corporation No. 1 Cassity well 13-2S-5W. Elevation 4255 feet app. ground. Spudded 12-15-54; set 10 inch casing at 892 feet with 200 sacks of cement.

	Feet
Quaternary	
Gray to black, very soft, limy mud containing a few thin stringers of sand and gravel. (driller's log)	0 - 892
Top (?) of Tertiary - Salt Lake group	
Marl unit	
Marl, gray to light gray, contains some oolites, fecal pellets, and molluscan shell fragments.	

	Feet
It has sandy streaks composed of quartz, mica, and dark minerals or lenses of tan colored, somewhat bentonitic clay.	892 - 1150
Same, but oolites make up 10 to 15 percent of the samples and other clastics run to 15 percent.	1150 - 1170
Marl, gray, soft, slightly bentonitic with shaly streaks due to higher clay content. Micro-gastropod, <u>Gyraulus</u> sp.	1170 - 1420
Same, but darker gray, more clay and fragments, show blocky fracture. Oolites few in number. No sand.	1420 - 1505
No samples.	1505 - 1560
Marl as above.	1560 - 1695
Shale unit	
Shale, tan to yellow, sandy, slightly calcareous with several streaks of clean clay. Sand particles composed of quartzite and black limestone that are angular to sub-rounded.	1695 - 1840
Marl, gray to white, somewhat shaly.	1840 - 1905
No samples.	1905 - 1995
Shale, light gray to tan, sandy, calcareous.	1995 - 2070
Sand and gravel unit	
Sand and gravel, tan, dirty, composed of angular to sub-rounded quartzitic fragments with lesser amounts of gray and black limestone. A few molluscan shell fragments and oolites.	2070 - 2320
Marl unit	
Marl, tan to gray, as above.	2320 - 2470
Shale, sand, and gravel unit	
Shale, light tan, slightly calcareous, alternating with lenses of poorly sorted, sands, gravels and clay. Sands and gravels composed primarily of	

	Feet
light colored quartzites and dark limestones. Clays are pink and bentonitic. Few oolites and shell fragments present. Samples through this interval could best be determined dirty.	2470 - 2925
No samples.	2925 - 3060
Sand, coarse, angular, composed of fragments of quartzite, and equal amounts of calcareous shale or mudstone.	3060 - 3125
No samples.	3125 - 3205
Sand, gravel, and shaly mud in about equal amounts. Represents either alternating strata or a fanglomerate.	3205 - 3305
Same, but clastics are finer; there are streaks of very light tan, silty marl or mud and the sands have more black limestone than above.	3305 - 3495
Sand and gravel, tan, coarse, unconsolidated with minor amounts of calcareous silt and micro-gastropod fossils. <u>Lymnaea</u> sp.	3495 - 3740
Same with the exception that first igneous detritus was recorded - andesites, feldspar, dark minerals of mica and tourmaline. Also found thin lenses of tan to yellow shale.	3740 - 3890
Same with higher percentage of shales and mudstones.	3890 - 3975
Same but oolitic - up to 15 percent, igneous detritus common. Pyrite and shell fragments present and lesser amounts of gypsum and salt.	3975 - 4045
Drilling mud for most part.	4045 - 4080
Clay, gray and yellow; calcareous, silty shales; light gray marls with numerous micro-gastropods, <u>Lymnaea</u>, <u>Vertico</u>, <u>Physa</u>.	4080 - 4120

<u>Conglomerate unit</u>

Gravel, coarse sand, and silts, tan in color, quartzite fragments dominant and range in size up to 1 inch across, lesser amounts of limestone, igneous fragments, gypsum, pyrite, dark minerals, mica, and calcite.

	Feet
Shales, tan, calcareous and sandy mixed in freely with the coarser detritus. (4880 is not corrected to coincide with electric log which shows a depth of about 4925)	4120 - 4880
— bottom of Tertiary —	
Paleozoic - Oquirrh formation (?)	
Limestones, black, with calcite streaks; gray silicious limestones; dark gray dolomites; tan shales; and light, brittle, highly fractured quartzites. No micro-fossils.	4880 - 5470
Cored approximately 17 feet but recovered only 7 feet. Electric log shows T.D. at 5480. Core sample was a porous, well-fractured, light colored quartzite, probably part of the Oquirrh formation.	

Several gas shows were reported but the writer was not at the well when the tests were made and cannot vouch for the reports. Oil stains were also reported but the cuttings examined did not reveal any oil stains. However, the core samples taken from the bottom of the hole smelled of petroleum and fluoresced under a black light. No stains were visible under ordinary light. The writer was not at the drilling site when the core samples were obtained.

ROZEL HILLS

Introduction

The Rozel Hills area lies along the shore of Great Salt Lake just west of the South Promontory Mountains and for the most part is represented by a group of low-lying, basalt capped, hills. A secondary road which follows the old Union Pacific Railroad route to Promontory, Utah gives access to the Rozel Hills. In the past, the area has received considerable attention because of the asphalt seeps just off Rozel Point.

Geomorphology

The Rozel Hills are part of the intermontane desert and there are no permanent streams. A portion of the older Lake Bonneville floor constitutes a broad flat valley several miles wide which separates the hills from the South Promontory Mountains to the east.

A series of alternating basalt flows and limestone beds produce a relatively sharp ridge or cuesta that parallels the lake front for a distance of several miles. The crest of the ridge rises about 300 feet above the lake and represents the maximum relief in the Rozel Hills. In a northerly direction from the lake front the ridge becomes subdued and merges with long, low, isolated, basalt-capped hills. Lake Bonneville sediments fill the intervening valleys and in many instances veneer the basalts.

Stratigraphy and Structure

General Statement

Only Cenozoic rocks are represented in the Rozel Hills. They are predominantly interbedded basalt flows and lacustrine limestones with small amounts of marls, silts, and sands.

The structure appears simple. Tertiary rocks have a regional dip to the northeast of 13°. This may be due to a major northwest-southeast trending fault that lies between the Promontory Mountains and the Rozel Hills, or one that lies directly west of the Rozel Hills cuesta. The cuesta has also been proposed to be the gently dipping limb of a fold. Not enough of the Tertiary rocks are exposed, however, to determine the larger structural relations. The Quaternary sediments are undisturbed. See cross sections on Plate XVIII.

Measured section

The following stratigraphic section was taken along the ridge paralleling the lake and at a point about 1/2 mile west of Rozel Point.

	Feet
Salt Lake group (Top of section)	
Basalt, dark gray to brown, somewhat crystalline, vesicular, and appears to be in two flows.	60
Limestone, light yellow to white, oolitic, massive, porous. Has a brecciated appearance because of numerous clay galls and siliceous fragments.	45
Covered by alluvium, probably limestone.	10
Basalt as above and sheeted.	32
Limestone, light tan, clastics as before, with some streaks highly siliceous.	19
Covered by alluvium, probably limestone.	8
Basalt as above and sheeted.	27
Limestone as above.	44
Alluvium cover of calcareous silts and clay, probably limestone.	30

	Feet
Basalt as above but strongly weathered and jointed. (Lake level)	10
Total thickness	295

Water well section

The data for this section was obtained from an old exploration well dug in search of water. The well is approximately 6 feet across and 50 feet deep. A channel sample was collected in 1 foot intervals. See Plate XVIII for location and cross section B-B for stratigraphic relation to the interbedded basalts and limestones. Microscopic examinations of the samples in the laboratory showed them to be barren of microfossils.

	Feet
Quaternary	
Clays and calcareous silts, very light tan to white.	4
Tertiary - Salt Lake group	
Marl, white, dirty, traces of yellow clay that is somewhat bentonitic. The clays are shaly in contrast to the blocky fracture of the marls.	7
Marl, same as above, but grayer in color, shaly, and fissile.	3
Tuff, gray, glittering, poorly cemented with $CaCO_3$. The bulk of the material is composed of glassy shards with small amounts of mica and other dark minerals.	3
Marl and tuff as above but interbedded.	3
Tuff, blue-gray, poorly consolidated, very clean.	4
Marl, dirty white, soft and shaly.	2
Marlstone, gray to white, hard, blocky fracture.	7

	Feet
Clay, light tan, calcareous and contains a 1 inch stratum of carbonaceous fragments in a quartz sand.	4
Marl, white, soft, crumbly, base not exposed.	10
Total thickness	47

Leonora-Raddatz well log

This section was taken from a well log supplied anonamously to the writer. The samples were not available for examination by the writer. The well was drilled in 14-9N-8W, Box Elder County, Utah in 1934. See Plate XVIII for location.

	Feet
Lake Bonneville and Recent lacustrine sediments. No samples	0 - 50
Shale, white to buff, calcareous, ashy, with some bentonitic streaks. Contains pebbles of sandstone and calcareous quartzite.	50 - 200
Top (?) of Salt Lake group	
Silt, light gray, ashy, calcareous and micaceous.	200 - 230
Sandstone, composed of aggregates of quartzite fragments, glauconite and mica. Cemented with ash and permeable.	230 - 250
Silt as above.	250 - 350
Shale, very light gray, ashy and calcareous.	350 - 380
Sandstone, gray, containing medium sized fragments of quartzite, some glauconite, and ashy calcareous cement.	380 - 390
Shale as above, becoming bentonitic and locally laminated.	390 - 610
Same with rounded pebbles of limy quartzite and silicious limestone, average diameter of 5 mm.	610 - 710

	Feet
Shale, dark brown, very hard, with traces of mica and carbonaceous streaks.	710 - 720
Shale, gray, as above and becoming more calcareous. Locally crystalline.	720 - 830
Marl, very light gray to green, hard, interbedded with brown, limy, shale. Marl grades into some dolomitic limestones.	830 - 890
Shale, brown to pink, hard, calcareous with blocky fracture.	890 - 910
Shale, brown to gray, soft, calcareous silty.	910 - 950
Marl or argillaceous limestone, white, gilsonite in small amounts.	950 - 980
Shale, white, calcareous, bentonitic, with pebbles of quartzite.	980 - 1080
Same as above with calcareous (aragonite) oolites. Average diameter of 1.5 mm.	1080 - 1090
Marl, white, very argillaceous, finely crystalline, probably porous. Had good live oil stain.	1090 - 1120
Shale, gray to tan, ashy, very silty, with bentonite.	1120 - 1180
Graywacke, black to dull gray, an aggregation of ferro-magnesium minerals. Source seems to have been an andesitic basalt.	1180 - 1250
Shale, light tan, silty, interbedded calcite stringers.	1250 - 1280
Shale, gray, very soft, bentonitic.	1280 - 1310
Same but very oolitic. Oolites round to egg-shaped with pyrite or clay nuclei.	1310 - 1420
Shale, light to dark brown, calcareous, bentonitic, containing limestone and pyrite grains. Locally streaks are very silty and some calcite vugs present.	1420 - 1500
Graywacke as above.	1500 - 1510

	Feet
Shale, white, hard, ashy, interbedded with graywackes and oolitic black shales.	1510 - 1640
Shale, black, flaky, calcareous and bentonitic. Has vitreous appearance resulting from much carbonaceous material.	1640 - 1660
Graywacke, dark green to black, as above.	1660 - 1670
Shale, gray to brown, calcareous, specked with calcite vugs.	1670 - 1780
Mudstone, gray to white, very hard, interbedded with ash beds containing coal streaks. Lenses of volcanic graywacke.	1780 - 1850
Sandstone, black volcanic wash with trace of volcanic glass but generally crystalline.	1850 - 1900
Sand, unconsolidated andesite basalt wash with grains and fragments of meta-carbonates. Grains are [illegible]ental to sub-rounded and up to 10 mm across. Included minerals are mica, feldspar, hornblende, quartz; has some secondary calcite crystals present.	1900 - 2140
Shale, gray to gray green, ashy and unconsolidated.	2140 - 2280
	Total Depth

Salt Lake group

The surface exposures are composed of massive, oolitic limestone beds intercalated with basalt flows. The limestones contain a high amount of silicious fragments and clay galls. In this paper the limestones are referred to as Tertiary limestones and placed in the Salt Lake group. Tentatively they are dated as Pliocene although no fossils were found to support this.

These limestones represent a near shore lacustrine environment that was invaded at least four times by basalt flows (Plate XVIII, cross sections).

If the regional dip at the surface is projected across the maximum width of outcrop, an approximate thickness of 1700 feet is obtained for the limestones and basalts. The log of the Leonora-Raddatz well shows a thickness of at least 2000 feet for the Salt Lake group. Since the well is located to the west of the basalts outcropping at the surface, it must penetrate an underlying series of beds and hence the Tertiary section in the well can be added to that measured on the surface. This yields a total thickness of at least, 3700 feet for the Salt Lake group.

Correlation with other formations of the Salt Lake group to the south and east is not feasible in view of the lack of fossil evidence. The tuffs, marls, and shales found in the subsurface section, however, seem to have a strong resemblance to the sediments of the Jordan Narrows unit.

The basalts are probably related to the Pliocene Snake River volcanic flows although they are shown as Eocene on the Geologic Map of North America. In thin section this rock shows a microphitic texture. Olivine is the predominant mineral present with considerable amounts of labradorite and augite.

Quaternary system

The Lake Bonneville lacustrine sediments make up the mass of Quaternary deposits and consist of fine silts, calcareous muds, algal limestones, and lesser amounts of tufa. The tufa is plastered in places on the basalts and limestones of Tertiary age. Springs and travertine deposits can be found off Rozel Point (Plate XVIII)

Petroleum Geology

The asphalt seeps in this area were known before the turn of the century but the first organized oil exploration was in the early 1900's (Boutwell, 1904, p. 470). Several wells were drilled but achieved little production. About 50 barrels of asphalt were obtained and shipped to Ogden, Utah for road paving. In the 1930's several further attempts were made to get production. Two wells were drilled out in the lake about 1/4 mile from the shore. See Plate XVIII for location. These failed to strike any petroleum other than the asphalt occurring at or near the surface. The wells were drilled either on or near the seeps or a few miles to the north and northwest.

The only reliable information regarding the source beds of the asphalt revealed in the wells that have been drilled is recorded by Boutwell (1904, p. 474). He states:

> The source of these seepages appears to those who have prospected this ground to be a bed of asphalt 2 or 3 feet thick, which was encountered 80 feet below the present lake bed, and an underlying series of asphaltic beds 3 to 5 feet thick, which alternate with beds of clay to a depth of 140 feet, at least.

The seeps are still active today and the heavy, viscous black oil rises through the lake sediments to form low, approximately circular mounds several feet in diameter on the lake bottom. Stringers float to the surface of the water and collect along the beach. An old casing left by the early drillers stands several feet above the water level and asphalt still flows from it slowly but freely.

The asphalt might represent an up-dip tar seal in the process of formation. No drilling down-dip to the northeast of Rozel Point has been done to prove or disprove the theory.

CONCLUSIONS

Stratigraphy

Salt Lake group

The Salt Lake group can definitely be subdivided on the basis of lithologic differences, unconformities, and stratigraphic relations. The paucity of fossils and the limited areas of outcrop render the designation of the units as formations open to question. The writer has preferred for the time being to refer to them simply as units.

Correlation

The Tertiary rocks of Tooele Valley and the Stansbury Mountains are somewhat similar to those found in Jordan Valley and the Oquirrh Mountains. The resemblance is limited to the thick volcanic sequence and fanglomerate unit of the Stansbury Mountains both of which might be correlated with the Traverse volcanics and Harkers fanglomerate, respectively, in the Oquirrh Mountains. No sedimentary deposits have been found in Tooele Valley that would correspond to the Jordan Narrows, Camp Williams, and Travertine units of Jordan Valley.

The limestones and basalts in the Rozel Hills are not duplicated farther south and represent a different geologic setting, perhaps related to the Snake River downwarp.

The formations of the Salt Lake group in Cache Valley do not closely resemble those found in the Great Salt Lake Basin. The fanglomerates in Cache Valley are much better consolidated; the finer, lighter deposits contain a high quantity of tuff or tuffaceous material but not the coarse volcanic detritus; the carbonate rocks are more like limestone than marlstone.

The variation in the sedimentary units from one locality to the next seems to be the normal rather than the exceptional condition within the Great Salt Lake Basin. This is probably true for the Basin and Range province in general. Small, intermittent lakes, isolated block fault mountains constantly rejuvenated by faulting, and widspread spasmodic volcanic activity all combine to make for patchwork deposits. Thus, correlation is difficult.

Geologic History

An outline of the Tertiary geologic history of the Salt Lake group in Jordan Valley is given below. The historical geology of the Great Salt Lake Basin as a whole should be similar, but more detailed knowledge of the individual ranges is necessary in order to compile a generalized outline.

1. Volcanism in early Oligocene (?) to mid-Miocene (?) time buried most of the Traverse Mountains and a portion of the Oquirrh Mountains. During the latter part of the period of volcanism, a large lake came into existance and occupied the intermontane basin. Its extent is unknown but apparently the lake covered much the same area defined in this paper as the Great Salt Lake Basin and may have extended into Nevada.

   Limy muds that were later to become the marlstones and limestones, covered the lake floor and were often disturbed by mud rock flows of volcanic detritus or buried by wide spread ash falls. These deposits, the volcanic extrusives and lacustrine beds, represent the Traverse volcanics and the Jordan Narrows unit.

2. The lake, perhaps unable to maintain itself in the face of higher aridity and evaporation, disappeared. The Jordan Narrows unit with the volcanics suffered both erosion and deformation by folding and faulting. Streams draining off the mountains and across the old lake beds deposited the Camp Williams unit, perhaps only locally, along the flood plains of the major valleys. This occurred sometime during Miocene (?) time.

3. In early Pliocene time the Oquirrh Mountains were much less rugged than today. Few if any permanent streams drained eastward from them and the climate was semi-arid. At this time block faulting commenced again, the Oquirrh Mountains were elevated, and the Jordan Valley block depressed. A fault is believed to extend almost the entire length of the east flank of the mountains although the evidence for its existance is rather tenuous in places. Little topographic expression of this old fault remains today. The travertine deposits of definite Pliocene age in the Traverse Mountains may have been a deposit from springs issuing along the faults during this time.

4. Uplift of the mountains thus rejuvenated the streams and they began to erode again carrying the detritus out along the mountain flanks and depositing it as alluvial fans, represented today by the Harkers fanglomerate. At first, most of the material eroded came from the volcanic rocks, but continued erosion eventually exposed the older Paleozoic quartzites and limestones, and these contributed largely to the upper parts of the fans.

   The climate was still semi-arid or arid and the relief bold for as pointed out by Lobeck (1939, pp. 242-245), Twenhofel (1950, p. 69), and Blissenbach (1954, p. 185), alluvial fans originate most commonly in arid climates. Blissenbach states, "Bold relief is essential, moderately arid to semi-arid climate most favorable for the development of fans."

5. Toward late Pliocene time, the faulting ceased and the streams reached equilibrium. The coalescing alluvial fans were then subjected to pedimentation. The pediment developed headward across the fault and in places extended a few hundred yards into the Paleozoic rocks.

6. The incision of the pediment and the development of two lower pediment terraces is a Pleistocene story and is probably closely connected with the glacial and inter-glacial periods. The growth of glaciers which marked the beginning of the Pleistocene, must have represented a much wetter climate (Stokes, personal communication) and the streams rejuvenated by the climatic change, would have been capable of cutting deeply into the pediment. More faulting in Recent times, probably along the old fault lines, has been noted along the base of the Wasatch Range and elsewhere.

The above outline is not proposed as a final, but as a framework which may serve to guide further work and perhaps to give a better insight into some aspects of the Tertiary history of northern Utah. New subsurface data, better paleontological material, and more mapping will all contribute to advance our knowledge and understanding of the Salt Lake group in the Great Salt Lake Basin.

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