GEOLOGY OF THE TERRACE AND HOGUP MOUNTAINS
BOX ELDER COUNTY, UTAH

by

Peter Beekman Stifel

A thesis submitted to the faculty of the University
of Utah in partial fulfillment of the requirements
for the degree of

Doctor of Philosophy

Department of Geology

University of Utah
June, 1964

This Thesis for the

Doctor of Philosophy Degree

by
Peter Beekman Stifel

has been approved
May 1964

[redacted]
Chairman, Supervisory Committee

[redacted]
Reader, Supervisory Committee

[redacted]
Reader, Supervisory Committee

[redacted]
Reader, Supervisory Committee

[redacted]
Head, Major Department

[redacted]
Dean, Graduate School

TABLE OF CONTENTS

Page

ABSTRACT

The Terrace and Hogup Mountains are in west central Box Elder County, Utah. They are in the middle of the mapped area which comprises a 300 square mile region between Kelton to the north and the Lakeside and Newfoundland Mountains to the south.

No rocks older than upper Pennsylvanian are exposed in the mapped area. Strata which aggregate approximately 22,200 feet are assigned to the following systems and formations: Pennsylvanian -- Oquirrh Formation, Virgilian Series (3000+); Permian -- Oquirrh Formation, Wolfcampian Series (6718+), Diamond Creek Sandstone (2852), Loray? Formation (3420), Park City Formation, Grandeur Member (1838), Phosphoria Formation, Meade Peak Phosphatic (404), Rex Chert Member (1157), Gerster Formation (903); Triassic -- Dinwoody Formation (1647), and Thaynes Formation (329+). Pliocene strata of the Salt Lake Group and Pleistocene strata of the Lake Bonneville Group are present in the Terrace Mountains area but neither of these groups has been differentiated.

Triassic strata are paraconformable above Permian strata. Angular unconformities are recognized at the base of the Pliocene and the Pleistocene sediments.

Igneous rocks of Pliocene age comprise diabasic and basaltic dikes, basalt flows and a welded tuff deposit.

The Terrace Mountains are structurally similar to neighboring ranges except for the apparent absence of high-angle reverse and large scale thrust faults. The Big Pass graben divides the Terrace Mountains into eastern and western structural blocks, each characterized by long, high-angle, north-south trending boundary faults and minor east-west normal faults. A system of arcuate rotational faults is present in the western block. Folds are broad and of large scale except for those at the north end of the eastern Terrace Mountains, in the Hogup Mountains, and at the south end of Crocodile Mountain. The structure of outlying areas is similar to that of the two principal blocks, but its interpretation is difficult due to the cover of Quaternary lacustrine sediments. The existence of concealed border faults along the eastern side of the area is postulated on physiographic evidence. Desiccation fractures and depression structures are present in unconsolidated sediments.

The geomorphic development of the area includes outstanding shore-line features left by Pleistocene Lake Bonneville. The elevations of three major terraces in the Hogup Mountains are: Bonneville - 5248 feet, Provo - 4833 feet, and Stansbury - 4518 feet. Shore lines are as much as 50 feet higher in the southern Terrace Mountains.

Non-metalic deposits of economic significance, including bentonitic clay, vitric tuff, gravel and phosphatic shale are present in the area.

During late Pennsylvanian and early Permian time the mapped area lay within the northwestern part of the Oquirrh Basin. Environmental conditions changed very little throughout this time. During Leonardian time the Diamond Creek Sandstone and the Loray? Formation were deposited in shallow marine water. Marine conditions prevailed during Guadalupian time when strata of the Park City, Phosphoria, and Gerster Formations were deposited.

A paraconformable relationship is indicated between strata of Permian and Triassic age. The Dinwoody and Thaynes Formations were deposited in shallow water in a subsiding basin.

Folds belonging to two groups were formed in late Mesozoic or early Cenozoic time. Folding was followed by block faulting and tilting of the blocks to the northwest.

Topography ancestral to that of the present developed during late Cenozoic time, previous to deposition of strata of the Salt Lake Group. Faulting of Pliocene and Pleistocene age is recognized.

LIST OF ILLUSTRATIONS

INTRODUCTION

PURPOSE OF STUDY

The purpose of study was to decipher the stratigraphy and the structure of the Terrace and Hogup Mountains and the hills surrounding them and to prepare a geologic map of the area. Special attention was paid to the lacustrine features of Lake Bonneville that are well developed.

LOCATION

The Terrace and Hogup Mountains are in west-central Box Elder County in northwestern Utah, and the northeast part of the Basin and Range Physiographic Province. The mapped area comprises a 300 square-mile region between the abandoned town of Kelton in the north and the northern ends of the Newfoundland and Lakeside Mountains to the south. It lies between the northern Great Salt Lake Desert on the west and the Great Salt Lake on the east (Plate II).

ACCESSIBILITY

The mapped area is generally accessible only from the northern end. An improved gravel road leads south into the area from State Highway 70, past the Bar F Ranch and Kelton, an abandoned railroad town in the northeast corner of the area. Another road leads west to Kelton from Corinne, along the abandoned Southern Pacific Railroad bed. It is designated State Highway 83 where it is paved in its eastern section, but it is

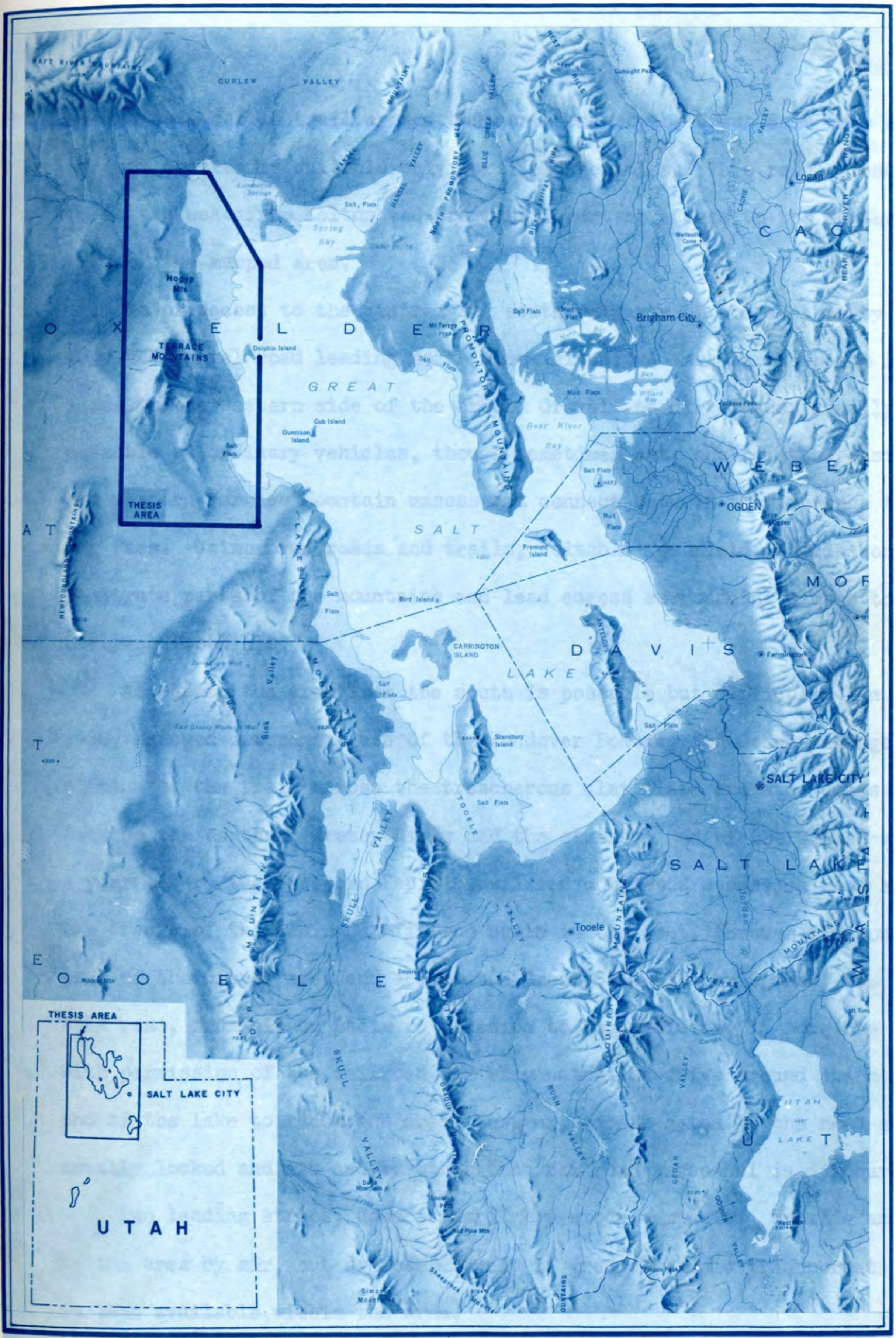


PLATE II. LOCATION MAP (from U.S.G.S. Relief Map of Utah).

marked as a cattle trail around the north end of the Great Salt Lake and in that section is suitable only for field vehicles. This road extends on to the west from Kelton and provides important access to the northern part of the mapped area.

Major access to the central and southern parts of the area is by an improved gravel road leading south from Kelton. A fork on the Hogup Bar leads to the western side of the area. Gravel and dirt roads, usually passable by ordinary vehicles, though sometimes not, encircle the eastern and western Terrace Mountain masses and connect between them through the Big Pass. Unimproved roads and trails, suitable for field vehicles only, penetrate parts of the mountains and lead across surrounding slopes to outlying foothills.

Access to the area from the south is possible but difficult. In 1960, renewed government use of the Wendover Bombing and Gunnery Range eliminated the trail across the treacherous clay flats and sand dunes between the northern Grassy Hills and the southern end of the mapped area. A year later, the Southern Pacific Railroad completed a service road along the tracks of the Lucin Cutoff from Lucin in the west, through the southern part of the mapped area and across the Great Salt Lake to Ogden. Use of this road, from either Lucin or Lakeside to Hogup Siding, is possible with permission of the railroad and eliminates the drive around the north end of the lake to reach the area; however, access gates to the road are usually locked and its use by other than railroad personnel is discouraged.

Two landing strips, used primarily by stock companies, provide access to the area by air, but are useful only if ground vehicle transportation is then available within the area.

Box Elder County annually maintains the more important access roads in the mapped area for use by stockmen, a fact for which the writer has often felt grateful. Were the area not utilized for winter range, it would probably be nearly inaccessible today.

NAMING OF THE TERRACE AND HOGUP MOUNTAINS

Because there has been some confusion as to which are valid names for the mountains within the study area, the Board on Geographic Names of the U.S. Department of the Interior was consulted for validation of the names. Their reply, dated May 20, 1959, includes the following decisions and information:

> "Hogup Mountains: mountain mass about 4 miles in diameter, with elevations over 5,000 feet, west of the northwestern arm of Great Salt Lake and immediately north of Terrace Mountains; Box Elder County, Utah; 41°35' N., 113°10' W.
> Not: Hog Mountains.
>
> Terrace Mountains: mountain mass about 12 miles in diameter, with elevations over 6,500 feet, west of the northwestern arm of Great Salt Lake; Box Elder County, Utah; 41°25' N., 113°12' W.
> Not: Hogup Mountains (q.v.)."

The Board quotes from a letter based on the files of the Utah State Historical Society, saying that possible origins for these names are as follows:

> "Terrace Mountains, 'so named because the terraces cut in slopes of old Lake Bonneville can be seen from the train'.
>
> "Hogup Mountains, 'A sheepman by the name of Brown came into these hills in the 70's, he tried to keep all other sheepmen out of these hills. So the herders called him hogup Brown, later the mts. were named that'.

The Board mentions further that others have suggested that the name "Hogup" may have some connection with the engineers and construction workers for the transcontinental railway.

The Terrace Mountains are divided by the Big Pass into eastern and western parts which will be referred to as such throughout this paper.

Names for lesser geographic features used by the writer for orientation within the study area and in this report are listed with their origins in the appendix.

PREVIOUS GEOLOGIC INVESTIGATIONS

The mapped area was first examined geologically by Captain Howard Stansbury and members of his surveying party in 1849. His report (1853) mentions the hardships encountered in traversing the northern part of the area, most of which were caused by the lack of water. Stansbury visited Dolphin Island while traversing the Great Salt Lake by boat. He described the island (1853, p. 191) and was given a report on the range to the west, the Terrace Mountains, by a Mr. Carrington of his party.

Arnold Hague visited the area in the 1870's as a member of the Fortieth Parallel Survey under Clarence King. Hague described the striking view from Tangent Peak and mentioned (in King, 1877, p. 427) that the summit of that peak is bluish-gray limestone, first underlain by a dark siliceous cherty band and further underlain by dark-gray limestones. It is interesting to note that Hague missed seeing the phosphatic shale and mudstone in this section, probably because they are largely concealed on Tangent Peak. Strata forming the mass of the mountains to the south Hague assigned to the Wahsatch limestone of lower Carboniferous age.

G. K. Gilbert traversed the northern part of the area in the 1870's and described the outstanding lacustrine features of that region in his monograph on Lake Bonneville (1890).

No further geologic work was done in the Terrace Mountains until the 1950's. The Triassic strata in the mapped area were first mentioned in a survey study by Clark and Stokes (1956) and were later described in greater detail by Clark (1957).

Grant Steele made a general survey of Permian strata in the Terrace Mountains between 1953 and 1956 in connection with his study of the Pennsylvanian and Permian Systems of the eastern Great Basin (Steele, 1959).

Stratigraphic work was done in the mapped area by T. M. Cheney and associates of the U.S. Geological Survey from 1955 to 1957 in connection with a regional study of the Park City and Phosphoria Formations. Results of this investigation have not been published at the time of this writing (1964).

In the fall of 1959, an investigation of the Meade Peak phosphatic shales was made under the direction of J. Stewart Williams for the Utah State Land Board. Results of this work are discussed in the section on economic geology.

CULTURAL HISTORY

The studied area was first occupied by Indians, although specific information regarding their use of the mapped area is extremely limited. First occupation of the Great Basin began earlier than 11,000 years ago, according to Jesse Jennings (1953). The Basin was sparsely populated, with most of the people present there living in small groups comprised of extended families. Their pattern of living has been designated the Desert Culture by Jennings (1953). The people were non-sedentary, seasonal gatherers who intensively exploited their meager environment, eating rodents, insects, and small game animals and harvesting seeds and pine nuts. Their material culture was also meager and probably included baskets, fur cloth, spear-throwers, projectile points, milling stones, and digging sticks, as evidenced by artifacts at Danger Cave, near Wendover, Utah. Agriculture was probably not practiced in the Terrace Mountains area, though it is known to have existed in some parts of the Basin. This type of occupation, characterized by living in rock-ledge or cave shelters similar to those in the southern part of the mapped area, persisted relatively unchanged into the ethnographic present.

Present-day Indians of the Great Basin and their immediate ancestors were closely associated with, if not descendants of, the prehistoric Indians of the same region (Jennings and others, 1959, p. 34). The Shoshoni-speaking people lived west of the Great Salt Lake, throughout an area which extended into eastern Nevada and southern Idaho, as well as western Wyoming. They were a non-agricultural, hunting and gathering people, and their economic, social, and political activities reflected the rigor of their environment (Dibble, 1947). Over most of the area, gathering was the main source of subsistence with seasonal supplements such as pine nuts, gathered in the fall, and game from rabbit, antelope, and deer drives in the winter. Groups came to be named after one of their principal food sources, such as the Pine Nut Eaters, as the Grouse Creek group was known. The Promontory group extended from Promontory Point to the lower portion of the Bear River Valley. Occasionally they travelled to Grouse Creek to gather pine nuts and undoubtedly passed through the northern part of the mapped area. The so-called Rabbit-Eaters extended roughly from the Kelton area, north to the Idaho border and probably also hunted in the studied area to the south. The enlarged or extended family was the basic economic unit of subsistence in these groups, that is, each group consisted of perhaps three generations, all of whom were engaged in food-getting. Seasonally, at pine nut gathering places, several such groups would combine and harvest the crop together, at which times social activities took place, usually connected with the harvest itself.

Boundaries of the groups of people involved are difficult to determine due to the nomadic sort of existence which they led. Because a specific group often used, or shared, an area with several other similar groups, there may have been a number of them which utilized the Terrace Mountains area.

Petroglyphs are carved on vertical surfaces of orthoquartzite at several places in the studied area south of the Southern Pacific Railroad.

At two places in the southwestern part of the mapped area small circular stone structures of Indian origin are still discernable. The number of pottery sherds and worked artifacts in the immediate vicinity of these structures leaves no doubt that they were built and used by Indians. It is expected that future work by archeologists will provide more specific information about the inhabitation and use of this region by Indians.

Occupation of the mapped area in historical times centered about towns along the former trans-continental railroad. The portion which passes through the northern part of the area was near the end of the Central Pacific line from California and was completed in 1869.

The town of Kelton served as a junction for stage and freight lines from Oregon for several years after the completion of the railroad, and as late as 1940 was still a shipping center for Idaho grain, then having a small store, a few buildings constructed of ties, and a large red warehouse (Utah Writers' Project, 1941). A weekly train had been run along the Golden Spike route by the Southern Pacific Railroad after completion, in 1903, of the Lucin Cutoff, which passes through the southern end of the study area, but regular service along the old northern route was abandoned in 1940. Only intermittent service was continued until the route was completely abandoned and the tracks were removed. The railroad grade has been used since then as a roadway, but deterioration of bridges and culverts has necessitated construction of the road off the railroad bed along much of its length. Nothing but a sheep loading platform, several deteriorating cabins, a graveyard, and a large old cottonwood tree mark the Kelton townsite at the time of this writing.

Of interest here is the brief description of an earthquake, the epicenter of which was near Kelton and which was the most severe since white occupation of Utah, according to the Utah Writers' Project, which says (1941, p. 364) that:

> "From the rent earth at Kelton gushed muddy water and black slime; the cracks at some places three feet across - were plainly visible along the highway for several years. Houses in Kelton were swung awry, and for a time school was held in a house, propped up by railroad ties and beams, which leaned at

an angle of almost 30 degrees."

A cook shack at the winter camp of a stock company in NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 1, T. 7 N., R. 12 W. is the only permanent dwelling within the study area. The several sheep camps are utilized only in the winter months. A water well in the SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 3, T. 7 N., R. 12 W. supplies a camp there and the one mentioned above. Water used during the writer's study was obtained either in Salt Lake City or from a well at the Bar F ranch north of the area. The writer is informed by D. C. Hahl (oral communication) that two new water wells have been drilled along the eastern side of the Terrace Mountains since the writer last visited the area in 1962.

FIELD WORK

Field work was carried out during the summers of 1959, 1960, and 1961. Mapping was done on aerial photographs taken in 1952 at a scale of 1:20,000. Original land surveying in the area was done in the 1880's. None of the rock cairns erected at that time to mark section corners was found by the writer after diligent search. Therefore, because land control was not available, information was transferred by precise inspection from the photographs to the Army Map Service topographic map, Brigham City Quadrangle, enlarged to 1:62,500. This method was felt to be as accurate as any other under the circumstances.

ACKNOWLEDGMENTS

To all of those who have contributed time, advice, material or finances to the project the writer expresses sincere thanks. Important among them are Dr. Frederick Schaeffer who suggested the problem and

Dr. W. Lee Stokes who gave advice and guidance throughout the project. Advice from Drs. A. J. Eardley, F. W. Christiansen, and H. D. Goode is gratefully acknowledged, as is their critical reading of the manuscript.

Advice on stratigraphic problems and mapping was kindly given by Drs. R. J. Roberts and E. W. Tooker of the U.S. Geological Survey and T. M. Cheney, formerly with that organization. The writer is grateful for fossil identifications by Drs. E. L. Yochelson, J. T. Dutro, Jr., D. W. Taylor, and R. C. Douglass of the U.S. National Museum. Dr. Grant Steele and Mrs. Betty H. Sealman both with the Gulf Oil Company and Dr. R. C. Douglass of the U.S. Geological Survey kindly identified fusulinid collections greatly aiding work involving the Oquirrh Formation. Dr. Bernard Kummel identified ammonites from the Thaynes Formation and Dwayne Stone identified conodonts from Triassic strata.

Appreciation is expressed to Max P. Erickson for help with igneous petrography and for flying the writer over the study area to obtain oblique photographs.

The writer gratefully acknowledges the discussion of stratigraphic problems with fellow graduate students Albert Young, Robert Maurer, Helmut Doelling, and Mounir T. Moussa, and especially thanks John F. Shroder, Jr., for his advice in preparation of the manuscript and help with drafting.

Two generous grants from the Graduate Research Committee of the University of Utah helped to defray field expenses.

Sincere thanks are expressed to the writer's father, W. Flaccus Stifel for the provision of a field vehicle and to his brother, Flaccus M. B. Stifel who helped measure some of the stratigraphic sections.

Finally the writer expresses deep appreciation to his wife, Gladys, for serving as field assistant throughout the project and for typing much of the manuscript.

STRATIGRAPHY

GENERAL STATEMENT

Eight formations in the study area, of Pennsylvanian, Permian and Triassic age aggregate approximately 22,000 feet in thickness. In addition to these, incomplete sections of Tertiary strata and Quaternary sediments were measured and are described. No rocks older than Pennsylvanian are exposed in the study area.

Measured sections including fossil collections are integrated with formation descriptions as are graphic columnar sections.

The writer considers the stratigraphic section in the Terrace Mountains to be in an important position both stratigraphically and geographically. It is the thickest and most completely exposed Permian and Triassic section in the wide area between southern Idaho and the Confusion Range on the north and south, and the Wasatch Range and Eastern Nevada on the east and west. Such neighboring ranges as the Goose Creek, Grouse Creek, Silver Island, Cedar, Newfoundland, and Promontory Mountains and the Grassy Hills all have some Permian strata, and two of these have Triassic rocks as well, but the sections are either incomplete, poorly exposed, or undifferentiated in each of them.

The thickness of the Permian section indicates that the study area was a marine basin receiving miogeosynclinal sediments throughout most of Permian time, and the lower Triassic section, also thick, indicates that the basin continued to subside in early Triassic time although the sea was persistently shallow.

Formations and lithologies with affinities to the Wasatch section to the east and the Nevada section to the west are present in, and in some instances they intertongue and intergrade in the mapped area.

PENNSYLVANIAN AND PERMIAN SYSTEMS

Oquirrh Formation

History of nomenclature. The name Oquirrh Formation was formalized by James Gilluly when he wrote (1932, p. 34) that ".... the thickest stratigraphic unit in the Oquirrh Mountains is the great mass of alternating limestones and sandstones (or quartzites) here named the Oquirrh formation". Previous to 1932 the name had been used only informally for the interval originally called the "Upper Intercalated series" by Spurr (1895).

As a result of recent work in the Oquirrh Range, the formation has been divided into five named members by Bissell (1959, p. 94), and into seven numbered units by Tooker and Roberts (1961, p. 21). For use within the Bingham Mining District, the Oquirrh Formation was raised to group status by Welsh and James (1961, p. 8), and was divided by them into four informally-named formations comprising 18 informal members. Welsh and James (1961, p. 7) also restricted the term Oquirrh to Pennsylvanian rocks in the Oquirrh Range, a practice followed by neither Bissell (1959, p. 127) nor by Tooker and Roberts (1961, p. 24) in the same range, nor by the writer in the Terrace Mountains. Each of these geologists assigns part of the Oquirrh Formation to the Permian.

Virgilian Series

The Pennsylvanian System is represented in the mapped area by rocks dated as middle and upper Virgilian age on the basis of fusulinids. Megafossils other than crinoid columnals and worm trails (Fig. 1) were not found in rocks assigned to the Virgilian Series. The Wolfcampian and Virgilian Series are separated entirely by fossil evidence, rather than by lithologic features. Where a transitional zone is present in the southern part of the area, an arbitrarily placed contact separates the two series.

Distribution and exposure. Rocks assigned to the Virgilian Series of the Oquirrh Formation constitute the north end of Crocodile Mountain, parts of Kelton Butte, and parts of the low hills in sec. 32, T. 7 N., R. 12 W., at the southern end of the area. Exposures are few and scattered on Crocodile Mountain, two of the larger outcrops forming the nose and eye of the silhouette for which the mountain was named. Numerous small exposures occur on the steep south-facing slope of Kelton Butte, especially in the larger gullies, but extensive gravel-covered areas intervene, preventing accurate measurement or structural interpretation. Exposures of the Virgilian Series in the southern hills are lithologically similar to those of the superjacent Wolfcampian Series. Strata of both ages dip uniformly northwest and the more resistant beds crop out as miniature hogbacks or ridges.

Thickness. Because of the paucity of fusulinid control, incompleteness of the section, and difficulty in detecting structural repetition or omission of parts of the section, strata of the Virgilian Series were not precisely measured. A calculated thickness of 2800 feet is

Figure 1. Worm trails in the Virgilian Series of the Oquirrh Formation, from exposures on northern Crocodile Mountain. Scale is six inches long.

present at the occurrence in the southern part of the area, but depending upon the position of the contact with the Wolfcampian Series, there may be as much as 3100 feet or as little as 2400 feet present. Excessive cover by lacustrine gravel prevented other than an estimate, of approximately 3000 feet of thickness, for the section on Crocodile Mountain. Structural complication and lack of exposures made impossible even an estimate of the thickness of Virgilian age strata present on Kelton Butte.

Lithology and stratigraphic relationships. In the northern part of the area, strata of late Virgilian age are yellow to orange calcareous sandstone, tan and gray siltstone, and pink to purple orthoquartzite. The sandstones are bioclastic in part. Quartzose sand grains, making up over 60 per cent of the rock, are well rounded, but poorly sorted and are fine to medium grained. Siltstone is of minor significance compared to the larger amounts in the Wolfcampian Series. Strata of middle Virgilian age are platy calcareous siltstone interbedded with fusulinid-bearing calcareous sandstone, superficially very similar to those of Wolfcampian age in the same area. A concealed fault apparently exists between the two series on Crocodile Mountain. Two faults separate strata of the two series on Kelton Butte. Fusulinids from a small intervening fault block are of late Virgilian age or possibly of late lower Wolfcampian age and the strata containing them apparently represent a transitional zone. Because outcrops are too few and fusulinids were found in only one bed, the writer could not accurately determine the stratigraphic position of this interval. The block is designated on Plate I as having strata of the Virgilian Series because of lithologic characteristics.

Strata of Virgilian age in the southern end of the area comprise interbedded calcareous sandstones, bioclastic limestones, and dark gray to black, fetid, calcareous siltstones, all similar to rocks in the overlying section which is of Wolfcampian age. Only two fusulinid-bearing beds are present in this entire sequence, so the contact between rocks of Pennsylvanian and Permian age could not be accurately placed.

Age and Correlation. Strata of Pennsylvanian age on Crocodile Mountain are so assigned on the basis of *Triticites* sp. and *Pseudofusulinella* sp. (upper Virgilian) identified by Grant Steele and the same two genera from 2000 feet lower in the section, identified by Betty Sealman and designated Virgilian age, probably middle. The section containing these two fusulinid occurrences, though much covered, appears to be concordant, and the different age designations, apparently made on the basis of structural development of the fusulinids (both identifications were made at the same laboratory), would be expected if the writer's stratigraphic interpretation of the section is correct.

Strata on Kelton Butte are assigned an upper Virgilian age on the basis of *Triticites* sp., *Triticites* cf. *T. hobblensis*, and *Triticites cullomensis* identified by Betty Sealman. *Triticites cullomensis* from strata in sec. 32, T. 7 N., R. 11 W., indicates that the lower part of the section there is of Virgilian age.

Rocks of Virgilian age in the mapped area are tentatively correlated with parts of the Oquirrh Formation to the south, specifically with units 4 and 5 of Tooker and Roberts (1961, p. 29-30) and with the Pole Canyon Member of Bissell (1959, p. 121). Bissell reports (ibid, p. 124) *Triticites cullomensis* from the southern Oquirrh Mountains, and Baker (1947) reports *Triticites* aff. *cullomensis* from the Oquirrh Formation in the Wasatch Mountains east of Provo. Oquirrh strata of Virgilian age are also present in the Stansbury Range (Rigby, 1958, p. 51), in the Cedar Range (Maurer, oral communication) and in the Grassy Hills (Doelling, oral communication).

Wolfcampian and Leonardian Series

Distribution and exposure. The Permian part of the Oquirrh Formation, of Wolfcampian and possibly lower Leonardian age, is exposed on the southern end of Crocodile Mountain and the northeast side of Kelton Butte in the northern part of the mapped area, in the eastern Terrace Mountains and along the southeastern edge of the western Terrace Mountains. In addition, it makes up most of the low-lying hills from the Terrace Mountains south to the southern end of the studied area. The Wolfcamp Series of the Oquirrh is exposed over more area within the region of study than any other bedrock unit.

Ledge and bench topography, characteristic of the cyclic parts of the Oquirrh in most places where it is exposed, is not well-developed in the mapped area. The exposed section in the Terrace Mountains contains much silty limestone and siltstone, and lacks the more resistant orthoquartzitic units that produce strong ledges elsewhere. Lithologic variations in the section are marked only by color variations, knolls, and saddles on subdued topography. In the southern part of the area, where resistant orthoquartzites are better developed and where the strata dip steeply to the northwest and west, a series of low hogback ridges has developed instead of the more usual ledge and bench topography found where dips are less steep. The surface of the resistant orthoquartzite and the calcareous sandstone is very dark brown, nearly black, from the casehardening or weathering rind that develops on it. Siliceous siltstones in this region sometimes form massive-ledge-like outcrops but are usually much fractured and more often form low knolls and gentle slopes. The intercalated shaley or silty limestone beds are usually concealed and form swales or depressions.

Lithology. Rocks of the Wolfcampian and Leonardian Series of the Oquirrh Formation are of varied but largely clastic lithology. In general, the lower parts comprise calcareous siltstone, arenaceous bioclastic limestone, and fine-grained crystalline limestone, all of which are interbedded with calcareous sandstone and orthoquartzite. The upper parts comprise silty, siliceous, and in part fetid limestone with orthoquartzite and chert becoming dominant immediately below the contact with Diamond Creek Sandstone.

Notable within the Wolfcampian Series are primary sedimentary structures that indicate an occasionally unstable environment of deposition. Apparent thickening of parts of the Series toward the south indicates that a basin or trough was present in the direction of the southern part of the mapped area during at least part of Wolfcampian time. Units of finely laminated argillaceous limestone are contorted by penecontemporaneous slumping, and although directional interpretation was difficult due to limited exposures, movement was apparently in a northerly or southerly direction, as axes of recognizable slump folds appear to be oriented generally east-west.

An additional indicator of deeper water or greater subsidence of the basin to the south is the thickening in that direction of coarse bioclastic limestone beds which unevenly and locally truncate laminations of underlying siliceous limestone. The bioclastic beds are characterized by a large molluscan fauna, in which Euphemitopsis sp. and Plagioglypta sp. are characteristic and prolific.

Where the Wolfcampian Oquirrh occurs in the eastern Terrace Mountains, only one such bed of bioclastic limestone is present. It is one to two feet thick and is apparently concordant with underlying beds. Six miles to the south, however, where the Wolfcampian Series was measured in the western Terrace Mountains, three similar limestone units are present, one 25 feet thick, and each has an undulatory or slightly disconformable contact with underlying laminated siliceous limestone units. Six miles further to the southeast, a similar bioclastic limestone unit is exposed on a knoll, and is 90 feet thick despite the fact that a portion has been removed by erosion (Fig. 2). Its lower contact with laminated siliceous mudstone appears gradational in places but is locally unconformable in others where it truncates the thinly laminated beds. The angle of truncation is as high as 5 to 10 degrees in places and is interpreted as a subaqueous erosional diastem. Figure 3 illustrates roll structures, lensing, and inter-mixing of the two lithologies at the contact. Fusulinids collected in close association with all three occurrences of this bioclastic unit suggest that they are of the same age and are probably directly correlative.

Lithologies of the Wolfcampian and Leonardian Oquirrh indicate that the region was probably under infraneritic conditions when the evenly and thinly laminated siliceous carbonate rocks accumulated and under epineritic conditions during times when, or at places where, the arenaceous and bioclastic limestones and sandstones were being deposited. The interbedded nature of these key lithologies is indicative of instability in the

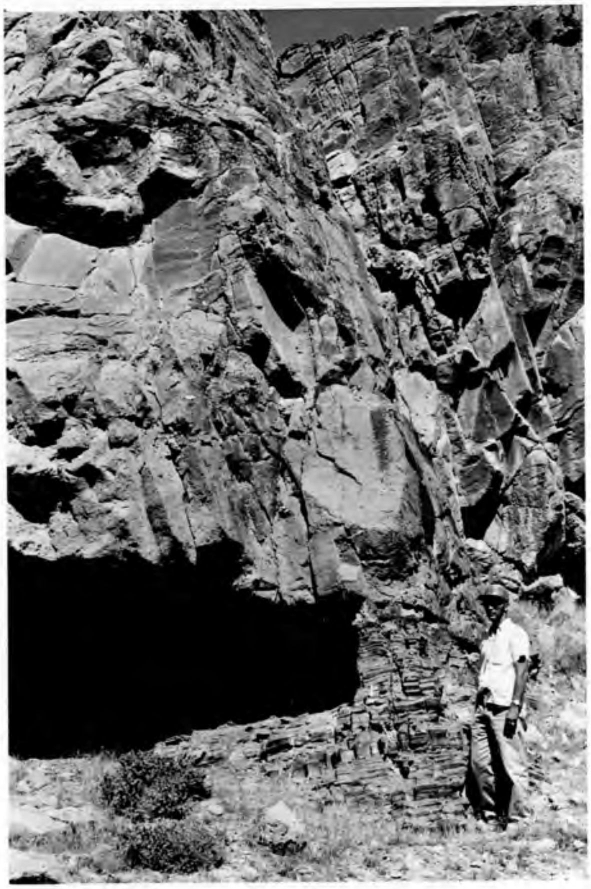


Figure 2. Cliff-forming, bioclastic limestone interval unit 13 of the "Twin Caves" section of the Wolfcampian Series of the Oquirrh Formation, overlying banded siliceous mudstone of unit 12.

Figure 3. Roll structures, lensing and intermixing of units 12 and 13 of "Twin Caves" section of the Wolfcampian Series of the Oquirrh Formation.

depositional area, especially during Wolfcampian time. The apparent thickening of the coarse clastic units toward the south may have been due to detrital material which had been moved by currents into deeper water from a shelf or shallower water to the north.

The contact or transitional zone between the Virgilian and Wolfcampian Series of the Oquirrh is present in the southern part of the mapped area, but both series are incomplete there, so the total thickness of neither of these intervals is known. Bissell states (1959, p. 127) that although there is a disconformity below strata of Wolfcampian age in western Utah and eastern Nevada, sedimentation may have proceeded without major change from Pennsylvanian time to Permian time in the Oquirrh Basin. Although the transitional zone in the studied area is unfortunately mostly concealed and there is too little paleontologic control to prove absolutely that the transition is uninterrupted, it appears that sedimentation was continuous and there is no evidence of a break.

The upper part of the Permian Oquirrh is lithologically gradational with the overlying Diamond Creek Sandstone. For mapping purposes, the contact was placed at the highest occurrence of bedded chert and siliceous siltstone. This arbitrary choice necessarily left a considerable amount of orthoquartzite of Diamond Creek affinity below the chosen contact.

Thickness. Three incomplete sections of Permian age Oquirrh Formation were measured in the mapped area. The most complete and best exposed section is that located in the southeastern part of the western Terrace Mountains. Here, approximately 6700 feet of rocks were assigned to the Oquirrh on the basis of stratigraphic position, lithology and fusulinid content. A second section, designated the "Twin Caves" section, was measured in sec. 3, T. 6 N, R. 11 W. Only 600 feet of rocks of middle Wolfcampian age are exposed here, but the section is significant because it gives evidence that some beds within the Permian Oquirrh thicken markedly to the south of the Terrace Mountains. A third section of Permian Oquirrh, of lower to upper middle Wolfcampian age, designated the "South End" section, was measured in the southernmost hills of the mapped area, in secs. 22 and 27, T. 6 N., R. 11 W. Here, approximately 1600 feet of rocks are exposed, which dip 20 degrees to the northeast. The section has several covered intervals that may conceal minor faults, but fusulinid control is good and little or no repetition or omission is apparent. Unfortunately, neither the top nor bottom of this section is exposed.

Measured section.

Section of the Oquirrh Formation, Wolfcampian and Leonardian Series
(incomplete) measured in
N$\frac{1}{2}$ sec. 25, T. 8 N., R. 12 W., and N$\frac{1}{2}$ sec. 30, T. 8 N., R. 11 W., Utah.

Permian:

Diamond Creek Sandstone.

Conformable contact

Oquirrh Formation (incomplete):

UNIT	DESCRIPTION	THICKNESS (feet)
55.	Siltstone, cherty, dark-gray, weathers light gray. Up to 40 per cent chert, dark-gray, nodular, very fine-grained. Non-calcareous. Bedding very thin but indistinct. Forms ledge..	5
54.	Orthoquartzite, light- to medium-gray, weathers lighter, fine-grained. No chert. Forms ledge....................	3

53. Concealed. Float is orthoquartzite, medium gray to tan, weathers tan to dark brown. Fine-grained. Apparently medium-bedded. Forms swale.................................... 57

52. Orthoquartzite, dark-gray, weathers light tan. Thin- to medium-bedded. Medium-grained. Chert nodules 5 to 10 per cent, irregular, dark-gray.................................. 5

51. Orthoquartzite, medium-tan, weathers same and darker. Fine-grained; less well-cemented than unit above. Medium-bedded. No chert. Rounded float.................................. 16

50. Siltstone, calcareous, dark-gray, weathers light gray. Thin-bedded. 15 to 20 per cent nodular chert, light-tan to dark-gray, weathers darker. Forms ledge. Silicified fossils include crinoid columnals 1/2 inch in diameter, echinoid spines 6 inches long, 1/4 inch in diameter....... 24

49. Orthoquartzite, medium-tan, weathers darker. Fine-grained. Lower part 5 to 10 per cent nodular chert. Thin- to medium-bedded.. 41

48. Siltstone, orthoquartzite, and silty chert. Most parts dark-gray, weather same or lighter. Upper part siltstone, thin-bedded. Two-foot bed of orthoquartzite in middle. Lower part 80 per cent dark-gray chert..................... 28

47. Orthoquartzite, medium-tan, weathers same to dark brown. Medium-bedded. Lower two-thirds concealed................ 26

46. Chert (60%) and siltstone (40%). Siltstone is calcareous, dark gray, weathers light gray. Thin-bedded. Chert is dark gray, weathers same. Nodules in irregular beds....... 40

45. Siltstone and sandstone, dark gray, weathers brown. Parts siliceous or cherty. Fine-grained. Very slight reaction to acid. Thin-bedded. Sandstone at top. Most concealed. Possibly faulted.................................... 199

44. Limestone, dark-gray, weathers light- to medium-gray. Fine-crystalline. Very thin- to thin-bedded. To 10 per cent small nodules of chert. Small spines and small crinoid columnals.................................. 52

43. Sandstone, orthoquartzitic, dark-gray, weathers tan to dark brown. Calcareous. Thin- to medium-bedded. No chert.. 14

42. Limestone, silty, dark-gray to black, weathers dark tan. Fine-grained. Part siliceous. Thinly laminated. Poorly exposed.. 26

41. Concealed. Float is limestone, siliceous, silty, very dark gray to black, weathers same to light gray and brown. Thin bed of coarse bioclastic material 250 feet above base. Very fine-crystalline. Very thin-bedded..... 346

40. Limestone. Same as unit 41. About 20 per cent siliceous material.................................. 74

39. Orthoquartzite, dark-gray to black, weathers light tan to dark brown. Calcareous. Fine-grained. Thin-bedded. Fossil hash at top and bottom. Fossils include ramose bryozoa, high-spired gastropod indet., *Aviculopecten*? sp., linguloid brachiopod indet., crinoid columnals and productid brachiopods indet................................ 47

38. Limestone, siliceous, medium- to dark-gray, weathers light gray. Siliceous material in thin bands, very dark gray-brown to black, weathers reddish brown to black; distinctly segregated from less siliceous parts. Proportions are about equal. Exposure has banded appearance............. 142

37. Siltstone or mudstone, siliceous, dark-brown, dark-gray and black, weathers lighter, reddish and orange. Most is non-calcareous. Chert in thin, regular bands. Very thin-bedded. Float is resistant, unit forms dark band on hills. *Orbiculoidea* sp.. 435

36. Limestone, bioclastic, gray, weathers same. Coarse-grained. Medium- to thick-bedded. Primary slump structures evident. Fossils include *Euphemitopsis*? sp., *Plagioglypta* sp., pelecypods indet., algal structures cf. *Osagia* sp., crinoid columnals.. 30

35. Siltstone or mudstone, siliceous, dark-gray, weathers dark brown. Thin-bedded. Float is small rectangular chips. Upper part concealed.................................. 80

34. Limestone, cherty, very dark gray to black, weathers same to light gray. Lower 100 and upper 60 feet contain about 20 per cent chert. The 100 feet between are thinly laminated argillaceous limestone, black when fresh, weathers light gray. Entire unit produces platy float............. 260

33. Limestone, cherty, dark-gray, weathers lighter. Very thin-bedded. Banded due to segregation of chert............... 100

32. Siltstone, siliceous, limestone and sandstone, calcareous, dark grayish-brown to black, weathers uniform medium brown. Siltstone has concentrations of siliceous material in middle of 2- to 6-inch beds giving banded appearance. Few beds of argillaceous limestone and some of calcareous sandstone. Float is rectangular, blocky.................. 300

31.	*Limestone*, silty and cherty, same as above but more calcareous. Chert content 10 to 15 per cent, thinly laminated. Banded appearance	600
30.	*Siltstone*, siliceous, dark-gray, siliceous bands weather dark brown, calcareous interbeds weather gray. Very thin-bedded to laminated. Bedding very uniform. Parts 75 to 80 per cent siliceous material. Float is small platy chips	75
29.	*Limestone*, very dark-gray to black, weathers light gray, pinkish gray to tan and maroon. Some siliceous material, especially in a 50-foot interval near the middle of the unit. This interval is very thin-bedded siliceous limestone with bands of nearly pure chert. Weathers very dark. Rest of unit very thin-bedded. Less than 20 per cent chert. Platy float. Most of unit concealed	178
28.	*Concealed*. Float is sandstone, slightly siliceous, gray, weathers brown. Fine-grained	20
27.	*Chert* (70%) and *limestone* (30%). Chert is very dark gray, weathers same. Limestone is silty, dark gray, weathers medium gray. Very thin-bedded to lamellar. Not well exposed	30
26.	*Limestone*, bioclastic, medium-gray, weathers same. Coarse-clastic. Evenly, medium-bedded. Fossils include *Euphemitopsis* cf. *E. subpapillosa*, *Plagioglypta* sp., *Schwagerina* aff. *S. elkoensis*, *Schwagerina* of form approaching *S. crassitectoria*, *Schwagerina* sp., algae	25
25.	*Limestone*, dark-gray, weathers light gray; fine-crystalline. Very thin-bedded. Laminated and cherty toward top. As much as 30 or 40 per cent chert in bands of irregular nodular masses. Chert is dark gray, weathers black. Most of unit concealed	80
24.	*Concealed*. Float of lower 130 feet is sandstone, orthoquartzitic, calcareous. Apparently very thin-bedded. Upper 65 feet more calcareous, approaching sandy limestone. Platy float. Unit mostly concealed	195
23.	*Limestone*, medium-gray, weathers light gray and brown. Fine crystalline, argillaceous, silty. Upper part is cherty, nodular. Lower part is calcareous sandstone. Several beds of coarse bioclastic limestone within unit. The lower parts are intraformational breccia. Lower contacts are wavy, apparently due to current erosion. Fossils include high-spired gastropods cf. *Meekospira*, *Euphemitopsis* sp., *Plagioglypta* sp., *Schwagerina* sp	110
22.	*Concealed*. Float is limestone, dark-brown to black,	

	weathers very light-gray. Apparently very thin-bedded. Argillaceous, silty, fetid. Platy weathering	135
21.	Limestone, same as unit 19, weathers dark brown	95
20.	Sandstone, orthoquartzitic, calcareous, light-gray, weathers dark brown. Thin-bedded	50
19.	Concealed. Float is limestone, dark gray-brown to black, lower third weathers dark brown, upper two-thirds weather light gray to tan yellow. Fine-crystalline. Brittle. Upper part slightly argillaceous. Few sandy beds. Very thin- to thin-bedded	220
18.	Sandstone, calcareous, medium-tan to gray, weathers yellow to very dark brown. Parts orthoquartzitic. Thin-bedded. Thin bioclastic limestone beds in lower part; 5-foot bed at base. Fauna similar to that of unit 26. Few beds of black fetid limestone near top	205
17.	Concealed. Float is limestone, black, weathers light gray. Lamellar to very thin-bedded; indistinct. Fetid. Indistinct small pelecypod impressions near middle	100
16.	Concealed. Float is sandstone, calcareous and orthoquartzitic, dark-grey, weathers same to dark brown. Laminated. Thin-bedded. Lower part very irregular bedding. Middle part is limestone, dark-gray, fetid, weathers light gray to purple	87
15.	Sandstone and limestone. Lower 50 feet is sandstone, medium- to dark-gray, weathers light yellow to medium brown. Very calcareous. Fine-grained; uniform. Grades upward into limestone, black, weathers dark reddish brown. Dense; parts siliceous. Limestone grades back to calcareous sandstone at top. Most of float is angular blocks	135
14.	Concealed. Float is limestone, carbonaceous, very dark-gray to black, weathers light gray to light purple. Fine-crystalline. Very thin-bedded; laminated. Some penecontemporaneous slumping. Fossils from 30 feet above base include ramose and fenestellid bryozoa, Nuculana sp., pelecypods indet., crinoid columnals, productid brachiopod indet., Schwagerina? sp., Near top is bed containing large (2½-inch) productid spines	85
13.	Sandstone, orthoquartzitic, steely-gray, weathers tan to dark brown. Fine-grained. Thin-bedded; laminated. Upper half has small limy nodules. Rough weathered surface. Angular float	50

12.	Concealed. Float is sandstone and limestone, gradational between units above and below	40
11.	Limestone, bioclastic, medium-gray, weathers darker. Locally unconformable on unit below. Base is intraformational breccia. Thin laminations of underlying unit are unevenly truncated by the contact. Fauna similar to that of unit 26	8
10.	Limestone, dark-gray, weathers lighter. Fine-crystalline, Silty or dolomitic lenses. Parts appear sandy. Thinly laminated. Very thin-bedded, irregular	50
9.	Limestone, dark-gray to black, weathers medium to light gray, uniform. Fine-crystalline; slightly argillaceous. Very thin- to thin-bedded; fine laminations. Badly contorted by penecontemporaneous slumping. Float is thin plates	40
8.	Limestone, bioclastic, dark-gray, weathers same. Sandy bands weather dark brown. Medium-bedded	50
7.	Sandstone, dark-brown, weathers lighter. Very fine-grained, Thin-bedded. Slightly calcareous	75
6.	Concealed. Float is limestone, dark-gray to black, weathers light gray. Platy float	85
5.	Concealed. Float is limestone, dark-gray, weathers gray, brown, and purplish tan in bands. Slightly argillaceous. Silty. Few thin bands of dolomitic or siliceous material	720
4.	Concealed. Float similar to above unit. Small blocky limestone chips. Dark weathering dolomitic or siliceous bands stand out	250
3.	Limestone. Same as unit 9. Badly contorted due to penecontemporaneous slumping. Base is bioclastic hash of microgastropods and bryozoa	100
2.	Limestone, gray-brown, weathers light gray and tan to dark reddish brown. Fine-crystalline. Silty and siliceous in parts. Contorted bedding; very thin- to thin-bedded. Most is banded by 1- to 2-inch siliceous zones	200
1.	Limestone, gray-brown, weathers light gray to purple, except lower 50 feet which weathers light yellowish tan to orange. Fine-crystalline, laminated. Very thin-bedded. Some silty or shaley beds. Float is angular blocks and flat plates	265
	Measured thickness of exposed Permian Oquirrh Formation	6718

Base concealed

Measured section.

"Twin Caves" section of Oquirrh Formation,
Wolfcampian Series (incomplete) measured in
W$\frac{1}{2}$ sec. 3, T. 6 N., R. 11 W., Utah. (unsurveyed)

Erosional top

Permian:

Oquirrh Formation:

Wolfcampian Series (incomplete):

UNIT	DESCRIPTION	THICKNESS (feet)
13.	*Limestone*, bioclastic, medium-gray, weathers same. Some intervals arenaceous, fine- to medium-grained. Coarse-clastic. Thin- to medium-bedded, irregular, Forms massive cliff and reef-like structure (Fig. 2); locally truncates beds of subjacent unit; locally has basal zone of interformational breccia and roll structures (Fig. 3). Fauna, lithology and age similar to that of units 11, 18 and 26 of section measured in Terrace Mountains, 9 miles to the northwest. A prolific but poorly preserved molluscan fauna recovered from this unit includes *Plagioglypta* sp. (common) (possibly not *P. canna*), *Nuculana* cf. *N. obesa* White, myalinid pelecypod, *Schizodus* sp. indet., *?Permophorus* sp. indetc., *Aviculopecten* spp. indet., *Euphemitopsis* cf. *E. subpapillosa* White (abundant), *Euphemites* cf. *E. imperator* Yochelson, *Euphemites exquisitus* Yochelson, *Euphemites* sp. indet., *Bellerophon* sp. indet., bellerophontacean indet. (A narrow compressed form. On external shape alone this is similar to *Sinvitrina* known from one specimen in the Leonard Formation), *Naticopsis* sp. indet., *Knightites* (*Retispira*) cf. *K.* (*R.*) *modesta* (Girty), neritacean gastropod, indet., subulitacean gastropods, indet. (probably two genera are involved, both indet.), high-spired gastropod, indet. cf. *Meekospira*, "*Strobeus*" sp. indet., straight cephalopod indet.	87
12.	*Limestone*, silty, siliceous. Dark-gray, weathers light tan and gray to dark and very dark brown. Very thin-bedded; platy but resistant. Siliceous zones in middle of beds; give marked banded appearance. Some beds of	

	dark brown to black nodular chert; to 4 inches thick; form up to 60 per cent of beds in middle of unit, up to 80 per cent toward base. Some fine-grained orthoquartzite at base, dark-brown to dark-gray....................	186
11.	Limestone, bioclastic. Medium-gray, weathers same. Coarse clasts of crinoidal hash and fusulines including *Schwagerina wellsensis* and *Schwagerina* sp. indet. (middle Wolfcampian)..	3
10.	Orthoquartzite, calcareous. Tan to dark-gray, weathers light tan to dark brown. Fine-grained. Medium-bedded. Forms cliff on which petroglyphs are cut.................	10
9.	Limestone and chert. Limestone dark-gray, weather light tan to dark brown. Chert dark-gray, weathers same. Lower part up to 60 per cent chert. Part forms cliff; lower 15 feet concealed..................................	53
8.	Sandstone, orthoquartzitic. Medium-gray, weathers medium to dark brown. Thin- to medium-bedded, middle third more quartzitic than upper, lower third orthoquartzite; platy; dark-gray, weathering light to dark tan; 1 to 3 mm. bands..	58
7.	Sandstone, calcareous. Light-tan mottled, weathers same and darker. Saccharoidal, fine-grained. Uniform. Thin- to medium-bedded. Poor exposure, forms swale............	17
6.	Siltstone, calcareous. Dark-gray and tan, weathers light orange-tan to dark tan. Very fine-grained. Very thin-bedded..	3
5.	Orthoquartzite, sandstone, orthoquartzitic, and siltstone, calcareous. Most of unit is medium to dark gray, weathers brown; upper beds average 10 inches, lower part very thin-bedded, platy; some nodules of silty limestone. Upper 10 feet is orthoquartzitic sandstone, medium- to dark-gray, weathers dark brown. Fine to coarse-grained. Forms resistant ledge. Only upper 40 feet of unit exposed.......	140
4.	Limestone, cherty. Dark-gray to black, weathers medium gray to tan. Small amount of bioclastic material. Laminated, very thin-bedded. Fusulinids include *Schwagerina* sp. indet., poorly preserved.................	11
3.	Orthoquartzite. Medium-tan, weathers medium to dark brown. Fine-grained. Medium-bedded; uniform. Fusulinids collected from base include *Schwagerina* aff. *S. pinosensis*, *Schwagerina* aff. *S. elkoensis*, and *Schwagerina* sp. indet. (middle Wolfcampian)..	22

2.	Chert (80%) and mudstone, siliceous (20%). Very dark-gray to black, weathers dark brown-black to light tan. Very thin-bedded. Banded. Resistant, forms cliff........	24
1.	Limestone, bioclastic. Medium-gray, weathers darker. Coarse- to medium-clastic, parts arenaceous. Medium-bedded. (incomplete)..	37+
	Total thickness of Wolcamp Series of Oquirrh Formation (incomplete), "Twin Caves" section....................	651

Base faulted and concealed.

Measured section.

"South End" section of the Oquirrh Formation,

Wolfcampian Series (incomplete) measured in

E½ sec. 15, and E½ sec. 22, T. 6 N., R. 11 W., Utah.(unsurveyed)

Concealed top

Permian:

Oquirrh Formation:

Wolfcampian Series (incomplete):

UNIT	DESCRIPTION	THICKNESS (feet)
21.	Orthoquartzite and calcareous sandstone. Medium- to dark-gray, weathers dark brown. Fine- to medium-grained. Thin- to medium-bedded. Alternating lithologies give banded appearance, calcareous beds weather more gray. Central part, from 72 to 127 feet is concealed. Calcareous interbeds in lower 72 feet are less arenaceous than those in upper part.................	157
20.	Limestone, bioclastic. Medium-gray, weathers darker and brownish. Medium- to coarse-grained coquina of crinoidal hash and fusulines, including Schwagerina cf. S. neolata and Schwagerina sp. (middle-middle to upper-middle Wolfcampian)..	10
19.	Orthoquartzite, calcareous and limestone, arenaceous. Tan to medium-brown and gray, weathers darker. Upper 70 feet has little or no calcareous material. Forty feet concealed above lower 14 feet of banded orthoquartzite and limestone. Thin- to medium-bedded....................	122

18.	*Orthoquartzite* and *limestone*, arenaceous. Same as above, partly concealed. Fusulines from 12 feet above base include *Bartramella* ? n. sp., *Schwagerina eolata*, and *Schwagerina* sp. indet. (middle-middle Wolfcampian)........	144
17.	*Siltstone*, calcareous. Very dark-gray, weathers lighter. Very thin-bedded, platy. Possible faulting at base.......	45
16.	*Orthoquartzite* and *limestone*, bioclastic, interbedded, medium-gray to brown, weathers dark brown and dark gray. Orthoquartzite fine- to medium-grained; limestone medium- to coarse-clastic. Upper 20 feet has very little limestone. Medium-bedded. Fusulines collected 30 feet above base include *Bartramella*? n. sp., *Schwagerina* aff. *S. pinosensis*, *Schwagerina* n. sp. (middle Wolfcampian).......	124
15.	*Orthoquartzite*, *limestone* arenaceous and *siltstone*, interbedded. Medium- to dark-gray to brown, weathers dark gray to dark brown. Thin-bedded, banded. Upper part largely calcareous siltstone; bioclastic limestone at top..	136
14.	*Orthoquartzite*, calcareous and *limestone* arenaceous. Tan and dark-gray, weathers dark brown. Limestone about 20 per cent, less than characteristic of section. Fine- to medium-grained. Medium-bedded. Some platy siltstone. Most orthoquartzites resistant and form good ledges. Poorly preserved fusulines collected from 192 feet above the base include *Schwagerina* aff. *S. andrewsensis*? (middle Wolfcampian).....................................	215
13.	*Orthoquartzite*, calcareous. Medium-gray, weathers very dark brown from weathering rind. Medium-grained, medium-bedded; uniform. Scattered fusulinids in upper part, unidentified.	25
12.	*Limestone*, silty. Medium- to dark-gray, weathers medium gray-brown. Thin, irregular bedding. Poor exposure, forms swale..	44
11.	*Orthoquartzite*, calcareous and *limestone*, arenaceous. Orthoquartzite is medium brown, weathers dark brown. Fine-grained. Limestone is bioclastic, medium-gray, weathers darker. Upper 20 feet thin-bedded, platy, weathering silty limestone. Very dark-gray, weathers medium gray to medium tan. Collection of fusulinids 46 feet above base includes *Pseudoschwagerina* sp. indet., *Pseudoschwagerina* aff. *P. texana*, and *Pseudofusulina* sp. indet., (lower-middle Wolfcamp). Collection of fusulinids 15 feet above base includes *Pseudoschwagerina* sp. and *Schwagerina* sp. indet. (lower-middle Wolfcampian).....................................	67

10.	Siltstone, calcareous and limestone, silty. Very dark-gray, weathers medium gray to medium yellow tan. Lower half siltstone, upper half fine-crystalline silty limestone. Thin-bedded, forms swale........................	31
9.	Orthoquartzite, calcareous. Medium-brown, weathers dark to very dark brown and tan. Fine-grained. Medium-bedded. Scattered limestone nodules in lower part. Possible faulting in unit. Collection of fusulinids 20 feet above base includes Schwagerina sp. and Triticites sp. (lower Wolfcampian).................................	95
8.	Siltstone, calcareous. Medium gray-brown, weathers medium tan to very dark brown. Few thin siliceous beds in upper part, as well as few silty limestone intervals. Bedding irregular, laminated to thin. Abundant worm trails throughout..	93
7.	Orthoquartzite, siliceous. Light gray, weathers brown. Some calcareous intervals weather dark gray, give banded appearance. Fine-grained. Resistant, forms ledge. Upper 8 feet siltstone. Thin- to medium-bedded...........	23
6.	Orthoquartzite and siltstone, calcareous. Orthoquartzite is medium-gray, weathers dark tan to brown. Siltstone is medium-gray, weathers medium brown. Lower 22 feet orthoquartzite with some limy pods containing organic spines. Thin-bedded. Rest of unit is siltstone; thin- to thick-bedded. Partly concealed; irregular weathering. Worm trails abundant throughout................................	158
5.	Limestone, bioclastic. Dark-gray, weathers lighter, to medium gray. Coarse-clastic. Forms ridge. Collected fusulinids have replaced structure.......................	3
4.	Concealed. Float is limestone, silty, bedding appears irregular; platy float; forms swale........................	17
3.	Orthoquartzite and siltstone, calcareous. Medium-gray, weathers light tan to dark brown. Fine-grained. Medium-bedded. Worm trails near top....................	15
2.	Limestone, bioclastic. Medium-gray, weathers darker, coarse-clastic. Coquina of crinoid and bryozoan hash, coral indet., and fusulinids including Schwagerina sp. indet., Pseudofusulinella sp. (lower Wolfcampian).........	2
1.	Orthoquartzite and siltstone, calcareous. Orthoquartzite is medium-gray, weathers brown. Fine-grained. Medium-bedded. Dominant in lower half of unit. Siltstone is dark-gray, weathers light gray to tan. Thin-bedded in lower half, medium-bedded and dominant in upper half	

except for quartzite at top. Unit forms cliff in the center, sec. 27, T. 6 N., R. 11 W., from base of which the section was begun....................................	77
Total thickness Oquirrh Formation, Wolfcampian Series (incomplete) in "South End" section..................	1603

Base concealed.

Age and correlation. The rocks mapped as Permian Oquirrh Formation are assigned to Wolfcampian age on the basis of fusulinid determinations, stratigraphic position, and megafossils.

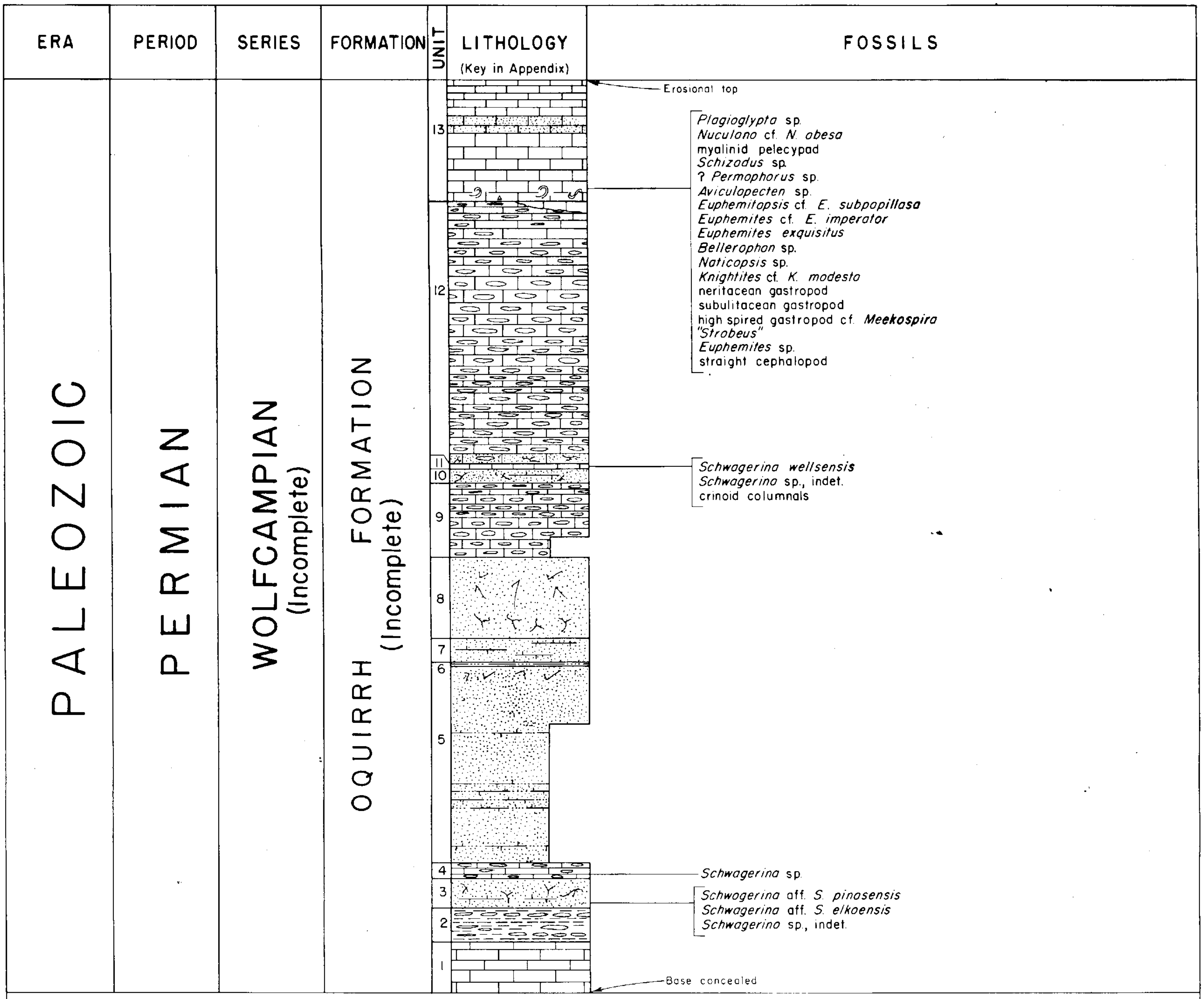
The following is a list of the fusulinids from this interval, identified by Grant Steele:

Bartramella? n. sp.
Pseudofusulina sp.
Pseudofusulinella sp.
Pseudoschwagerina cf. *P. texana* (n. var.)
Pseudoschwagerina sp.
Schwagerina aff. *S. andrewsensis*?
Schwagerina approaching *S. crassitectoria*
Schwagerina aff. *S. crebrisepta*
Schwagerina aff. *S. elkoensis*
Schwagerina eolata
Schwagerina linearis
Schwagerina aff. *S. pinosensis*
Schwagerina aff. *S. wellsensis*
Schwagerina n. sp.
Schwagerina sp.
Schwagerina cf. *S. neolata*
Triticites sp.

These forms and their respective ages, as determined by Steele, are included in the measured and columnar sections above with the units from which they were collected.

Following is a list of fusulinids collected from isolated, unmeasured sections of Permian Oquirrh:

Collection from NE¼NE¼ sec. 13, T. 11 N., R. 12 W. on northeast side Kelton Butte. (Field No. 6-126-6)



COLUMNAR SECTION OF THE OQUIRRH FORMATION
IN THE SOUTHERN TERRACE MOUNTAINS — "TWIN CAVES" SECTION

VERTICAL SCALE 1" = 100' PLATE IV P. B. STIFEL

Triticites cf. *T. ventricosus*
Dunbarinella sp.
Pseudofusulinella fergusonensis
Lower Wolfcamp (by Betty Sealman)

Collection from NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 13, T. 11 N., R. 12 W., approximately 100 feet stratigraphically above previous collection. (Field No. 6-126-7)

Triticites cf. *T. creekensis*
Triticites cf. *T. cellamagnus*
Pseudofusulinella fergusonensis
Dunbarinella?
Schwagerina sp.
Lower Wolfcampian (by Betty Sealman)

Collection from center SE$\frac{1}{4}$, sec. 12, T. 11 N., R. 12 W. undetermined stratigraphic distance above previous collection. (Field No. 6-126-5)

Triticites cf. *T. ventricosus*
Dunbarinella sp.
Schwagerina sp.

Collection from NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 26, T. 11 N., R. 12 W. southwest side of Kelton Butte. (Field No. 6-127-10)

Triticites cf. *T. creekensis*
Triticites cf. *T. cellamagnus*
Triticites sp.
Dunbarinella sp.
Lower Wolfcampian (by Betty Sealman)

Collection from SE$\frac{1}{4}$ sec. 27, T. 11 N., R. 12 W, southwest side of Kelton Butte. (Field No. 6-128-6)

Triticites sp. aff. *T. meeki*?
Pseudofusulina sp. aff. *P. powwowensis*
Wolfcamp equivalent (by R. C. Douglass)

Collection from NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 32, T. 11 N., R. 11 W., southern end of Crocodile Mountain. (Field No. 5-23-1)

Triticites sp.
Schwagerina sp.
Lower to middle Wolfcampian (by Grant Steele)

Pseudofusulinella sp.
Triticites sp. cf. a large inflated type
Pseudofusulina sp.
Early Permian, Wolfcampian age suggested.
(by R. C. Douglass)
Generic difference thought insignificant by writer as age determinations same.

Collection from SE¼SE¼ sec. 33, T. 9 N., R. 11 W., southern end of ridge, eastern Terrace Mountains. (Field No. 5-34-11)

Schwagerina linearis
Schwagerina aff. S. crebrisepta
Upper Wolfcampian (by Grant Steele)

Collection from NE¼SE¼ sec. 30, T. 10 N., R. 12 W., hills southeast of western Terrace Mountains. (Field No. 5-38-3)

Schwagerina sp. resembling S. extumida
Wolfcamp (by R. C. Douglass)

Collection from NE¼NE¼ sec. 18, T. 7 N., R. 11 W., hills in southern part of area. (Field No. 5-41-12)

Steele recovered an odd form, believed it to be Wolfcampian and probably lower or middle Wolfcampian, but was doubtful.

Collection from SW¼SW¼ sec. 17, T. 7 N., R. 11 W., undetermined stratigraphic distance below previous collection. (Field No. 5-41-3)

One specimen recovered, lower Wolfcampian, possibly as young as lower-middle Wolfcampian according to Steele.

Collection from NE¼NE¼ sec. 32, T. 7 N., R. 11 W. in southern end of area. (Field No. 5-44-1)

Triticites sp. exgr. T. ventricosus or T. meeki
Earliest Permian (by R. C. Douglass)

Triticites sp.
Lower Wolfcamp (by Betty Sealman)

Collection from outcrop in sec. 34, T. 6 N., R. 12 W., isolated hills in southwest corner of mapped area.

Fusulinids totally replaced. Large size suggests possibly lower Wolfcamp. (by Betty Sealman)

The Permian Oquirrh of the mapped area is correlated directly with other occurrences from which Permian age fusulinids have been identified including, questionably, the northern Oquirrh Mountains (Douglass, in Tooker and Roberts, 1961, p. 31), and definitely, the southern Wasatch Mountains (Thompson, 1954, pp. 27-31), and the Grassy Hills (Doelling, oral communication). In addition to these, Bissell mentions (1962, p. 33) seven localities in the northeastern Great Basin where he has recognized lithologies and fusulinids belonging to Wolfcampian age Oquirrh.

Correlation of the Terrace Mountain section with the Grassy Hills section, 20 miles to the south, is based on stratigraphic position, lithologic similarity, and megafossil content, although slightly different ages are suggested by fusulinids. Fusulinids identified by Grant Steele, in close association with the bellerophontacean-scaphopod zone, include Schwagerina aff. S. elkoensis, Schwagerina wellsensis and Schwagerina sp. of middle Wolfcampian age. Fusulinids identified from the same megafossil zone in the Grassy Hills were assigned an age of lower Leonard according to Doelling (oral communication). In both the Grassy Hills and the Terrace Mountains, the upper contact of the Oquirrh was chosen at the top of an interval of bedded chert and siliceous siltstone which, in both sections, is underlain by a thick, banded, siliceous mudstone or siltstone sequence. Also, in both of these sections, the previously discussed interval of bioclastic limestone containing the prolific bellerophontacean-scaphopod fauna is present, and is associated with similar lithologies approximately 3000 feet below the upper contact with the Diamond Creek Sandstone. Distribution of this faunal zone is thus indicated over a distance of no less than 50 miles, and although it was not reported by Welsh and James (1961) or by Tooker and Roberts (1961) from rocks of Permian age in the northern Oquirrh Mountains, and has not yet been found by Maurer in the Permian Oquirrh in the Cedar Range, 20 miles south of its occurrence in the Grassy Hills (Maurer, personal communication), it is of significance that Euphemites sp. and an indeterminate bellerophontid gastropod were identified by Ellis Yochelson from the Oquirrh Formation in the Promontory Range, 30 miles east of the mapped area (Olson, 1960, p. 149). It is unfortunate that this fossil collection was not correlated by Olson with his measured sections, for if it were shown that the fauna was from the upper part of the Promontory section, further support would be lent to the possibility of using this zone for limited regional correlation. It is also important to realize, however, that the bellerophontacean-scaphopod fauna is not in any sense restricted to the Wolfcampian Series or even to the Oquirrh Formation and that the above discussed beds probably represent only relatively local proliferations of the fauna.

Ellis Yochelson mentions (personal communication), with respect to a collection of this fauna submitted to him by the writer from unit 13 of the "Twin Caves" section of Wolfcampian Oquirrh that,

> "One collection from the Grandeur Member of the Park City at Strawberry Valley (12684 - PC) from bed L - 38 in the section given in USGS Circular 306, p. 35-39 is comparable. That collection, though small, contains abundant Plagioglypta and some Euphemites. There is little that can be done with Plagioglypta but it is possible that this (above) occurrence and 19525 - PC (Terrace Mountains - Oquirrh) may represent a species distinct from the characteristic P. canna of the Franson Member of the Park City."

Of the abundant bellerophontaceans in this collection he says further (personal communication) that,

> ". . . I am reasonably certain that some of the species are the ones I described from the Bone Spring Limestone (Wolfcamp). They are particularly characteristic of the lower part of that formation in the Sierra Diablo area of West Texas.
>
> Euphemitopsis subpapillosa occurs in the Arcturus Formation (upper Wolfcamp - lower Leonard) near Eureka, Nevada. I have not seen any Euphemites from the Arcturus." (Statements in parentheses added by writer.)

Besides their occurrence in the Grandeur in Strawberry Valley, bellerophontacean gastropods and indeterminable scaphopods were identified by Ellis Yochelson (personal communication to Albert Young, 1961) from rocks tentatively assigned to the Grandeur Formation of probable late Leonardian age in the Goose Creek Mountains (Albert Young, personal communication). The highest stratigraphic occurrence of this fauna in the Terrace Mountains is in unit 21 of the measured section of the Diamond Creek Sandstone, the characteristic members of the fauna not having been found in Park City or younger rocks.

Pennsylvanian-Permian Undifferentiated. Neither fusulinids nor other fossils diagnostic of age were found in several isolated exposures of strata probably belonging to the Oquirrh Formation. These exposures have been designated Pennsylvanian-Permian Oquirrh Formation undifferentiated on Plate I.

Diamond Creek Sandstone

Definition and type locality. At the type locality, at the head of Little Diamond Creek in the southern Wasatch Mountains, the Diamond

Creek is gray or buff to red, fine- to coarse-grained, cross-bedded sandstone. In large part, it is lime-cemented and friable, but locally it has siliceous cement, according to Baker and Williams (1940, p. 625) who named it. In a later paper (Baker and others, 1947), Baker mentioned its ledge-forming nature, the presence of occasional thin beds of limestone, and a thickness of 835 feet at the mouth of Kirkman Hollow, a refinement of an earlier estimate of 600-1000 feet at the nearby type section (1940).

Distribution and exposure. The Diamond Creek Sandstone is exposed in a linear belt about three quarters of a mile wide which extends approximately seven miles in a north-south direction across the east slope of the western Terrace Mountains, and in a U-shaped belt, concave to the north, in the eastern Terrace Mountains (see Plate 1).

In all of its occurrences in the studied area the Diamond Creek is well exposed. The orthoquartzitic units form ledges or small hogbacks, with the more calcareous or poorly indurated units forming swales or small saddles in between. Strata of the Diamond Creek weather into coarse blocky float and scree which is very dark because of the brown weathering rind that develops on the blocks. The scree usually fills long narrow gullies, forming parallel dark stripes on the steep slopes of Scorpio Mountain and the interior hills to the north. Because the scree-filled gullies become more resistant to erosion than the less protected intervening areas, topography has been locally reversed in some places. The scree-covered areas become topographically high between gullies cut in the intervening areas which were formerly high themselves. This case is similar to one in the Book Cliffs region of

Utah described to the writer by W. Lee Stokes (personal communication).

Scorpio Peak and the high interior hills north of it are developed on strata of the Diamond Creek Sandstone, as is the high ridge in the central part of the eastern Terrace Mountains.

Thickness, lithology, and stratigraphic relationships. The Diamond Creek is 2850 feet thick where it was measured on Scorpio Peak in the southern Terrace Mountains. Here the formation is calcareous sandstone and orthoquartzite, composed of clear, well rounded, medium to well sorted, fine- to coarse-grained quartzose sand. Cross-bedding is well displayed in some intervals. Cementing material is partially siliceous and partially calcareous, and several arenaceous limestone beds are present near the base.

Both upper and lower contacts are gradational, the lower with the Oquirrh Formation and the upper with the Loray? Formation. Because the upper limit of bedded chert is more easily detectable than the initial influx of Diamond Creek-type sand, the lower contact was chosen at the top of the uppermost bed of chert. The upper contact was arbitrarily chosen on lithologic changes described in detail with the Loray? Formation.

Measured section.

Section of Diamond Creek Sandstone measured in

SE$\frac{1}{4}$ sec. 14 and NE$\frac{1}{4}$ sec. 23, T. 8 N., R. 12 W., Utah.

Permian:

Loray? Formation.

Conformable contact

Diamond Creek Sandstone:

UNIT	DESCRIPTION	THICKNESS (feet)
70.	Sandstone, orthoquartzitic, medium- to dark-brown, weathers light tan. Fine-grained; fractures across grains. Calcareous, strong reaction to acid; thin weathering rind. Medium-bedded. Well-exposed, forms ledge and stripped dip slope of small extent	9
69.	Sandstone, calcareous; similar to above unit except in being more calcareous, very thin-bedded and in forming a swale. Weathers into thin platy float	38
68.	Sandstone, medium gray-brown, weathers darker. Lower third weathers light tan. Slightly calcareous, most in middle third. Small blebs of calcareous material cause pits on weathered surface. Thin- to very thin-bedded. Upper part quite blocky weathering, middle part has very irregular weathered surface from higher carbonate content and poor induration. Poorly exposed	22
67.	Sandstone, orthoquartzitic, light tannish-gray, weathers tan to dark brown. Fine-grained; well-cemented; hard; brittle. Thin-bedded; sharp contacts. Blocky weathering	11
66.	Sandstone, yellowish-tan, weathers same. Slightly calcareous; poorly cemented, friable on surface. Thin- to medium-bedded. Platy weathering	15
65.	Sandstone, upper half light yellowish-white, weathers buff to tan. Lower half grayish-tan, weathers light gray. Calcareous. Thin-bedded. Middle part pitted on weathered surface. Lower 10 feet coarse-grained	58
64.	Concealed. Float is calcareous sandstone	40
63.	Sandstone, orthoquartzitic, light brown, weathers light tan to gray. Fine-grained; well-cemented; brittle; weathered surface smooth. Medium-bedded. Good exposure	50
62.	Orthoquartzite, light- to medium-gray, weathers tan to dark brown. Fine-grained, vitreous. Medium-bedded. Mostly concealed	57
61.	Sandstone, calcareous, tan to light-gray, weathers dark gray to dark brown. Upper 20 feet coarse- to medium-grained, lower two-thirds fine-grained. Thick-bedded; well cross-bedded. Lower third concealed	73
60.	Orthoquartzite, light-gray, weathers slightly darker. Medium grained; vitreous. Thin-bedded. Forms swale on ridge	10

59. Sandstone, calcareous, light tannish-gray, weathers medium to dark brown. Medium- to fine-grained. Medium-bedded. Upper part orthoquartzitic; well-exposed. Lower part less well-cemented, partly concealed.............................. 14

58. Concealed. Float is siltstone, calcareous, medium-gray, weathers same. Fine-grained.............................. 8

57. Orthoquartzite, medium-gray, weathers slightly darker gray. Medium- to coarse-grained. Thin-bedded. Weathered surfaces quite rough... 18

56. Orthoquartzite, light-gray, weathers tan to dark brown. Fine-grained, brittle. Middle part slightly calcareous, pitted surface. Thick-bedded; forms blocky float.......... 90

55. Orthoquartzite, lower part tan, upper part pinkish-tan, both weather dark brown. Medium- to fine-grained. Medium-bedded... 12

54. Sandstone, grayish-tan, weathers tan. Slightly calcareous. Fine-grained. Thin-bedded. Lower 10 feet light-gray; medium-bedded.. 49

53. Concealed. Float is orthoquartzite, calcareous, very fine-grained.. 47

52. Orthoquartzite, medium-gray, weathers same. Fine-grained. Non-resistant unit, partially concealed.................. 88

51. Orthoquartzite, calcareous, light-gray, mottled, weathers same. Medium- to coarse-grained. Medium- to thick-bedded. Well developed cross-bedding. Well exposed; ledge-former.. 19

50. Orthoquartzite, tan to pinkish-brown, weathers orange brown. Thin-bedded. Poor exposure, forms swale.................. 19

49. Orthoquartzite, tannish-gray, weathers brown to dark brown. Medium-grained. Thick-bedded. Massive outcrop, forms ledge. 22

48. Concealed. Float is sandstone, orthoquartzitic, tannish-gray, weathers tan to gray brown. Slightly calcareous. Fine-grained. Weathered surface pitted.......................... 62

47. Orthoquartzite, light-gray, weathers dark gray. Medium- to coarse-grained. Medium-bedded. Well-developed cross-bedding.. 13

46. Sandstone, calcareous, tan and light-gray, weathers dark brown. Fine- to medium-grained; poorly cemented. Float blocky. Forms swale. Upper 40 feet concealed...................... 55

45.	Orthoquartzite, tan, weathers same. Fine-grained. Medium-bedded. Upper half concealed; lower half has poor exposure..	98
44.	Orthoquartzite, gray, weathers tan. Fine-grained. Vitreous. Thin-bedded. Weathered surfaces saccharoidal. Float is medium sized angular blocks................................	31
43.	Sandstone, orthoquartzitic, light tannish-gray, weathers dark brown. Coarse-grained. Thin-bedded. Coarse grains stand out on weathered surface................................	53
42.	Sandstone, tan-brown, weathers light tan to gray. Medium-grained; lower part fine. Medium-bedded. Poorly cemented, friable on broken surface. Most of unit concealed...........	56
41.	Orthoquartzite, gray, yellow, and pinkish, mottled, weathers light tan to dark brown. Fine- to medium-grained. Upper half medium-bedded, lower half thin- to medium-bedded. Well-exposed, ledge former.......................................	52
40.	Orthoquartzite, calcareous, brownish-tan to gray, weathers buff gray. Medium- to fine-grained. Thin- to very thin-bedded. Upper part concealed, lower part forms small ledge..	42
39.	Orthoquartzite, medium-tan to gray, weathers dark brown. Very fine- to medium-grained. Upper half thin-bedded, concealed, cherty appearance, small chunky float. Lower half thick-bedded, forms ledge................................	94
38.	Orthoquartzite, yellow to gray, weathers dark brown. Medium-bedded. Slightly pitted weathered surface. Forms ledge..	6
37.	Orthoquartzite, tan, weathers yellowish tan. Fine-grained. Very thin- to thin-bedded. Upper part forms ledge, lower part forms swale..	42
36.	Concealed. Float is sandstone, medium-gray, weathers same. Float is well-rounded blocks...................................	72
35.	Orthoquartzite, tannish-gray, weathers dark brown. Medium- to fine-grained. Medium-bedded. Lower part well cross-bedded..	93
34.	Sandstone, orthoquartzitic, light-gray to tan, weathers tan to dark brown. Vitreous. Medium- to fine-grained, slightly calcareous. Upper half well cross-bedded, forms ledge. Lower half concealed......................................	35
33.	Orthoquartzite, medium-tan to gray, weathers light to dark brown. Medium- to fine-grained. Thin-bedded. Cross-bedding weakly developed. Forms ledge. Lower 10 feet finer grained, concealed...	33

32.	Sandstone, orthoquartzitic, medium-tan and gray, weathers same. Fine-grained. Evenly, thin- to medium-bedded. Partially concealed	33
31.	Sandstone, orthoquartzitic, medium gray-tan, weathers same. Calcareous. Medium- to coarse-grained. Thin-bedded. Cross-bedded. Most forms ledge, lower part covered and forms swale	40
30.	Orthoquartzite, medium- to light-gray, weathers dark brown. Medium-bedded. Forms ledge	21
29.	Sandstone, gray and tan, weathers same. Calcareous. Fine-grained; upper 3 feet is siltstone. Thin-bedded. Few beds of fossil hash. Middle part forms strong ledge	30
28.	Siltstone and sandstone. Upper part siltstone, medium-gray, weathers same. Has irregular thin bands of black chert in upper part. Lower half is sandstone, tan, weathers darker. Fine-grained. Little nodular chert. Unit mostly concealed.	19
27.	Siltstone, cherty, medium-gray, weathers light gray. Very thin-bedded. Gray to black chert in 1- to 2-inch bands. Forms ledge	15
26.	Sandstone, light-gray to tan, weathers light tan to dark brown. Fine-grained. Thin-bedded. Slightly calcareous.	24
25.	Concealed. Float is siltstone, dark-gray to brown, weathers medium tan. Very fine-grained. Platy float	10
24.	Orthoquartzite, medium grayish-tan, weathers tan to dark brown. Medium-grained, coarser in lower part. Thin-bedded. Lower 14 feet concealed	43
23.	Orthoquartzite, calcareous, light-gray, weathers light gray to very dark brown. Medium- to coarse-grained. Middle part cross-bedded; forms ledge. Lower 14 feet concealed; sandstone, calcareous; fine-grained. Six-foot bed of gray, silty carbonate rock at base	36
22.	Orthoquartzite, medium-gray, weathers light tan to dark brown. Fine grained. Thin-bedded. Some beds form ledges	43
21.	Sandstone, orthoquartzitic, medium- to light-gray, weathers light gray. Calcareous. Very fine-grained. Thin-bedded. Scattered chert nodules. Fossils include *Euphemites* sp., *Plagioglypta*? sp., shark tooth	3
20.	Orthoquartzite, calcareous, light-gray and tan, weathers gray to dark brown. Fine- to medium-grained. Thin-bedded. Upper half forms ledge. Lower part more calcareous;	

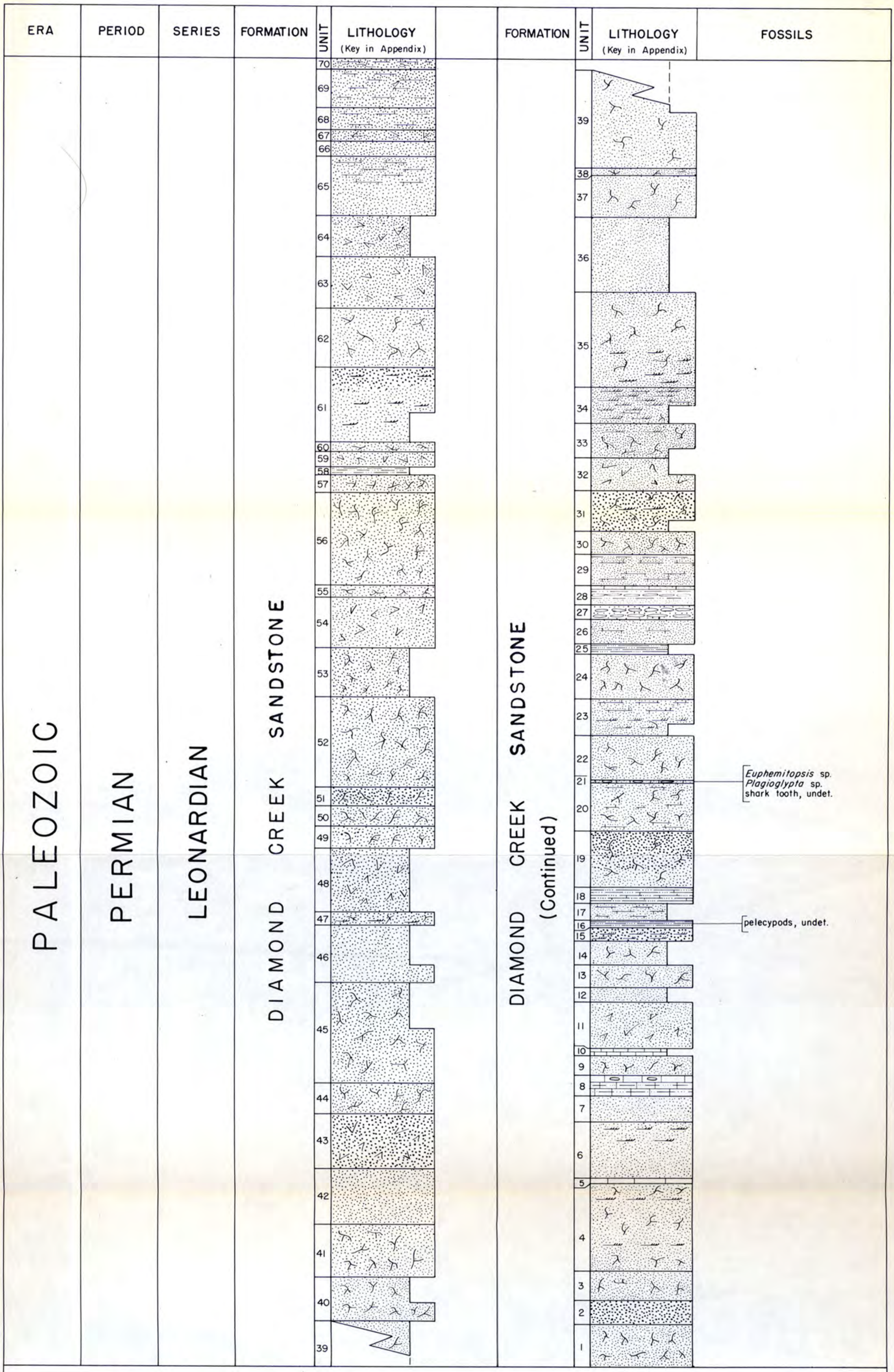
	pitted weathered surface	47
19.	Orthoquartzite, light-gray, weathers same. Coarse-grained, except at base where medium- to fine-grained. All of unit except base forms ledge	55
18.	Siltstone, medium-gray, weathers light gray to tan. Very calcareous. Thin-bedded	15
17.	Concealed. Float is sandstone, gray to tan, weathers slightly darker. Calcareous. Fine-grained. Lower part orthoquartzitic	17
16.	Siltstone, medium-gray, weathers light gray. Calcareous. Thin-bedded. Blocky float. Upper part has small pelecypods in hash of crinoid columnals	8
15.	Sandstone, light-gray to white, weathers tan. Coarse-grained. Thin-bedded. Cross-bedded. Poorly exposed	12
14.	Concealed. Float is orthoquartzite, medium-gray to tan weathers dark tan. Medium- to fine-grained. Rounded chippy float	23
13.	Orthoquartzite, medium- to light-gray, weathers very dark brown. Fine-grained. Medium-bedded. Part has pitted weathered surface. Resistant; forms ledge. Large blocky float	24
12.	Concealed. Float is orthoquartzite, light-gray, weathers dark brown. Fine-grained	14
11.	Sandstone, orthoquartzitic, medium-gray to tan, weathers dark brown. Medium- to fine-grained. Medium-bedded. Forms strong ledge	45
10.	Concealed. Float is limestone, dark-gray, weathers light gray. Fine-crystalline. Forms swale	7
9.	Orthoquartzite, calcareous, mottled-pink and yellow, weathers dark brown. Medium-bedded. Forms ledge	19
8.	Limestone, silty and cherty, dark-gray, weathers lighter. Very fine-crystalline. Medium-bedded. Thin bands of irregular chert nodules	20
7.	Orthoquartzite and sandstone, pinkish-gray to tan, weathers light gray and dark tan. Slightly calcareous. Fine- to medium-grained. Medium-bedded. Slightly cross-bedded. Lower part concealed	26

6.	Orthoquartzite, light-gray to tan, weathers gray to dark brown. Medium-grained. Medium-bedded. Upper part cross-bedded; forms ledge. Lower part less resistant, blocky float	55
5.	Limestone, medium-gray, weathers light gray. Porous. Medium-bedded. Forms ledge	5
4.	Orthoquartzite, cherty, medium-gray, weathers gray to dark-brown. Fine-grained. Medium-bedded. Cross-bedded in part, calcareous in part. Bands of silicious material stand out on weathered surface	80
3.	Orthoquartzite, dark-gray, weathers tan to dark brown. Fine-grained. Medium-bedded. Non-resistant. Forms swale	28
2.	Sandstone, calcareous, light-gray, with mottled blebs of yellow and white, weathers medium tan. Coarse-grained. Thick-bedded. Very porous	24
1.	Orthoquartzite, light-tan to pink, weathers medium- to dark brown. Lower 20 feet light-gray, weather lighter. Very fine-grained. Thick- and evenly bedded. Forms good ledge	37
	Total thickness of Diamond Creek Sandstone	2852

Conformable contact

Oquirrh Formation

Age and correlation. Because fossils are absent in most exposures of the Diamond Creek Sandstone, the Permian age designation has been based largely on the stratigraphic position of the unit above Oquirrh strata of Wolfcampian age, on the position below the Park City interval of Guadalupian and upper Leonard age, and on a probable correlation with the Coconino Sandstone to the southeast (Baker and Williams, 1940, p. 625). In the mapped area it lies between the Loray? Formation of upper Leonardian age and 3300 stratigraphic feet above middle Wolfcampian fusulinids in the Oquirrh Formation. The Diamond Creek in the Terrace Mountains is correlated by stratigraphic position and lithology



COLUMNAR SECTION OF THE DIAMOND CREEK SANDSTONE IN THE WESTERN TERRACE MOUNTAINS

VERTICAL SCALE 1" = 100'

PLATE VI

P. B. STIFEL

with rocks of the same formation in the Grassy Hills and the Cedar Mountains to the south.

Loray? Formation

General statement. The writer has been variously advised with respect to the proper treatment of the stratigraphic interval between the Diamond Creek Sandstone and the Grandeur Member of the Park City Formation. The interval has considerable affinity with both of these units, but it is sufficiently distinct to be mapped as a separate formation.

It is similar in lithology, in structural behavior, and in stratigraphic position to the Loray Formation (Steele, 1960) of eastern Nevada, and because it more probably represents the Loray than a new, unnamed formation, it is herein designated Loray?. A queried assignment to the Loray, it is felt, indicates both its affinity to that formation where it is well established and the uncertainty with which the assignment is made. Regional investigation of this interval will clarify the stratigraphic relationships.

Definition and type locality. The Loray Formation was named by Grant Steele (1960, p. 106) for a sequence of yellow-tan, gypsiferous siltstones and bioclastic limestones exposed at the head of Loray Wash in a Southern Pacific Railroad cut on the southwest side of Montello Valley, Elko County, Nevada. At the type locality the Loray is underlain conformably by the Pequop Formation and overlain by the Kaibab Formation.

Distribution and exposure. The Loray? crops out in a continuous band one-half to one mile wide which trends northeast across the central part of the western Terrace Mountains and in a seven square-mile area in the north part of the eastern Terrace Mountains.

The Loray? is nowhere well exposed in the mapped area. The poorly indurated sandstone and siltstone of this formation can be seen only as float, or occasionally as exposures in gullies or on very steep slopes. The cherty and dolomitic intervals crop out more commonly. It is characteristic of the formation not only to be poorly exposed but to be severely affected by structural disturbances as well (Steele, oral communication). In the Terrace Mountains, major faulting seems to have been initiated within the Loray?. The faulting is in formations above the Loray?, both stratigraphically and in most cases physically as well, and it may be due in part to the structural weakness of that formation, possibly caused by content of unstable gypsum. Although the formation is best exposed in the eastern Terrace Mountains, only the lower part is present there, so measurement was made in the western part of the range in direct conjunction with the underlying and overlying units.

Lithology, thickness, and stratigraphic relationships. A 3420-foot section of yellow to gray, fine-grained calcareous sandstone and silty and cherty limestone and dolomite in the studied area is considered to be representative of the Loray Formation elsewhere. Both the upper and lower contacts are arbitrary, and are based on gradual lithologic changes. The lower contact was chosen where the orthoquartzitic sandstones of the underlying Diamond Creek Sandstone become finer grained, less well indurated, more yellow than gray, and much more calcareous. Aequeous cross-bedding is present in the Loray?, but on a much smaller scale than in the subjacent Diamond Creek. Both siliceous material and chert are present, especially in the upper part of the Loray? but are absent in the Diamond Creek. No fossils were found in the Loray? or in the upper part of the Diamond Creek as the extremely sandy conditions were probably unfavorable for most organisms.

The upper contact of the Loray?, that with the Grandeur Member of the Park City Formation, was placed beneath an interval showing lithologic change and also having the lowest occurrence of Park City age fossils. Cherty and fossiliferous dolomite becomes dominant in the Grandeur, replacing the calcareous sandstone and siltstone of the underlying Loray?. The minor siliceous material present in the Loray? increases in percentage in the dolomite of the Grandeur.

The first good dolomite bed, below which the contact is drawn, contains the brachiopod Phricodothyris sp. which is characteristic of the Grandeur Member of the Park City (Ellis Yochelson, personal communication).

Steele (1959, p. 154) suggests that the uplift of a positive feature to the south and subsidence of the Northeast Nevada High shifted the marine connection between the Oquirrh Basin and the Butte-Deep Creek trough northward in upper Leonardian time until it was centered on or near the present location of the Terrace and Hogup Mountains. The thickness of the Loray? and Grandeur units in the Terrace Mountains seems to substantiate this suggestion. The writer suggests, however, that the subsidence of much of the Oquirrh Basin to the east had probably largely slowed or ceased during deposition of the Diamond Creek Sandstone.

Measured section.

Section of the Loray? Formation measured in

S$\frac{1}{2}$ sec. 11 and N$\frac{1}{2}$ sec. 14, T. 8 N., R. 12 W., Utah.

Permian:

Park City Formation:

Grandeur Member.

Conformable contact

Loray? Formation:

UNIT	DESCRIPTION	THICKNESS (feet)
35.	Concealed. Float is calcareous, quartzose sandstone, medium-gray to yellow and orange-tan, weathers same. Some chert and siliceous siltstone with thin bands of dark-gray siliceous material. Some very small-scale cross-bedding	150
34.	Sandstone, medium brownish-gray to yellowish-pink, weathers both light tan to pink and dark tan to brown. Very fine-grained to silty. Orthoquartzitic in upper part. Mostly concealed except upper 50 feet. Slightly calcareous. Considerable chert in upper part. Small-scale cross-bedding throughout. Bedding somewhat contorted, possibly due to penecontemporaneous slumping, but more probably due to structural deformation	225
33.	Sandstone, medium grayish-tan, weathers lighter. Fine-grained. Thin-bedded; average 8 inches. Large nodules of grayish-brown and dark-gray to black chert. Very fine-grained to silty; siliceous cement. Weathers into 1- to $1\frac{1}{2}$-inch sub-angular chips. Both upper and lower contacts are concealed. Unit is badly contorted to the north and faulting may be present to some degree where it was measured	145
32.	Sandstone, light- to medium-gray and tan, weathers medium gray to dark tan. Fine- to medium-grained; clear, frosted, sub- to well-rounded quartz grains. Thin-bedded; well-developed cross-bedding. Unit largely concealed. Float is small, rounded blocks	160
31.	Sandstone, light yellow-tan, weathers medium tan. Calcareous. Fine-grained. Thin-bedded; weakly developed cross-bedding. Largely concealed. Float is sub-rounded blocks	35
30.	Limestone, siliceous, medium- to light-gray, weathers very light-gray, siliceous parts weather dark brown. Dark-gray chert near top. Bedding indistinct; mound-like exposure. Weathers in spalls and by solution. Small clastic quartz content. Much of unit brecciated; forms slightly resistant ledge	15

29. Sandstone. Similar to unit 31. Much of unit appears brecciated, poor exposure.. 40

28. Limestone, siliceous. Similar to unit 30.................... 25

27. Sandstone. Similar to unit 31. Mostly concealed except upper part. No cross-bedding. Not brecciated............... 80

26. Limestone, siliceous. Similar to unit 30. Not brecciated... 45

25. Sandstone, medium-gray to yellow-tan, weathers same except yellow parts weather red orange. Very fine-grained. Calcareous. Part orthoquartzitic. Thin-bedded; average 4 inches. No evident cross-bedding. Float is sub-rounded blocks... 150

24. Sandstone (70%) and limestone (30%). Lower part gray to tan sandstone, calcareous. Upper part medium-gray limestone, cherty. Most of unit brecciated. Two-foot bed of evenly bedded dark-gray chert at top of unit................ 105

23. Chert (50%) and sandstone (50%). Chert is light gray, weathers flesh color. Sandstone is light to medium gray, weathers same. Thin bands of bedded chert are intercalated between thin to medium beds of fine-grained sandstone. The siliceous beds stand out in sharp relief......... 10

22. Concealed. Float is sandstone, yellow to orange, weathers same. Weakly indurated; portions with siliceous, portions with calcareous cement. Much of unit badly brecciated....... 175

21. Sandstone, yellow to yellow-orange, weathers same. Mostly concealed. Poorly indurated. Only the more siliceous beds are exposed. Similar to unit 22.......................... 50

20. Sandstone, medium-gray, weathers very light gray. Thin-bedded. Large nodules and blebs of siliceous material in upper part. Resistant unit, appears to cap several hills.... 160

19. Limestone, siliceous, mottled medium-gray, weathers very light gray and light to dark tan. Thin-bedded; average 2 to 3 inches. Considerable quartzose sand content. Reacts to acid only when scratched. A few lenses and blebs of light-gray chert.. 20

18. Sandstone, whitish-gray, weathers light yellowish to pinkish and tan gray. Thin-bedded; averages 1 foot. Homogeneous, uniform beds. Fine- to medium-grained. Calcareous cement. Well developed cross-bedding. Well-rounded float... 155

17. Orthoquartzite, medium- to light pinkish tan, weathers same, but with mottled surface. Medium- to fine-grained. Thin-bedded; average 6 inches to 1 foot; no cross-bedding.

	Float blocky and angular. Contacts sharp with enclosing units. Exposure poor but abundant float	70
16.	*Sandstone*, light to medium yellowish-gray, weathers same. More yellow parts are very fine-grained; the more gray parts are fine- to medium-grained and are well cross-bedded. Parts are very well indurated. Thin-bedded; bedding well-defined	95
15.	*Sandstone*, light- to medium-gray, weathers gray-brown. Fine- to medium-grained. Clear, frosted, well-rounded grains stand out as dark-gray specks against light-gray calcareous matrix. Thin-bedded, most 6 inches to 1 foot. Poor exposure	60
14.	*Concealed*. Dominant float is quartzose sandstone, light pinkish-gray, weathers medium brown. Fine- to medium-grained; calcareous cement. Sub- to well-rounded clear quartz. Thin-bedded; some intervals cross-bedded, especially the more coarse-grained parts	385
13.	*Sandstone*, medium-gray, weathers light gray to tan. Fine-grained. Bedding irregular; average 6 to 10 inches. Some cross-bedding. Poor exposure. Float is small rounded chips.	30
12.	*Concealed*. Float is sandstone, light to medium pinkish-tan, weathers same. Fine- to medium-grained; clear, sub-rounded quartz. Very thin-bedded. Weakly developed cross-bedding. Poorly indurated. Saccharoidal surface	145
11.	*Sandstone*, red-orange to reddish-tan, weathers same and pinkish gray. Thin-bedded; average 10 inches. Cross-bedded. Some marks possibly worm borings. Part orthoquartzitic; part calcareous cemented. Poor exposure. Float is well-rounded blocks	130
10.	*Orthoquartzite*, flesh-colored to pink, weathers brownish pink. Fine-grained; uniform. Thin-bedded. Brittle. Well exposed; jagged outcrop. Float is sharp angular chunks. Lower contact sharp, upper concealed	30
9.	*Limestone*, sandy, light- to medium-gray, weathers same. Bedding averages 2 feet. Medium-sized quartz grains throughout, frosted, well-rounded. Lower part is brown weathering, calcareous sandstone. Well-exposed	115
8.	*Sandstone*, light-gray, weathers medium to very dark brown. Part calcareous, part orthoquartzitic. Fine-grained. Thin-bedded. Cross-bedded in part. Uniform. Largely concealed except in more quartzitic intervals. Float is resistant, angular	155
7.	*Limestone*, crystalline, medium-gray, weathers lighter. Thin- to thick-bedded but indistinct. Considerable fine- to medium-	

grained quartz sand content. Partially concealed........... 20

6. *Concealed*. Float is sandstone, light tannish-yellow, weathers dark brown. Medium- to fine-grained........................ 80

5. *Sandstone*, whitish-gray, weathers light gray, slightly darker than when fresh. Medium-grained. Thin-bedded; irregular. Float weathers to sub-rounded blocks......................... 50

4. *Concealed*. Float is sandstone, very light-tan, weathers dark yellowish brown. Fine-grained; calcareous cement. Weakly developed cross-bedding...................................... 50

3. *Sandstone*, whitish-tan, weathers medium- to dark-brown and gray. Medium- to fine-grained. Calcareous. Portions cross-bedded.. 115

2. *Sandstone*, yellowish-white, weathers medium tan. Fine-grained. Calcareous. Small calcareous blebs weather out causing pitted surface. Very thin-bedded; average 2 inches. Brecciation in the upper part. Both upper and lower contacts concealed.. 50

1. *Sandstone*, very light-gray to tan, weathers light gray. Medium-grained. Calcareous. Poorly indurated. Bedding thin, irregular, averages 16 inches. Float is small blocks.. 95

Total thickness of Loray? Formation..................... 3420

Conformable contact

Diamond Creek Sandstone.

Age and correlation. The Loray? Formation is correlated with an interval to the west originally referred to as the Summit Springs Unnamed Evaporite Formation by Steele (1959, p. 159) and later named the Loray Formation by him. According to Steele (1959, p. 159), the evaporite sequence in the Summit Springs Basin, which includes dolomites, limestones, siltstones, sandstones, and anhydrites, lies between the Upper Member of the Moorman Ranch Formation, of lower Guadalupian age and the Butte Mountain Formation of middle Guadalupian age. An early Guadalupian age is, therefore, assignable to the Loray Formation in the type area. To the east, however, the Loray is equated to the upper 300-400 feet of the Arcturus Formation of Leonardian age in the Confusion Range (Steele, 1960, p. 107), and because of its stratigraphic position below the Grandeur of upper Leonardian age in the Terrace Mountains, it is of lower-upper Leonardian age there. This age and stratigraphic position suggest that environmental conditions responsible for the deposition of the Loray Formation were initiated to the north and east, and spread with time to the west where the formation is apparently younger.

The stratigraphic section in the Promontory Range does not include rocks of Leonardian age, and although the Loray Formation is probably present in the Grassy Mountains, the stratigraphic interval in which it occurs is concealed by sediments of Lake Bonneville (Helmut Doelling, oral communication). In the Cedar Range further to the south, the Grandeur Member of the Park City Formation rests directly, and apparently conformably, on the Diamond Creek Sandstone, so the Loray interval there is represented by an obscure hiatus or by parts of one or both of those formations.

Park City Formation

Rocks of Park City age in the western phosphate field were first named the "Quadrant Formation" by Peale in 1893 (McKelvey, 1959, p. 5), but this unit was modified three years later by Weed to include the Quadrant Quartzite and the Teton Formation.

The name Park City Formation was first applied by Boutwell in 1907 (p. 443) to rocks between the Pennsylvanian Weber Quartzite and the Triassic Woodside Formation in the Park City Mining District, Summit Co., Utah. Since then, the work of many geologists has considerably modified the concept of the Park City Formation where it is present in northern Utah, southeastern Idaho, and western Wyoming. Conflict arose as to whether the name should be applied to an interval determined specifically by age or to units based on lateral lithologic continuity. This and other nomenclatural problems are discussed in detail by McKelvey and others (1959). To clarify the existing problems, it was their decision to adopt the second of the above choices. They have thus proposed (1959, p. 9) that the Park City, Phosphoria, and Shedhorn Formations be based on the dominant lithology in their respective type areas and that members and tongues of any one may extend into regions where one or both of the other formations are present or even into their type sections. They recognize eleven subdivisions of these three formations, of which three are present in the Terrace Mountains; the Grandeur Member of the Park City Formation, and the Rex Chert and Meade Peak Phosphatic Shale Members of the Phosphoria Formation.

Grandeur Member

Definition and type locality. The Grandeur Member of the Park City Formation was named and described by T. M. Cheney (in McKelvey and others, 1959, p. 12). His type section, exposed about one mile southwest of Grandeur Peak in the central Wasatch Mountains, includes interbedded carbonate rock, cherty carbonate rock, carbonatic sandstone, and carbonatic siltstone. At its type locality the Grandeur is underlain by the Weber Quartzite of Permo-Pennsylvanian age and is overlain by the Meade Peak Member of the Phosphoria Formation.

Distribution and exposures. The Grandeur is exposed on the southeast-facing slope of Tangent Peak in the western Terrace Mountains. From there to the south it is exposed along the drainage divide of that part of the mountains and along the east limb of the West Terrace syncline to the southwestern part of the mapped area. In several places the Grandeur is displaced to the west of the divide by faulting and is exposed in canyons on the west slope of the mountains. The Grandeur also makes up most of the west-facing side of Shelter Mountain Pass. It is not present in the eastern Terrace or in the Hogup Mountains.

The upper, massively bedded units of the member are well exposed and usually form ledges and prominent outcrops wherever they occur. The lower part of the Grandeur has relatively few good exposures, probably due to the high sand and silt content.

Thickness, lithology, and stratigraphic relationships. Approximately 1190 feet of dolomite, silty dolomite, silty limestone, sandstone, and cherty carbonate rocks are assigned to the Grandeur Member of the Park City Formation in the Terrace Mountains. The upper part of the member is more dolomitic and cherty and contains less silt than the lower part. Beds of medium- to dark-gray chert are interbedded with dolomite and dolomitic limestone. The upper part is also more fossiliferous and the beds are thicker and more resistant.

The lower part of the Grandeur is largely silty dolomite, silty and cherty limestone, and calcareous sandstone. The high silt and sand content of this part of the Grandeur seems to be due to continued influence of the conditions responsible for deposition of the underlying Loray? Formation. The Grandeur Member in the mapped area, as in other localities, is differentiated from underlying sandstone units by an increased amount of, or dominance of carbonate rock and in the mapped area, by an increase of chert as well. Also, as in some other places, notably the eastern Uinta Mountains, a lighter and grayer color, finer scale cross-bedding in arenaceous units, and occasional brecciated intervals serve to distinguish the Grandeur from the underlying formation. Some of the brecciated zones in the Grandeur Member of the Terrace Mountains may be tectonic, due to slumping and faulting of the units above the incompetent Loray? Formation, but most appear to be genetically related to the formation itself. Poor exposures of this interval in the mapped area make interpretation of the breccia problem difficult.

The lower contact of the Grandeur is sharp in a few areas, such as the Cedar Range in northwest-central Utah, where there is abrupt change from sandstone to carbonate rocks. In the Terrace Mountains and other places, however, the transition is gradational or intertonguing and an arbitrary contact must be drawn.

Measured section.

Section of the Grandeur Member of the Park City Formation measured in

W½ sec. 11, T. 8 N., R. 12 W., Utah.

Permian:

Phosphoria Formation:

Meade Peak Member.

Conformable contact

Park City Formation:

Grandeur Member:

UNIT	DESCRIPTION	THICKNESS (feet)
26.	Dolomite, light- to medium-gray, weathers lighter. Several 2- to 3-foot bioclastic limestone beds near	

base and a fossiliferous bed at the top. Chert nodules, distinct, medium- to dark-gray, distributed throughout the dolomitic intervals, more abundant in the upper part. Lower part, distinct, medium-bedded; poor exposure; weathers into small chips. Upper part, irregular, thick-bedded; average 2 feet. Forms prominent ledge. Fossils from uppermost bed include Composita sp., Composita subtilita (Hall), Spiriferina sp., Phricodothyris sp., ramose bryozoa, crinoid columnals.. 85

25. Dolomite, medium brownish-gray, weathers lighter. Lower 30 feet fine-crystalline. Small siliceous content; some very fine silt; slightly calcareous. Upper 70 feet gives no reaction to acid. Cross-bedding, small-scale, high-angle, well-developed (Fig. 4). Laminae of fine-grained quartz stand out by differential weathering. Very angular float, sharp edges. Considerable bioclastic material in upper part; some silicified crinoid columnals, Euomphalid gastropod (indet.).. 100

24. Chert, medium- to dark-gray, weathers same. Bedding distinct average 6 inches. Bedding surfaces silty, undulatory. Good exposure.. 7

23. Limestone, light- to medium-gray, weathers lighter. Lower half fine-crystalline, upper half bioclastic. Thin-bedded; poor exposure. Fossils include Euomphalid gastropod, Composita sp., crinoid columnals.................................. 20

22. Concealed. Float is sandstone, calcareous, yellowish-tan, very fine-grained, very thin-bedded. Forms small swale........ 5

21. Chert, light- to very dark-gray, weathers slightly lighter. Bedding indistinct, average 8 inches; bedding planes fairly smooth, not wavy.. 22

20. Orthoquartzite, medium-tan to brown, weathers lighter, yellowish. Thin-bedded, average 5 inches. Medium-grained; float blocky.. 20

19. Dolomite, light- to medium-gray, weathers light gray. Thin-bedded, average 10 inches. Very rough weathering surface. Small quartz clastic content, increasing upwards............... 43

18. Dolomite, very dark-gray, weathers light yellowish tan. Thin-bedded, averages 5 to 6 inches. Little clastic content and no evident cross-bedding. Exposure poor but uniform; weathers into small chips. Forms marked yellowish band on surface. Notable lack of chert or fossils.................................. 120

17. Dolomite, medium-gray, weathers light-gray. High quartz clastic content, the upper part being dolomitic sandstone;

Figure 4. Hand specimen showing fine-scale, high-angle cross bedding characteristic of the lower part of the Grandeur Member of the Park City Formation (x $\frac{1}{2}$).

medium gray-tan, weathering tan brown. Faintly expressed cross-bedding in parts. Chert in thin zone near top.......... 50

16. Dolomite and chert. Dolomite, light- to medium-gray, weathers light gray. Comprises 20% of lower half, 80% of upper half of unit. Chert, medium- to dark-gray, weathers same; silty partings weather reddish brown. Lithologic proportions complimentary. Both lithologies in irregular, nodular masses, thin-bedded, average 4 to 5 inches. Blocky and angular float.. 30

15. Concealed. Float is fine-grained dolomitic sandstone or sandy dolomite. Yellow-gray, weathers light yellow tan. Apparently little chert. Weathering chips very small; unit forms swale on ridge. Some fine-grained fossil hash........... 40

14. Dolomite, medium- to light-gray, weathers very light gray. Middle part sandy, yellowish-tan; poor exposure. Upper and lower parts, small blebs of chert, well-exposed. Weathers into 5- to 6-inch cubic blocks. Well-silicified fossils include crinoid columnals (indet.), Marginifera sp., Wellerella sp., Phricodothyris sp., Linoproductid? sp. (indet.), Crurithyris sp., Hustedia cf. H. mormoni............. 60

13. Concealed. Float is dolomite and sandstone, medium-gray to medium yellowish-tan. Fine-crystalline and fine-grained. Bedding apparently averages 10 inches.......................... 55

12. Chert and dolomite, medium gray-tan and yellow-tan, weathers light gray and yellow. Only chert beds exposed. Dolomite is silty and siliceous in part. Unit forms yellow band on surface. Chert beds similar to underlying unit................ 125

11. Chert, medium- to dark-gray, weathers same. Beds 5 to 10 inches, separated by thin silty zones; bedding surfaces irregular or wavy.. 50

10. Sandstone, medium gray-tan, weathers medium to light yellow tan. Thin-bedded, average 4 to 5 inches; no evident cross-bedding. Fine, subangular grains. Slightly calcareous; parts siliceous. Mostly concealed, forms swale...................... 30

9. Chert, medium- to dark-gray, weathers same. Very thin-bedded; weathered blocks irregular, angular. Abundant, light-colored, possibly organic blebs in chert. Bedding surfaces irregular... 27

8. Concealed. Float is sandy and silty dolomite. Some chert, apparently increases upward. One exposed, 2- to 3-foot chert bed 250 feet above the base. Unit possibly faulted........... 300

7. Sandstone, quartzose, medium yellowish-tan to gray, weathers lighter in general, some purplish intervals near top. Largely concealed. Some calcareous, siliceous, and dolomitic intervals; especially dolomitic in upper part. Thin-bedded; well

cross-bedded near top. Several zones of breccia within unit, probably from faulting, but possibly intraformational breccia penecontemporaneous with deposition. Several beds with poorly preserved fossils 50 feet below top. *Composita* sp............ 285

6. *Sandstone*, quartzose, medium-gray to tan, weathers reddish orange in lower part, medium gray in middle, and reddish brown in upper part. Color bands distinct on surface though lithology is fairly uniform. Bedding indistinct, thin. Very fine-grained; calcareous-cemented; strong reaction to acid. Small-scale cross-bedding in upper part. Most brecciated, probably from faulting, although individual faults are not traceable within the unit.. 65

5. *Concealed*. Float is siliceous or dolomitic limestone, medium- to dark-gray, weathers light gray and tan. Considerable amount of very fine sand or silt; cross-bedding evident in lower part. Thin-bedded; average 3 to 4 inches; poor exposure. Float is very small chips. Some chert nodules in upper part. Both upper and lower contacts gradational. Fossils collected from a bed tentatively correlated with this unit include "*Murchisonia*" sp. indet. (abundant), subulitacean gastropods (rare), bellerophontacean gastropods (rare), of *Platyworthenia?* sp. indet. (common), neritacean gastropods (rare)............. 65

4. *Concealed*. Float is very silty dolomitic limestone, light- to medium-gray, weathers lighter except upper part which is brownish from silt. Well-developed cross-bedding in upper part. Slight reaction to acid. Float composed of semi-angular blocks and a few chert nodules. Bedding apparently several inches. Fossils in float include large *Composita* sp. and *Phricodothyris* sp.. 85

3. *Siltstone*, cherty, medium- to dark-gray, weathers yellowish orange to tan. Very thin-bedded; weathers into thin plates and very small chips. Considerable white, probably collophaneous material in the more siliceous beds........................ 75

2. *Chert* (70%) and *dolomite* (30%). Chert is dark brownish gray, weathers same. Dolomite is medium gray, weathers light gray. Chert most concentrated in middle of unit. Upper part sandy. Thin-bedded. Good exposure, forms ledges on steep hillside.... 60

1. *Dolomite*, cherty, medium-gray, weathers light gray. About 5% chert in irregular but well-defined nodules. Thin, uniformly bedded, average 1 foot. Considerable brecciation in unit, probably indicative of faulting. Upper contact gradational, lower contact concealed. Silicified fossils include *Phricodothyris*? sp., productid brachiopods indet., and ramose bryozoa.. 15

Total thickness of Grandeur Member................................ 1838

Conformable contact

Permian:

Loray? Formation.

Age and correlation. The Grandeur is of late Leonardian age in most places, although its deposition may have begun as early as late Wolfcampian in parts of Montana (Dunbar and others, 1960). It is correlated by fossils, lithology, and stratigraphic position with the Kaibab Formation of Leonardian age in west-central Utah and eastern Nevada, and with the Opeche Shale of late Leonardian age in central and eastern Wyoming.

At its type locality in the central Wasatch Range, the Grandeur is underlain by the Weber Quartzite and in the western Uinta Mountains it is gradational with, or may intertongue with and therefore be equivalent to, the upper part of the Weber (Cheney and others, in McKelvey and others, 1959, p. 13). Elsewhere, it is underlain by the Wells, Tensleep, or Quadrant Formations of Pennsylvanian and Permian ages. In the Terrace Mountains it is underlain by the Loray? Formation of Leonardian age.

The Grandeur is nearly everywhere overlain by the Meade Peak Member of the Phosphoria Formation of Wordian age. An exception is in Montana, where in places it is overlain by the Shedhorn Sandstone, of late Wordian and Capitanian age.

A small brachiopod fauna, characterized by Phricodothyris sp. and Composita subtilita (Hall), is present at intervals throughout the entire sequence assigned to the Grandeur in the Terrace Mountains. Because of the unrestricted distribution of Phricodothyris within the Grandeur there, and the fact that the genus seems to be characteristic of the upper part of the Grandeur Member in western Utah and northeastern Nevada (Ellis Yochelson, personal communication), it is possible that only the upper part of the member is present in the mapped area, the lower part being represented there by the underlying Loray? Formation. This possibility is further suggested by the fact that, in the Terrace Mountains, the Loray? Formation occurs between the overlying Grandeur and the underlying Diamond Creek Formation, whereas in the Cedar Range to the south and the southern Wasatch Range to the east, the Loray is absent and the Grandeur rests directly and conformably on the Diamond Creek.

Dr. Ellis Yochelson mentions (written communication, 1961) that assemblages of *Composita* in the upper part of the Grandeur Member are known from the Gold Hill district, the Pequop Mountains, the Goose Creek Mountains, and the Terrace (Hogup) Mountains. He mentions further that although the fossils in themselves are not diagnostic as to age, the widespread occurrence of these beds with abundant *Composita* suggests that this might be a zone useful for correlation in the northern Nevada-Utah area.

Dr. Yochelson also mentions (written communication, 1961) that the Grandeur has been considered to be of late Leonardian age in areas other than northwestern Utah, but that there is no direct evidence in fossil collections from that part of Utah to confirm that age assignment. He says that on the other hand, the possibility of a lower Wordian age cannot be disregarded.

Phosphoria Formation

The type locality of the Phosphoria Formation is Phosphoria Gulch, Bear Lake County, Idaho, for which feature it was named by Richards and Mansfield (1912, p. 684). In the vicinity of the type area the formation comprises up to 450 feet of dark chert, phosphatic and carbonaceous mudstone, phosphorite, cherty mudstone, and minor amounts of dark carbonate rock according to McKelvey (in McKelvey and others, 1959, p. 20). At the type area the formation is underlain by the Grandeur Member of the Park City Formation and is overlain by the Dinwoody Formation of Triassic age.

The Phosphoria Formation at its type locality is divided into the Meade Peak Phosphatic Shale Member, the Rex Chert Member, the Cherty Shale Member, and the Retort Phosphatic Shale Member, in ascending order. The lower two of these, the Meade Peak and the Rex, are present in the study area and are discussed below.

Meade Peak Phosphatic Shale Member

Definition and type locality. The Phosphatic Shale Member of Richards and Mansfield (1912, p. 683) (the middle shale member of the Park City Formation) was renamed the Meade Peak Phosphatic Shale Member of the Phosphoria Formation by V. E. McKelvey (in McKelvey and others, 1956, p. 22). The type area of the Meade Peak is the same as that of the Phosphoria Formation, Phosphoria Gulch in southeastern Idaho, where the member is composed mainly of dark carbonaceous, phosphatic, and argillaceous rocks. Away from the type area, as is the case in the Terrace Mountains, the member also includes variable amounts of carbonaceous, cherty, or silty rocks.

The Phosphoria Formation characteristically has a horizontal succession of different lithologies, which lithologies are also evident as a vertical cycle in some individual sections (McKelvey and others, 1956, p. 5). This is also somewhat the case with the Meade Peak Member itself, and as McKelvey mentions (1956, p. 22), the cycle is symmetrical in the type area of the Meade Peak.

Distribution and exposures. The Meade Peak is exposed in the western Terrace Mountains in four arcuate bands. The northernmost band encircles the southeastern flank of Tangent Peak and the others result from downfaulting of the stratigraphic section to the south. In each of these four occurrences beds of the unit dip from 15 to 30 degrees to the northwest, and in all but the southernmost, they are overlain by considerable thicknesses of the Rex Chert Member. Southwest of these outcrops, mainly in secs. 21 and 28, T. 8 N., R. 12 W., the Meade Peak is present in several small fault blocks. Exposures are poor, however, and stratigraphic and structural relations are difficult to decipher in this area. South of the Terrace Mountains, in secs. 4, 9, and 16, T. 7 N., R. 12 W., the member is present along the east limb of the West Terrace syncline. It is concealed in most of this area by Bonneville gravel, but apparently dips 5 to 10 degrees to the west. Structural complication is indicated by the fact that the Grandeur, below it on the east, and the Rex, above it on the west, both dip westerly about 30 degrees. The Meade Peak may have thickened here during folding of the West Terrace syncline.

The phosphatic shale is concealed in most of its occurrences and is usually covered with soil, although float of the more siliceous and carbonaceous units is normally present on the surface. The lower part of the Meade Peak is nearly everywhere marked by a shallow but distinct swale cut above the prominent ledges of the underlying Grandeur carbonates. Because of faulting and erosion, most exposures of the Meade Peak are incomplete. Surfaces are smooth and topography is rounded where developed on the Meade Peak, producing a contrast with other units that is helpful in its recognition on aerial photographs.

Trenching of the phosphatic shale was done in October 1959 by J. Stewart Williams for the Utah State Land Board, the purpose being to evaluate the material and to facilitate accurate measurement and sampling. Five separate trenches were cut in the following locations: (1) center E½NE¼, sec. 3, T. 8 N., R. 12 W.; (2) and (3), center E½NW¼ sec. 3, T. 8 N., R. 12 W.; (4) and (5), SW¼SW¼ sec. 2, T. 8 N., R. 12 W. Only the first of these was of use to the writer, the others having been cut at uncertain stratigraphic positions in incomplete sections. Results of this investigation are further discussed under economic geology.

Thickness, lithology, and stratigraphic relationships. In the Terrace Mountains, the Meade Peak comprises 400 feet of mudstone, silty and cherty carbonate rock and shale. Two phosphatic intervals are present, one in the basal ten feet and one near the middle of the member. These are separated by approximately 160 feet of dolomitic, siliceous and in part silty carbonate rock, an interval which is very probably a tongue of the Plympton Formation. The upper half of the Meade Peak is a very thin bedded to laminar mudstone, shale, and siltstone. The uppermost 50 feet are platy, calcareous siltstone and very fine-grained sandstone. This interval is possibly a clastic tongue of the Franson Member from the east or of the Plympton Formation from the southwest.

The basal unit of the Meade Peak rests conformably on and causes a swale to form above the resistant, ledge-forming dolomite of the Grandeur (Fig. 5). This ledge and swale is persistent in the Terrace Mountains

Figure 5. The swale in the center foreground is on the contact between shale of the Meade Peak on the left and dolomite of the Grandeur on the right. Swale and ledge in the background mark the contact across hills in the southern part of the western Terrace Mountains.

and greatly facilitates location and mapping of this contact. The upper contact of the Meade Peak is placed at the base of the first bed of black bedded chert of Rex type. This position is in apparent disagreement with T. M. Cheney (personal communication, 1960) who would place the contact at the base of unit 12 of the section of this report. The writer does not recognize that the siliceous material in his units 12, 15, and 16 is of sufficient quantity or of such character that it should be included as part of the overlying Rex. The siliceous material may represent conditions of deposition genetically related to those of the overlying Rex, but the more clastic lithology of these units and others in the upper Meade Peak indicates that they belong, in the opinion of the writer, more appropriately to the Meade Peak than to the Rex. The dominance of carbonaceous rocks and mudstone in the Terrace Mountains section as compared with greater amounts of shale in the type area is further justification of this procedure, which is to say that the Meade Peak is of more heterogenious lithology in the Terrace Mountains than it is in its type area.

Also of significance is the fact that the first distinct bed of Rex-like chert, at the base of which the writer has drawn the upper contact of the Meade Peak, represents a sharp depositional change from the underlying siltstones, although units 2 and 4 of the Rex are also siltstone, tongues of the Meade Peak or Franson in the interpretation of the writer, and represent brief returns to Meade Peak conditions after the first deposition of the Rex-type chert. Although it may seem so, the writer does not feel that his interpretation is at variance with the general policy of the U.S. Geological Survey, which is to include transitional beds at the top of the Meade Peak with the Rex or Franson because of lithologic alliance to those units (McKelvey et al, 1956, p. 23).

The Meade Peak in the Terrace Mountains is of such diverse lithology that limitation of the term to only the thin phosphatic shale units would be unduly restrictive. For this reason, siltstone units above the upper phosphatic shale and mudstone beds below the first good Rex chert bed are included in the Meade Peak. Shaley mudstone and siltstone beds above the first good Rex-type chert are included with the Rex, in accordance with Survey policy. Also, as opposed to siliceous zones within the Meade Peak, the basal chert bed of the Rex provides a useful horizon by which the contact can be mapped.

A vertical cyclic sequence of lithologies may be present in the Terrace Mountains section, but if so, it is not complete and is not easily distinguishable. The general sequence continues upward from basal bioclastic, phosphatic limestone, through phosphatic shale and mudstone, to the middle of the cherty carbonate unit. This sequence is then reflected by the upper part of the cherty carbonate unit, mud and siltstone, and phosphatic shale.

Measured section.

Section of the Meade Peak Member of the Phosphoria Formation
measured in trench,
center, E$\frac{1}{2}$NE$\frac{1}{4}$ sec. 3, T. 8 N., R. 12 W., Utah.

Permian:

Phosphoria Formation:

Rex Chert Member.

Concordant contact

Meade Peak Member:

UNIT	DESCRIPTION	THICKNESS (feet)
24.	Siltstone, tan to gray, weathers light gray to medium brown. Considerable iron staining; poorly developed Liesegang rings. Lamellar bedding; fissile. Partially concealed. Sharp contact with overlying unit	25
23.	Shale, silty, black, weathers dark brownish black; lower part browner. Lamellar bedding; fissile. Silty content in thin pods	10
22.	Sandstone, dark gray, weathers yellow tan to brown. Well-developed Liesegang rings. Calcareous; very fine-grained; very thin-bedded, some to 3 inches. Weathers in plates and spalls. Minor amount of shaley mudstone	6
21.	Mudstone, silty, medium-brown, weathers light gray. Non-calcareous. Very thin-bedded to lamellar. Weathers in small, angular, fissile chips	13
20.	Mudstone, black, weathers gray with greenish yellow stain. Non-calcareous; fissile; shaley	5
19.	Shale, dark-brown to black, weathers lighter. Most calcareous, some not. Very thin-bedded to lamellar; fissile. Bedding indistinct. Several beds of leached, silty mudstone; non-calcareous. Several zones of calcareous concretions. Parts of unit phosphatic	45
18.	Mudstone, calcareous, and shale. Mudstone is medium brown to black, weathering light gray. Very thin-bedded, some to 3 inches. Parts concretionary; concretions 1 to 5 feet in length. Shale interbedded with mudstone; very black; bedding lamellar; fissile. Weathers to thin flakes	8
17.	Mudstone, calcareous, brown, weathers lighter. Bedding lamellar, 1 to 10 mm. Few siliceous zones. Large calcareous concretions at top of unit. *Streblochonchria montpelierensis* (Girty), rare	9
16.	Mudstone, calcareous, and limestone, dark-gray to black, weathers light gray. Very thin-bedded to lamellar. Large concretions in upper part; 1 X 2 X 6 feet; most fractured, show white calcite veins. Unit weathers into blocky float and this into fissile flakes	10
15.	Concealed. Siliceous mudstone is dominant float; very thin-bedded; weathers to blocky, brittle chips	21
14.	Mudstone, calcareous, mottled brownish-black, weathers very light gray with some red-orange iron staining. Very thin-bedded; blocky weathering. Some siliceous beds in middle	17

13. Mudstone, calcareous, medium-brown, weathers lighter. Bedding lamellar; fissile. Non-resistant unit. Thin bed of black, plastic clay near middle. Fossils from part include *Streblochonchria montpelierensis* (Girty), *Crurithyris arcuata* (Girty), *Pseudogastrioceras* sp. (abundant) (Fig. 6), straight nautiloid (indet.), coiled nautiloid? (indet.), cephalopod (indet. - possibly 2 genera?), onychites (belemnoid tentacle hooks - rare) (Fig. 7), *Dentalina*? sp. (rare), shark tooth (rare), fish parts? (rare), organic spines, organic material (indet.).... 11

12. Mudstone, calcareous, medium gray-brown, weathers light gray. Very thin-bedded to lamellar, bedding indistinct. Some yellowish and some siliceous zones. Weathers to blocky chunks.. 2

11. Mudstone, phosphatic, medium brownish-gray, weathers dark brown. Bedding lamellar; fissile; weathers to shaley fragments. Abundant small-to medium-sized nodules near middle often contain fossils, including *Pseudogastrioceras* sp., pelecypods (indet. - 2 genera)........................ 32

10. Limestone and mudstone, black to dark-brown, weathers gray to tan. Heterogeneous lithology; some siliceous or cherty limestone. Silty beds near center show faint Liesegang rings. Some mudstone beds calcareous, some not. Lamellar to very thin-bedded. Partially concealed. Possibly up to 5 feet repeated in upper part by small fault............... 28

9. Limestone, very dark-gray, weathers lighter. Crystalline, fine-grained. White calcite veining. Very thin- to thin-bedded. Possible large concretions; poorly exposed......... 4

8. Concealed. Float is dolomitic limestone, very dark-gray, weathers medium gray. Upper part silty. Crystalline, very fine-grained; siliceous in part, gives conchoidal fracture. Lower part very thin-bedded, upper part lamellar. Possible repetition of a few feet by small-scale faulting... 105

7. Concealed. No predominant float. Possible small-scale faulting... 25

6. Mudstone, dark-brown to brownish-black, weathers light brown. Slightly phosphatic; sparse dark blebs or pellets. Very thin-bedded, some to 3 inches. Fissile in part; non-calcareous. Partly concealed............................ 10

5. Shale, brownish-black, weathers medium tan to brown. Bedding lamellar to very thin. Slightly phosphatic, pelletal in part. Part calcareous, part appears leached and earthy. Mostly concealed.. 11

Figure 6. Pseudogastrioceras sp. from unit 13 of the measured section of the Meade Peak Member of the Phosphoria Formation. (x 1).

Figure 7. Onychite, a belemnoid tentacle hook, from unit 13 of the measured section of the Meade Peak Member of the Phosphoria Formation (x 8).

4.	Limestone, very dark-gray to black, weathers lighter. Phosphatic. Several thin beds in unit; bedding planes appear to be stylolitic..	8 inches
3.	Shale, phosphatic, brownish-black, weathers dark brown to tan. Bedding lamellar; fissile. Sparse phosphatic pellets. Non-calcareous, leached; usually concealed........	3
2.	Shale, phosphatic, brownish-black, weathers dark brown. Lamellar bedding; weathers to thin, fissile chips; pelletal. Slightly calcareous. Forms topographic swale along with units 3 through 7; usually concealed.........................	28 inches
1.	Limestone, bioclastic, dark-gray, weathers lighter. Lower part dolomitic. Phosphatic; pelletal in part. Thin-bedded, average 3 to 4 inches. Considerable amount of shell hash and fish scales?..	1
	Total thickness of Meade Peak Member....................	404

Conformable contact

Park City Formation:

Grandeur Member.

Age and correlation. On the basis of stratigraphic correlation, the Meade Peak is of Wordian age. Almost everywhere it was deposited it overlies the Grandeur (late Leonardian-early Wordian) and underlies the Rex or Franson (Capitanian) (Dunbar and others, 1960). In places in Utah and Idaho, parts of the Meade Peak are interbedded with and therefore equivalent to parts of these underlying and overlying units.

The lower beds of the Meade Peak are laterally gradational with the Lower Chert Member of the Phosphoria Formation in western Wyoming (McKelvey and others, 1959, p. 21), and in southern and eastern Wyoming the Meade Peak is correlated with the Minnekahata Limestone of lower Wordian age. Further east and south it correlates with redbeds in South Dakota, Nebraska, and Kansas (Dunbar and others, 1960). Southwest of the mapped area the Meade Peak is correlated with the lower part of the Plympton Formation of Wordian age, and perhaps with a portion of the upper Plympton as well.

Faunal evidence of late Wordian-Capitanian age is indicated by the presence in the Terrace Mountain section of *Pseudogastrioceras*, certain species of which, according to Miller and Cline (1934), are abundant and widespread in the United States and Mexico only in beds of Wordian age. Miller, Furnish, and Clark questioned the designation of Wordian age for the Meade Peak in 1957, however, when they suggested that the ammonoid assemblage in that unit in southeastern Idaho and the central Wasatch Mountains was of Leonardian age. In spite of this, recent assignment of the overlying Gerster Formation to the Capitanian on the basis of ammonites by Mackenzie Gordon (*in* Dunbar and others, 1960, p. 1775) again lends support to the probability of late Wordian-Capitanian age for the underlying Meade Peak.

Ellis Yochelson mentions (written communication, 1961) that the brachiopod *Leiorhynchoidea* and the cephalopod *Pseudogastrioceras*, occur together in collections that have been assigned an early Capitanian age in the Las Delicias area, Mexico. He further says that on the basis of the association of genera in the fossil collections from northwestern Utah, he would suggest that the Meade Peak equivalent in that area is no older than middle Wordian age.

Rex Chert Member

Definition and type locality. Although the Rex Chert was named by Gale for Rex Peak in the Crawford Mountains, Rich County, Utah, the type section is apparently taken to be that described by Richards and Mansfield (1912) in the area of Phosphoria Gulch, Bear Lake County, Idaho (McKelvey and others, 1956, p. 25). Richards and Mansfield described the Rex at that locality as gray limestone and black chert, red-stained black chert, and cherty shale (1912, p. 684). McKelvey (1956, p. 26) restricted the name "Rex" to the hard, resistant, dark chert above the Meade Peak, and designated the cherty shale as a separate member (1949, p. 272).

Distribution and exposures. The Rex Chert forms the summit and all but the southeast slope of Tangent Peak in the northern part of the western Terrace Mountains. To the south from the peak, it is extensively exposed along the west side of the range. It is present on both sides of the West Terrace syncline, and forms the most southerly outcrops of that structure. There are no occurrences of the Rex in the eastern Terrace or the Hogup Mountains.

The Rex forms the most prominent cliffs in the western Terrace Range and usually is well exposed. Because of extensive faulting, however, there is no single unbroken section in the mapped area. It was, therefore, necessary to compile a section for measurement, partly from exposures in the southern Terrace Mountains and partly from the south slope of Shelter Mountain.

Thickness, lithology, and stratigraphic relationships. A 1157-foot sequence of bedded chert, cherty siltstone, and cherty mudstone is assigned to the Rex Chert Member of the Phosphoria Formation. Included within this sequence are several intervals of limestone, dolomite, and cherty carbonate rock which are considered tongues of the Gerster and Plympton

Formations. The latter formation is a sequence of gray chert, yellowish-gray dolomite, cherty dolomite, and minor sandstone, siltstone, and gypsum exposed on and named for Plympton Ridge in the Confusion Range, Millard County, Utah (Hose and Repenning, 1959, p. 2181). The Plympton Formation is bounded by the Kaibab below and the Gerster above, and is correlated generally with the Meade Peak and the lower parts of the Rex and the Franson Member of the Park City Formation in the Wasatch area.

Tongues of the Plympton comprise units 8, 9, and possibly 6, as well as parts of other units in the Rex section. Carbonate intervals which show strong lithologic and/or faunal affinity to the Gerster include units 18, 13, and 11, and parts of others. These carbonate tongues aggregate 396 feet, a considerable part of the Rex section.

Contacts between the tongues of carbonate rock and the chert beds of the Rex are somewhat gradational. Chert is present within the carbonate intervals, usually as discreet nodules, and carbonate rock is usually present in the chert beds as irregular but distinct nodules or segregations rather than being disseminated throughout the chert.

Within the lower part of the Rex are several thin intervals of cherty shale or mudstone, quite similar to the type assigned by McKelvey (1956, p. 28) to the Cherty Shale Member of the Phosphoria Formation. Cherty shale is the dominant lithology in and above the Rex interval in the Sublette and other ranges in southern Idaho, and although the beds in the Terrace Mountain section may be in part correlative with those to the north, they may only represent similar lithofacies development. In any case, they are not sufficiently distinct in the mapped area to be differentiated from the Rex.

Deposition of Rex-type chert was interrupted above the initial or basal bed by a brief influx of fine clastic material similar to that in the upper Meade Peak (or Franson Tongue?). Higher in the Rex, the chert was again contaminated, through a considerable thickness, by extremely fine clastic material, producing the above mentioned intervals of siliceous or cherty mudstone.

The placing of both the upper and lower contacts of the Rex in the Terrace Mountains was necessarily a somewhat arbitrary choice. The lower contact was placed at the base of the first interval of homogeneous, relatively pure, bedded black chert above the Meade Peak. The upper contact was chosen at the base of a richly fossiliferous, chert-free carbonate interval which was assigned to the Gerster on the basis of fauna and lithology. Thin carbonate units containing the Spiriferina pulchra fauna characteristic of the Gerster are present below the above mentioned bed, but are considered tongues of the Gerster within the Rex. None is distinct enough to be used as a base for mapping. As will be further discussed with the Gerster Formation, a tongue of Rex-like chert is present within the Gerster, produced by a partial return to Rex depositional conditions above the upper contact as here chosen.

Vertical columnar structures or pipes are well developed in several of the chert beds of the Rex, especially in unit 14. These sedimentary structures average one to four inches in diameter and most are 12 to 15 inches long. In transverse section they show a circular core of impure dark chert enclosed by an alternating sequence of thin concentric rings of pure white chert and impure dark chert of the type that forms the core and the surrounding bed (Fig. 8). In vertical section of some, the core is cylindrical, but in others it is conical, with the apex at the bottom. In the latter case, the concentric tubes are vertical, but are stepped around the conical core (Fig. 9). The white tubes of pure chert are possibly fillings of concentric tensional fractures, developed penecontemporaneously with or shortly after deposition; or, as suggested by Steele (1959, p. 192), the entire structure may represent an alge-sponge organism. Steele says further that at some localities such organisms make up entire beds, some reaching several hundred of feet in thickness, and that the cherts of the Gerster and Phosphoria Formations in many places are composed almost entirely of the monaxon spicules of this organism.

It is characteristic that the bedding surfaces in the Rex are wavy or irregularly undulatory. They are marked by thin silty partings which weather orange and tan to dark brownish-red, which colors stain the surface of the chert in some instances.

The Rex weathers by fracturing into small rectangular blocks which are individually quite resistant and form a dark residual covering on the surface. This residuum can be seen in the field and on aerial photographs, and is an aid to mapping the unit.

The source of silica in the Rex has been investigated by numerous geologists. Most of them believe the ultimate source to have been either volcanism or chemical weathering, and many also feel that the silica was later directly precipitated from seawater, although some consider organic precipitation, in the form of sponge spicules, to have been a significant part of the immediate source. Spicules are present in some beds of the Rex in the Terrace Mountains and in a few zones they are so abundant that they form a considerable part of the rock. However, the source of the material that formed the bulk of the Rex chert remains questionable.

Figure 8. Transverse section of one half of a columnar or "pipe" structure from unit 14 of the measured section of the Rex Chert Member of the Phosphoria Formation. The scale is six inches long.

Figure 9. Vertical section of the same specimen shown in figure 8. Scale is six inches long.

Measured section.

Section of the Rex Chert Member of the Phosphoria Formation

measured in

NE¼NE¼ sec. 3, and in NE¼ sec. 16, T. 8 N., R. 12 W., Utah.

Permian:

Gerster Formation.

Conformable contact

Phosphoria Formation:

Rex Chert Member:

UNIT	DESCRIPTION	THICKNESS (feet)
19.	*Chert*, gray-brown in upper part, very dark-brown in lower part. Thin- to medium-bedded. Limestone, 5 to 10 per cent, medium-gray, weathers yellow tan to orange; nodular. Contact sharp with overlying formation............	73
18.	Gs: *Limestone* (90%) and *chert* (10%). Limestone is medium-gray, weathers darker. Bioclastic. Non-resistant unit, forms swale on ridge. Fossils include *Derbya magna*, *Hustedia* sp., *Spiriferina pulchra*, *Echinauris subhorrida*, *Bathymonia nevadensis*....................................	5
17.	*Chert* (70%) and *limestone* (30%). Chert is yellow brown, weathers lighter. Bedding indistinct, nodular in part. Limestone is medium gray brown, weathers yellow tan. Silty. Bed containing abundant crinoid columnals 5 feet above base..	70
16.	*Chert* (90%) and *limestone* (10%). Same as unit 15 with addition medium-gray limestone nodules......................	10
15.	*Chert*, brownish-gray, weathers same. Bedding indistinct. Some white calcite blebs. Some cherty shale or mudstone; thin-bedded. Unit mostly concealed.........................	1074 180
14.	*Chert* (90%) and *limestone* (10%). Chert is brownish black to black, weathers same. Medium-bedded, distinct. Marked development of vertically laminate chert pipes and cones; 1 to 4 inches in diameter, up to 15 inches long. See Figs. 8 and 9. Limestone is silty, medium gray, in irregular nodules..	894 4
13.	Gs?: *Limestone*, cherty, medium-gray, weathers lighter.	

Crystalline; medium-grained. Parts have up to 30 per cent dark gray-brown chert nodules.................................. 6

12. Chert, gray-brown, weathers same. Bedding distinct, average five inches. Up to 5 per cent medium-gray, crystalline limestone; nodular... 16

11. Gs?: Limestone, medium-gray, weathers lighter. Cherty. Bedding indistinct. This unit correlated on the basis of fossils, lithology, and stratigraphic position with a unit on Tangent Peak, four and two-thirds miles to the northeast, from which the following fossils were collected: Crurithyris? sp. indet., Chonetes? sp., Cancrinella? n. sp., Rhynchopora cf. R. taylori, Plagioglypta sp., Nucula spp., Nuculana cf. N. obesa, Nuculana? aff. N. bellistriata, Aviculopecten sp., Euphemites exquisitus, Bellerophon deflectus, Retispira sp., Worthenia sp., "Glabrocingulum" sp., "Phymatopleura" sp., Knightites (Retispira) sp., gastropod genus indet., Pseudozygopleura sp., Strobeus sp. indet., fish fragment indet., ramose bryozoans undet., vertebrate limb bone, indet........ 10

10. Chert (85) and dolomite (15%). Chert is dark gray to brown black, more brown in upper part, weathers same. Medium- to thin-bedded. Dolomite is light gray, weathers dark gray. Small reaction to acid. Unit is resistant and well exposed. Lower contact gradational................................ 120

9. Pl: Concealed. Float is dark gray, siliceous dolomite with 10 to 20 per cent chert in the lower part, up to 60 per cent chert in the upper part. Chert is apparently in irregular nodules in the dolomite.................................. 190

8. Pl: Concealed. Float is dolomite, siliceous. Dark-gray, weathers tan to reddish brown. Crystalline, fine-grained. Abundant brachiopod spines in lower 20 feet. Weathers to small angular chips and chunks.............................. 65

7. Chert and dolomite. Chert is dark-gray to black, weathers same. Nodular in part and very thin-bedded, 2 to 4 inches, in part. Bedding indistinct. Thin interbeds of dark-gray siliceous and silty dolomite constitute 10 to 15 per cent of the unit. Dolomite weathers dark gray brown. Disseminated blebs of phosphatic material in the lower part, some possibly bone.. 280

6. Pl?: Concealed. Float is siliceous or dolomitic siltstone and silty dolomite, medium- to dark-gray, weathers orange brown to very dark brown. Very thin-bedded, apparently averages 2 inches. Occasional thin beds of black chert throughout.. 120

5. Chert and mudstone, siliceous. Mudstone dominant in lower part, chert in upper. Mudstone is dark gray, weathers lighter

	gray; hard and brittle. Blebs of siliceous material give mottled appearance. Chert increases upward to dense black chert at top. Bedding 2 to 3 inches in lower part, 5 to 6 inches in upper part. Bedding distinct; unit well exposed.	48
4.	Siltstone, dark gray-brown, weathers yellowish orange, tan and gray. Slightly calcareous. Very thin-bedded; weathers to thin fissile flakes. Faint Liesegang rings. Possibly Franson	2
3.	Chert, dark gray to black, weathers same. Thin-bedded; 5 to 10 inches. Dark reddish orange silty partings on undulatory or wavy bedding surface. Beds persistant laterally. Homogeneous, no concretions or pipe structures. Resistant unit, forms cliff or ledge. Contacts sharp with enclosing units	23
2.	Shale, gray to black, weathers tan to medium brown black. Bedding averages 10 inches, indistinct. Concretionary in part. Weathers into small fissile chips. Upper 6 inches, siltstone, siliceous, medium gray-tan to very dark brown, weathers lighter. Lower bed concretionary, black with white coating. Bedding surfaces wavy but beds persistant laterally. Possibly a tongue of Meade Peak or Franson	8.5
1.	Chert, dark-gray to black, weathers same, mottled appearance. Lower contact sharp. Unit is a 12-inch bed with several thin beds on top. Resistant, forms ledge	1.5
	Total thickness of Rex Chert Member	1157

Conformable contact

Phosphoria Formation:

Meade Peak Member.

Age and correlation. James Steele Williams states (in McKelvey and others, 1956, p. 40) that the faunas of the parts of the Park City above the Meade Peak Member (including the Rex Chert Member) are not definitely known to be younger than the Wordian, but some may be younger.

On the basis of its stratigraphic position above the Meade Peak, the upper part of which is herein assigned an early Capitanian age, the Rex Chert is of middle Capitanian age.

The Rex Chert in the studied area is correlated with the Franson Member of the Park City Formation in the Wasatch Range to the east and with the Gerster Formation in areas to the southwest of the studied area. The extensive intertonguing of the Rex Chert and the Gerster Formation in the Terrace Mountains is a significant indication of their equivalence.

Units correlated with the Phosphoria Formation by Williams (ibid., p. 40) include the Clover Creek greenstone, the Seven Devils and Casto volcanics, the Gerster, and the Edna Mountain Formations, these units being distributed throughout several far western states.

Gerster Formation

Definition and type locality. The Gerster Formation was named by T. B. Nolan (1935, p. 39) for Gerster Gulch near the Gold Hill Mining District in western Utah. He included in the new unit all strata between the "Oquirrh Formation" and the overlying Triassic shale. Grant Steele (1960, p. 112) later recognized that the lower part of this sequence was equivalent to the Kaibab Formation and suggested that the name Gerster be restricted to limestones above the Kaibab, and above the Phosphoria where that formation is present, as it is in the Terrace Mountains.

The Gerster was recognized in the Confusion Range by Hose and Repenning (1959, p. 2184) who included it, along with the underlying Kaibab and Plympton Formations, in the Park City Group. Rocks of Park City age in the Confusion Range were originally assigned to the Phosphoria Formation by Newell (1948).

Distribution and exposure. The Gerster Formation is exposed at disconnected intervals along the west side of the western Terrace Mountains, entirely within the area influenced by the West Terrace syncline. A complete section is present in a gulch (N½, sec. 8, T. 8 N., R. 12 W.) on the west limb of the syncline, where relatively good exposures and a moderately high dip facilitated accurate measurement. Good exposures of the lower part of the formation are present on the northwest slope of Shelter Mountain, and south of the mountain the lower part of the formation is exposed along the axis of the syncline, where it covers an area of approximately four square miles.

Thickness, lithology, and stratigraphic relationships. Approximately 900 feet of strata which comprise crystalline and bioclastic limestone, silty and argillaceous limestone, beds of cherty limestone, and beds of nearly pure chert are assigned to the Gerster Formation in the mapped area.

The base of the formation is conformable with the underlying Rex Chert. The lower contact was drawn by the writer at the base of a 23-foot, medium- to dark-gray bioclastic limestone characterized by an abundance of the productid *Echinauris subhorrida*, formerly "*Avonia*". Although thin tongues of Gerster-like limestone, containing the diverse *Spiriferina pulchra* or Gerster fauna, are present in the upper part of the Rex (units 11, 13, 19, and parts of 18), the "*Avonia*" bed, as it is informally referred to, is the most appropriate basal unit. It is a key bed, easily distinguished and useful for mapping purposes in the study area (Fig. 10). It also represents the first large-scale deposition of Gerster type limestone and is an appropriate boundary marker for that reason as well. Ellis Yochelson comments (personal communication) that the brachiopod collection submitted from this unit in the mapped area is certainly typical of the Gerster and could be taken to indicate the base of that formation.

The "*Avonia*" bed or zone has been recognized at several other localities in northwestern Utah, and may be useful for correlation in that general area. In the Goose Creek Mountains in the northwest corner of the state it is present at the base of the Gerster and contains at least one bed up to 40 feet thick (Albert Young, personal communication). There, as in the Terrace Mountains, much of the interval is a coquina of *Echinauris* shells in a silty limestone matrix. A single thin bed containing productids, tentatively identified by the writer as *Echinauris* sp., is located at or near the base of the Gerster Formation in the Grassy Hills, 30 miles southeast of the mapped area. These three occurrences would indicate that the interval thickens to the north and west and probably pinches out south and east of the Grassy Hills area. Correlation using this interval must be done judiciously, however, as there are several coquina beds of *Echinauris* in some localities, and the fossil is also present, though in lesser abundance, both above and below the key bed.

In addition to their large megafossil fauna and crinoidal hash content, the limestones in the basal part of the Gerster have considerable argillaceous and calcareous matrix and a few thin zones of small dark brownish-black chert nodules. The argillaceous content produces a light yellowish-gray color on weathered surfaces.

The amount of nodular chert increases irregularly upward from the top of these nearly chert-free basal limestones. Chert constitutes more than 50 per cent of the rock 270 feet above the base, and 95 to 100 per cent 400 feet above the base. This abundance of siliceous material is interpreted as a partial return to Rex conditions, and the interval could

Figure 10. View of unit 19 of the Rex Chert (bedded brown chert at lower right) overlain by unit 1 of the Gerster Formation. Location is at the base of the measured Gerster section on the west limb of the West Terrace syncline. Staff is 5.5 feet long.

be considered a tongue of the Rex, or on the other hand, the limestone beds here designated basal Gerster could be considered tongues of Gerster within the Rex.

Above the Rex tongue is 495 feet of gray-brown crystalline and light- to medium-gray bioclastic limestone. Chert nodules are abundant throughout this upper sequence in varying amounts, and some of the beds are abundantly fossiliferous.

Bioclastic beds throughout the formation are massive and usually several feet thick. The more argillaceous or silty limestones are thinner and individual beds are usually separated by shaley or silty interbeds. The shaley zones are easily eroded and cause the more resistant parts to stand out prominently.

All gradations between chert and limestone are present in the Gerster. Limestone beds with a few scattered chert nodules grade through limestone beds with distinct medial chert zones, to units of bedded chert containing only a few scattered limestone nodules or concretions.

Stratigraphic relations between the Gerster and the overlying Dinwoody Formation will be discussed below with the Triassic System.

Measured section.

Section of the Gerster Formation measured in
center N$\frac{1}{2}$ sec. 8, T. 8 N., R. 12 W., Utah.

Triassic:

Dinwoody Formation.

Paraconformable contact

Permian:

Gerster Formation:

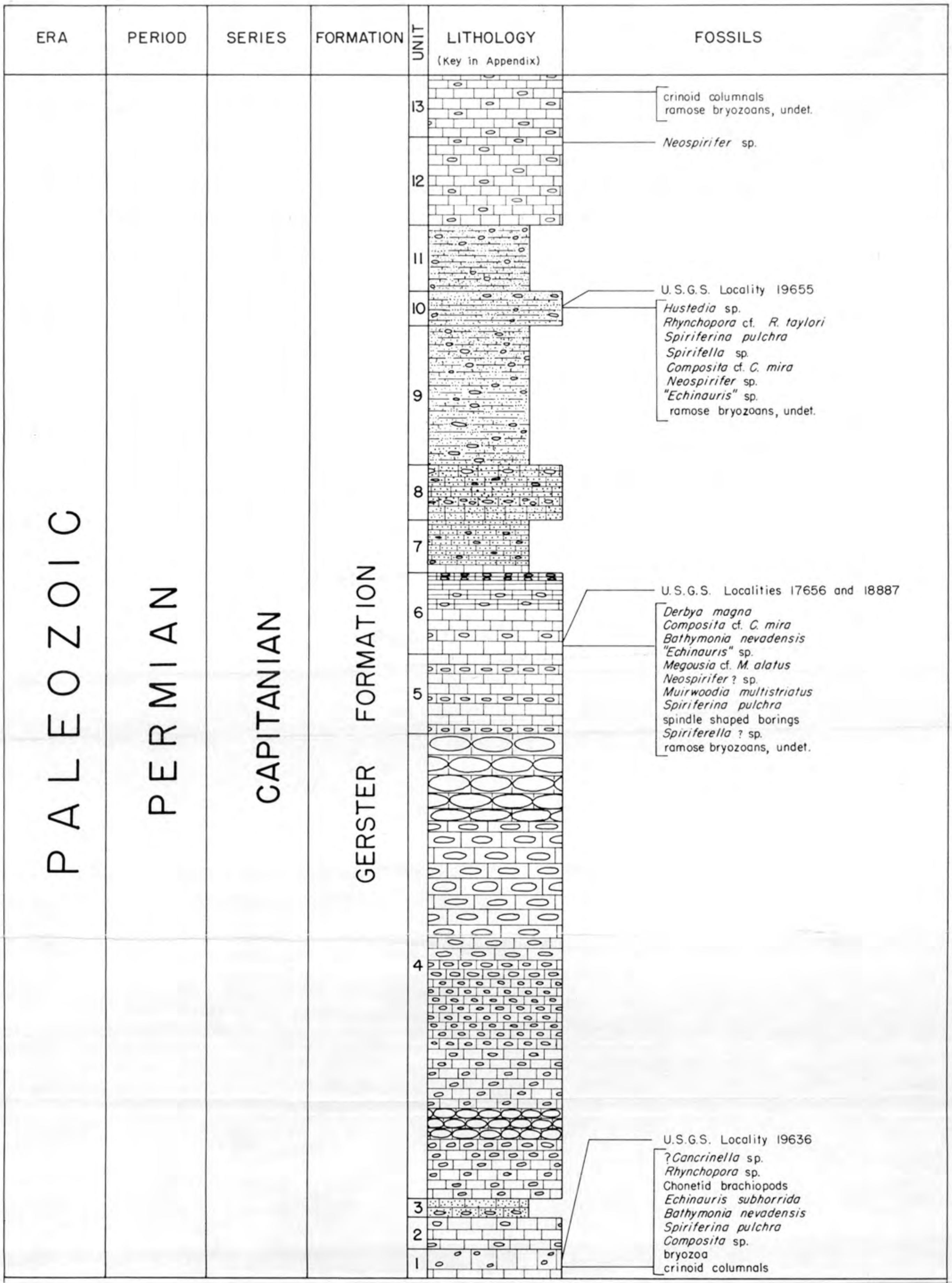
UNIT	DESCRIPTION	THICKNESS (feet)
13.	*Limestone*, bioclastic, light- to medium-gray, weathers lighter. Clasts largely crinoidal, medium- to coarse-grained. Nodules of black chert scattered through most beds; a few are chert free. Chert less than 5% of unit. Several beds with large ramose bryozoa. Upper part concealed	49
12.	*Limestone*, light-gray, weathers same. Distinct black chert nodules, 3 to 4 inches in diameter, throughout unit. Some chert pipes present. Very fine-clastic and crystalline. Bedding 1 to 2 feet, indistinct. Lower part resistant, upper part less so; 20 feet in middle concealed. One bed with large *Neospirifer* sp. 5 feet from top	65
11.	*Concealed*. Float similar to underlying unit	50
10.	*Siltstone*, calcareous, light reddish-brown or tan, weathers same. Cherty. Bedding thin, indistinct. Much of unit is concealed. Fossils include ramose bryozoans, *Hustedia* sp., *Rhynchopora* cf. *R. taylori*, *Spiriferina pulchra*, *Spiriferella*? sp., *Composita* cf. *C. mira*, *Neospirifer* sp., "*Echinauris*" sp.	25
9.	*Concealed*. Float similar to overlying unit	105
8.	*Limestone*, silty, cherty, medium- to dark brownish-gray, weathers yellow-tan. Chert in indistinct scattered nodules, very dark-brown to black. Chert as much as 40% in parts. Beds average 4 inches, none greater than 6 inches. Poorly exposed	40
7.	*Concealed*. Float similar to overlying unit	40
6.	*Limestone*, bioclastic, cherty, medium-gray, weathers yellow and reddish-brown from iron oxide staining. Upper part as much as 50% brown chert, lower part chert free. Bedding distinct, 12 to 18 inches at base, 2 to 3 inches at top. Unit resistant with good exposures in stream bed. Fossils include *Derbya magna*, *Composita* cf. *C. mira*, *Bathymonia nevadensis*, "*Echinauris*" sp., *Megousia* cf. *M. alatus*, *Neospirifer*? sp., *Muirwoodia multistriatus*, *Spiriferina pulchra* and spindle shaped borings collected from the lower 10 feet	60
5.	*Limestone*, silty, cherty, dark-brownish-gray, weathers bright yellow-orange. Dark-brown to black chert nodules in well-defined zones, not scattered. Nodules themselves indistinct; 5% of unit. Lower part well-bedded, average 20 inches, upper part indistinctly bedded. Upper contact	

	gradational, lower contact sharp. Unit not resistant, forms swale and stream juncture	60
4.	*Chert* and *limestone*. Limestone is medium to dark gray, weathers tan-brown. Chert is dark grayish-black, nodular, up to 30% in lower part, increases irregularly upward, comprises about 90% 70 feet above base and again near top of unit; medium yellow-brown near top. Unit averages 60 to 70% chert and could be considered a tongue of the Rex Chert. It indicates a partial return to Rex conditions of deposition. Outcrop massive, bedding indistinct, lower part 14 to 16 inches, upper part 6 to 7 feet, marked by alignment of chert nodules. Limestone slightly less resistant than chert. Limestone fossiliferous in places but preservation very poor.	348
3.	*Concealed*. Float is silty, cherty, limestone	13
2.	*Limestone*, bioclastic, medium-gray, weathers light yellowish-gray. Chert nodules 5 to 10%, dark-brown to black, weathering dark reddish-brown. Silty or shaley partings between beds to 2 inches. Wavy bedding surface. Unit not resistant. Gradational contacts	25
1.	*Limestone*, bioclastic, medium- to dark-gray, weathers lighter. Small gray chert nodules. Thick-bedded, average 3 to 4 feet; marked contrast with thin beds in units above and below. Fossils include Chonetid brachiopods, *Echinauris subhorrida* (Meek) abundant, *Bathymonia nevadensis* (Meek), *Spiriferina pulchra* (Meek), *Composita* sp., bryozoa, and crinoid columnals collected 2 feet above the base (see Fig. 10)	23
	Total thickness of Gerster Formation	903

Conformable contact

Rex Chert Member of Phosphoria Formation.

Age and correlation. J. Steele Williams reports (in Hose and Repenning, 1959, p. 2185), that in approximate terms, the Gerster correlates with the Word Formation of Texas, with the middle phosphatic shale member of the Park City in the type locality of the Park City, and with the Meade Peak (Member) and some overlying beds of the Phosphoria Formation. He further states, however, that the precise vertical limits of the Gerster in terms of the above formations were not known



COLUMNAR SECTION OF THE GERSTER FORMATION
IN THE WESTERN TERRACE MOUNTAINS, UTAH

VERTICAL SCALE: 1" = 100'

PLATE X

P. B. STIFEL

at the time of writing (1959). Grant Steele states (1960, p. 112) that the Gerster is of upper Guadalupian (Capitanian) age by reason of stratigraphic position and a prolific megafauna which correlates with genera and species of Texas and New Mexico.

The writer questions Williams' correlation of the Gerster with the Word Formation and with the Meade Peak, because, for one reason, there are 1200 stratigraphic feet between the Gerster and the Meade Peak in the Terrace Mountains. The Capitanian age suggested by Steele is probably more correct. The Gerster is more probably equivalent in part to the Rex Chert Member than to the Meade Peak. The Plympton Formation, of Wordian age, which underlies the Gerster in the Confusion Range, is correlative with the Meade Peak and at least the lower parts of the Rex Chert, and both the Plympton and the Meade Peak directly overlie the Kaibab Formation or its equivalent, the Grandeur Member of the Park City Formation of late Leonardian and early Wordian age. In the mapped area, the Gerster overlies and intertongues with the upper part of the Rex Chert of Capitanian age.

By virtue of its stratigraphic position, the Gerster correlates to the east with the upper part of the Franson Member of the Park City Formation, previously called the Upper Carbonate Member of the Park City.

TRIASSIC SYSTEM

General Statement

Marine rocks of Lower Triassic age are present in the mapped area and are assigned to the Dinwoody Formation and to part of the Thaynes

Formation. As the marine Triassic deposits of the northeastern Great Basin were not discovered by the Geologic Exploration of the Fortieth Parallel (1863-1869), it was not until the early twentieth century that the exposures were found, and even then descriptions were not forthcoming until the 1930's (Smith, 1932). Although rocks of Lower Triassic age were by then known in southern Idaho, western Montana, and Wyoming, the first general survey of the Triassic rocks in the eastern Great Basin was made from 1949 to 1955 by D. L. Clark and W. L. Stokes (1956). Their report contained the first mention of the exposures in the Terrace (Hogup) Mountains along with seven other localities, all in northeastern Nevada. The Terrace Mountain occurrence was again mentioned, in slightly more detail, by Clark (1957, p. 2198).

Permian - Triassic Boundary

Although the Permian-Triassic contact is exposed in the West Terrace syncline, the outcrops which show it are small, occurring only on steeply dipping strata in washes and gullies, so the exact nature of the boundary is not determinable. At the two best exposures on the west limb of the syncline (secs. 5 and 8, T. 8 N., R. 12 W.), the contact is apparently a paraconformity or possibly a disconformity, and if there is angular unconformity at the contact regionally, it is not perceptible there. The upper beds of the Gerster are massive bioclastic limestones, none of which is a key bed recognizable individually over any distance, and the basal Triassic bed is a 20-foot gray-green shale, which lacks distinguishable bedding where the contact is best exposed. These discouraging conditions in the mapped area confirm a statement of Kummel, who says (1954, p. 167) that there is lack of physical evidence of a hiatus between the Phosphoria and Dinwoody or Woodside Formations at most exposures in the Middle Rocky Mountains. However, physical evidence of an unconformity between the Permian and Triassic Systems within their mutual basin of deposition has been mentioned by numerous authors, including Newell and Kummell (1942, p. 938) in southwestern and central Wyoming, Baker and Williams (1940) in the southern Wasatch Mountains, and Hose and Repenning (1959, p. 2189) in the Confusion Range in west central Utah.

Dinwoody Formation

Definition and type locality. Blackwelder (1918, p. 425-425) named and described the Dinwoody Formation, choosing the type section in Dinwoody Canyon in the Wind River Mountains near Du Bois, Wyoming. The formation was redefined by Newell and Kummel (1942, p. 941) on a lithologic rather than the color basis used by Blackwelder. The Dinwoody is 90 feet thick at the redefined type locality, although it reaches a thickness of up to 2443 feet in southeastern Idaho (Kummel, 1954, p. 169).

In southwestern Montana, the Dinwoody Formation was divided into a lower "Shale Member" and an upper "Limestone Member" by Moritz (1951) and in western Wyoming, three informal members were designated by Newell and Kummel (1942); a basal siltstone, later redefined as silty limestone (Kummel, 1954), a middle Lingula zone, and upper Claraia zone.

Distribution and exposure. The most extensive exposures of the Dinwoody Formation are in an arcuate pattern along the east and west limbs and across the axis of the northern part of the West Terrace syncline, over an area of approximately 3 square miles. Other smaller exposures occur in sec. 17, T. 8 N., R. 12 W., on the axis of the syncline, and in sec. 22, T. 9 N., R. 12 W., at the base of the western flank of Tangent Peak.

A fourth occurrence of Triassic rocks is present in the SW$\frac{1}{4}$ sec. 4, T. 8 N., R. 11 W., near the southern end of the Big Pass. Although no actual outcrop is present there, dominant limestone float covering a small knoll is lithologically similar to the Dinwoody rocks in the West Terrace syncline, and contains pelecypod impressions similar to those on many bedding surfaces in that section. This small, unexposed block apparently lies as a wedge between major Basin and Range type faults, having been dropped nearly 20,000 stratigraphic feet to its present position among Permian rocks of lower to middle Wolfcampian age.

The Dinwoody Formation is best preserved and best exposed in the core of the West Terrace syncline. A few scattered outcrops protrude through the covering of lake sediments, but better, and in many cases, very good, though limited, exposures are present in dry washes on the west limb of the syncline. The formation was measured in three such washes by offsetting on key beds.

The limestone units are nearly always exposed and usually form ledges or falls in the wash bed. Shale units are sometimes concealed, but the sides of the washes are steep in most places and the bedrock is easily uncovered.

Characteristics and thickness. As delineated by the writer, the Dinwoody Formation is 1670 feet thick in the Terrace Mountains, and is divided into the Lingula and Claraia zones of Newell and Kummel (1942) or at least their equivalents, which the writer feels are recognizable in this section. The basal silty limestone zone recognized by Newell and Kummel was apparently truncated to the north, as it is not present in the Terrace Mountains section.

Lingula zone. The probable equivalent of the *Lingula* zone in southeastern Idaho is approximately 260 feet thick in the Terrace Mountains. Its lower boundary is the Permian-Triassic contact, and its upper limit was chosen at an arbitrary position based on gradual faunal and lithologic changes. The zone is characterized by interbedded maroon, green and olive-gray shale and both bioclastic and crystalline, maroon, chocolate, and gray limestone. The shale units are indistinctly bedded, weather into small chips or flakes, and constitute 70-80 per cent of the zone. Thin- to medium-bedded limestone units which weather into blocks, make up the complimentary 20-30 per cent.

Strata assigned to the *Lingula* zone were measured in a deep wash in sec. 8, T. 8 N., R. 12 W., west of the axis of the syncline. Through the gradational interval between the *Lingula* zone and the overlying *Claraia* zone, shale becomes less abundant, and platy, silty limestone (calcarenite) largely takes its place between units of massive crystalline limestone and calcareous siltstone, and the lower part of the *Claraia* zone retains many lithologic characteristics of the subjacent *Lingula* zone.

Claraia zone. Approximately 1320 feet of strata are assigned to the *Claraia* zone, although because parts of it are not well exposed and offsetting was necessary for measurement, there is a possibility of slight duplication or omission in this interval. As mentioned above, the lower third of the zone is similar to the *Lingula* zone, but has less shale and a higher percentage of silty limestone. The thin-bedded to lamellar, olive-yellow to buff and tan calcarenite is the dominant lithology in the upper two-thirds of this zone. It is usually ripple-marked (symmetrical ripples) and it parts on micaceous laminae into thin platy float.

Measured section.

Section of the Dinwoody Formation measured in

sec. 5 and N½ sec. 8, T. 8 N., R. 12 W., Utah.

Triassic:

Thaynes Formation.

Conformable contact

Dinwoody Formation:

UNIT	DESCRIPTION	THICKNESS (feet)
90.	Limestone, silty, olive-brown, weathers same. Indistinct ripple-marks; most very thin-bedded; micro-laminations. Several beds 6 to 8 inches. Fossiliferous bed 20 feet from top; poor preservations. *Eumorphotis*? sp.	196
89.	Limestone, gray-brown, weathers medium to dark brown. Bedding irregular, weathers into blocky float. Micaceous partings on bedding planes; white calcite veining.	20
88.	Concealed. No dominant float.	70
87.	Siltstone, calcareous, olive-brown, weathers medium to dark brown. Thin-bedded.	5
86.	Concealed. Float is calcareous shale.	20
85.	Limestone, silty, dark yellowish-tan, weathers same. Thin-bedded. Mostly concealed.	65
84.	Siltstone, calcareous, olive-brown, weathers dark brown. Resistant outcrop.	5
83.	Concealed. Float is limestone, silty.	25
82.	Limestone, medium yellowish-tan with greenish tinge, weathers slightly darker. Lamellar-bedded, average 1 to 3 mm.; fissile. Silty interbeds.	50
81.	Concealed. Float is calcareous shale, olive-tan, fissile.	25
80.	Limestone, bioclastic, medium-gray, weathers medium gray brown. Crystalline appearance.	1
79.	Concealed. Float is silty limestone, light yellowish-tan. Very thin-bedded; platy; fissile.	25

78.	Limestone, medium-gray, weathers medium gray brown. Bioclastic, apparently recrystallized. White calcite veining. Nonresistant	23
77.	Limestone, shaley, greenish-gray, weathers same. Fissile, very thin-bedded. Poorly exposed	18
76.	Limestone, medium gray-brown, weathers same. Medium crystalline	2
75.	Limestone, shaley, medium yellow-tan, weathers tan. Some crystalline limestone beds to 2 inches. Bedding irregular; 1 to 2 mm.; micaceous partings. Poor exposure	62
74.	Limestone, shaley, greenish-gray, weathers same. Fissile; part nodular. Poor exposure	15
73.	Limestone, medium yellow-tan, weathers same. Medium-bedded. Lower part shaley; nodular. Middle part blocky weathering	12
72.	Shale, gray-green, weathers same. Fissile. Few calcareous, micaceous beds, to 1 inch	19
71.	Limestone, medium-gray, greenish tint, weathers yellowish-brown; mottled appearance. Fine-crystalline. Beds 1 to 3 cm. Few beds gray, crystalline limestone, to 2 inches. Faint ripple marks. Relatively well-exposed	13
70.	Limestone, yellow-tan, weathers same. Thin-bedded; fissile; platy. Partially concealed	13
69.	Limestone, medium-gray, weathers brown. Fine-crystalline. Well-bedded; ½ to 1 inch. Weathered surface rough, mottled appearance	3
68.	Concealed. Float is limestone, green-gray, weathers lighter. Micaceous, platy. Few resistant beds form rectangular chunks in float	25
67.	Limestone, gray-green, weathers same. Silty. Poorly bedded.	3
66.	Concealed. Probably shale	20
65.	Limestone, medium gray-brown, weathers dark brown. Weathered surface mottled and rough. Indistinct fossil casts include *Myalina*? sp., *Nucula*? sp., and *Claraia*? sp.	15
64.	Limestone, mottled gray, weathers tan to brown. Bedding indistinct; 1 to 4 inches. Parts quite nodular	15
63.	Limestone, silty, gray-green, weathers same. Very thin-bedded to lamellar	6

62. Limestone, silty, brownish-gray, weathers darker brown. Some uniform beds average 4 inches. Surfaces mottled. Blocky weathering.. 4

61. Limestone, silty and shaley, gray-green, weathers same. Platy; ripple-marked. Chunky weathering. Fissile, shaley limestone at base, maroon shale at top. Non-resistant unit.. 10

60. Shale and limestone. Lower part shale, maroon and green, weathers same. Upper part shale, yellowish-green, calcareous, silty; interbedded with $\frac{1}{2}$- to 1-inch beds of gray limestone. Partly concealed... 15

59. Limestone and siltstone, mottled-gray, weathers same. Several 1-foot siltstone beds. Thin-bedded, micaceous, silty limestone at base. Limestones resistant, form falls in stream... 11

58. Limestone and shale, light tannish-gray with green tint, weathers same. Green and maroon shale in upper part; green shale at top. Fissile. Bedding indistinct.................. 4

57. Limestone, silty-greenish-gray to maroon at top, weathers same. Very thin- but well-bedded; average $\frac{1}{2}$ inch. Upper part calcareous nodules in shaley matrix..................... 4

56. Limestone, crystalline, gray-brown, weathers darker. Weathered surface rough; resistant unit.................................. 2

55. Limestone, medium greenish-gray, weathers same. Smooth surface. Weathers into cubic blocks............................ 9

54. Shale, calcareous and limestone. Shale is gray-green, weathers same. Fissile. Limestone in upper part brownish maroon.. 6

53. Limestone, bioclastic and silty, mottled-gray, weathers dark gray. Very thin-bedded; irregular, average 1 to 2 inches, several 1-foot silty beds. Unit resistant, makes falls in gully. Indistinct fossil impressions on bedding surfaces.... 13

52. Concealed. Float is shale, calcareous........................ 20

51. Limestone and shale. Limestone is gray, weathers lighter; silty; part massive, part very thin-bedded, platy. Shale is bright maroon, weathers same; fissile. Some concretionary limestone.. 23

50. Concealed. No dominant float, probably shale................ 20

49. Limestone, silty, gray-brown, weathers dark brown. Thin-bedded, 2 to 4 inches. Weathers into small blocks........... 12

48. Siltstone, greenish-tan to gray, weathers darker. Lamellar

to very thin-bedded. Oscillation ripple-marked. Uniform; platy. Poorly exposed........ 27

47. *Limestone*, silty, tan-gray, with greenish tinge, weathers brown. Lower 5 feet very thin-bedded; platy; micaceous. Cross-bedded; ripple-marked. Upper part quite silty. Weathers to angular blocks and spalls........ 7

46. *Limestone*, gray, weathers same. Medium-crystalline. Weathered surface rough........ 2

45. *Limestone*, silty, buff to greenish-gray, weathers slightly darker. Very thin-bedded to lamellar; fissile. Micaceous surfaces; platy weathering. Part nodular........ 10

44. *Limestone*, gray-brown, weathers same. Massive bed; calcite veined; rough weathered surface........ 3

43. *Limestone*, silty, buff-yellow to gray-brown, greenish tinge, weathers slightly darker. Bedding irregular, lamellar to thin-bedded, to 8 inches. Fossils include *Nucula* sp., *Anodontophora?* sp., *Eumorphotis multiformis*, *Corbula?* sp., *Claraia stachei?*, *Claraia* cf. *C. mulleri*, *Myalina* sp., *Myalina spathi*........ 27

42. *Shale* and *limestone*. Shale maroon, weathers same. Limestone is greenish-tan, weathers dark brown. Medium-bedded. Blocky limestone float. Oscillation ripple-marked. Mostly concealed........ 30

41. *Concealed*. No dominant float, probably shale........ 20

40. *Siltstone*, calcareous, buff to tan, weathers same. Beds average 1 inch. Oscillation ripple-marked. Non-resistant unit. Worm trails on some bedding surfaces........ 8

39. *Concealed*. No dominant float, probably shale........ 30

38. *Limestone*, mottled-gray to yellow-tan, weathers same. Indistinct bedding, average 1 to 2 inches........ 4

37. *Limestone*, silty, light-gray to tan, weathers dark brown. Thin-bedded, 2 to 4 inches, uniform. Resistant unit, weathers to small blocks........ 19

36. *Concealed*. No dominant float, probably shale........ 10

35. *Limestone*, medium-gray, weathers same. Medium-crystalline. Solid but contorted beds; white calcite veining; rough weathered surface........ 5

34. *Siltstone* and *limestone*, tan to gray, most weathers dark gray brown. Thin-bedded; resistant unit but partially concealed.. 10

33.	Concealed. No dominant float, probably siltstone and shale....	55
32.	Limestone, gray, weathers dark gray to brown. Distinctly but irregularly bedded; 2 to 12 inches. Some thin shaley partings. White calcite veins in upper part. Poorly preserved fossil impressions on bedding surfaces....................................	13
31.	Concealed, probably shale....................................	40
30.	Limestone and siltstone. Limestone, gray, weathers yellow tan. Dense; crystalline. Abundant poorly preserved fossils. Siltstone, calcareous, orange-yellow, weathers greenish-tan. Thin-bedded; platy. Indeterminable pelecypod impressions throughout. Partially concealed..	25
29.	Limestone, siltstone, and shale. Limestone, gray, weathers same, solid, medium-bedded; at base of unit. Siltstone, calcareous, yellow-tan, weathers darker; thin-bedded, platy. Shale, mostly maroon, some green; interbedded with siltstone. Upper part of unit mostly concealed............................	25
28.	Concealed. Probably shale. Light greenish-gray clay on surface..	5
27.	Siltstone, calcareous, yellowish-tan, weathers same. Very thin-bedded; indistinct. Weathers into small chips. Partially concealed..	5
26.	Limestone, gray, weathers darker. Lower part shaley. Irregularly bedded. Nodular appearance on surface. Resistant beds in upper part; contorted bedding. Small detrital mica content..	12
25.	Limestone, silty, yellowish-tan, weathers darker. Very thin-bedded; to 2 inches. Micaceous partings on bedding surfaces. Oscillation ripple-marks.....................................	9
24.	Shale and limestone, silty. Shale, greenish-gray, weathers same. Limestone, tan. Thin-bedded. Partially concealed.....	13
23.	Limestone, medium-gray, weathers brown. Very thin-bedded. Resistant unit...	23
22.	Shale, green and maroon, weathers same; interbedded. Several 1- to 2-foot beds of limestone. Shale mostly concealed.......	45
21.	Limestone, gray, weathers medium brown. Medium-crystalline...	3
20.	Shale, in part calcareous, and limestone. Shale green; bedding indistinct, wavy. Calcareous parts ripple-marked. Limestone, gray-brown, weathers brown. Very thin-bedded, to 2 inches. Ammonite? impressions on surface..............................	12

19.	*Limestone*, medium-gray, weathers gray brown to maroon. Very thin- to thin-bedded. Residue shows small mica and detrital quartz content, abundant shell fragments and echinoid (?) spines..	4
18.	*Shale*, maroon to green, weathers same. Fissile; current ripple-marked. Bedding indistinct. Several thin calcareous beds. Pelecypod impressions on surfaces..................	10
17.	*Limestone*, gray to red-brown, weathers same. Crystalline, fine-grained..	3.5
16.	*Shale*, green, weathers same. Bedding indistinct. A few thin silty, gray limestone beds near top. Platy; wavy bedding surfaces..	10
15.	*Limestone*, medium-gray with brown blebs, weathers brown. Bedding 2 to 4 inches; wavy surfaces. Resistant exposure, forms fall in stream bed. Fossil impressions on upper surface..	3.5
14.	*Shale* and *limestone* interbedded. Shale mostly green, some deep-maroon in middle and upper parts, usually between green intervals. Limestone medium-gray, weathers light gray to brown. Fine-crystalline, some silty, slightly glauconitic. Most very thin-bedded, wavy bedding surfaces commonly having fossil impressions. Fossils from near top include *Myalina spathi*?, *Aviculopecten* sp., *Eumorphotis*? sp., *Lingula borealis* (throughout)..	66
13.	*Concealed*. No dominant float, probably shale................	10
12.	*Limestone* and *shale*, interbedded. Shale green and maroon, in 3- to 4-foot beds. Limestone gray to dark-brown, weathers gray brown to dark brown. Beds from 3 inches to 2 feet. Upper part very thin-bedded, wavy bedding surfaces. Most limestone beds contain microgastropods and have *Lingula* sp. and *Yoldia*? sp. on bedding surfaces..........................	25
11.	*Limestone*, reddish-brown, weathers darker. Some light-gray bands. Crystalline, medium-grained. Bedding distinct; 4 to 6 inches. Weathered surface rough. Low silt content. Siliceous spicules and the conodont *Hindeodella* sp...........	3
10.	*Concealed*. Probably green shale............................	8
9.	*Limestone*, medium-gray, weathers lighter gray. Crystalline, medium-grained. Bedding distinct but irregular.............	4
8.	*Shale*, green to mottled greenish-gray, weathers same. Bedding indistinct. *Lingula borealis* abundant.................	16
7.	*Limestone*, gray, weathers mottled brownish-gray. Crystalline,	

medium- to coarse-grained. Bedding distinct, 4 to 6 inches. Small detrital quartz content, considerable pyrite. Microgastropods abundant, conodont fragments indet................ 7

6. Shale, green and maroon, weathers same. Bedding indistinct. Liesegang rings partially developed. Several limestone beds in unit, medium-gray, weather light gray-green. Crystalline. Large pyrite crystals. Limestones nodular and lenticular; contacts sharp. Fossils in limestone beds include Eumorphotis? sp., Myalina putiatinensis?, pelecypod indet., small and microgastropods and pelecypods, echinoid (?) spines, conodonts including Lonchodina mulleri Tatge (not Hibbardella subsymmetrica Muller), Lonchodina sp., indet, Lonchodina n. sp., and Hindeodella sp.................................... 14

5. Limestone, gray-green, weathers light gray. Bedding indistinct, very thin, upper part platy; micaceous surfaces. Slightly pyritic. Microgastropods, pelecypods, shell fragments, spines, conodonts including Hindeodella triassica and Hindeodella sp.; Lingula borealis on bedding planes...... 5

4. Shale, green-gray, weathers same. Bedding indistinct; contacts with enclosing units sharp. Iron staining on joint surfaces. Slightly pyritic. Weathers into small chips. Partly concealed. Residue shows mica, apparently phlogopite, microgastropods and pelecypods, Lingula? sp. fragments, possible fish bones, and conodonts including Lonchodina mulleri, Hindeodella triassica, Hindeodella sp.................. 26

3. Limestone, medium-gray, weathers lighter. Thin-bedded, crystalline, fine-grained. Pyritic. Poorly preserved megafossils, echinoid spines, microgastropods, and conodonts including Lonchodina mulleri Tatge, Neoprioniodus bransoni Muller, Ozarkodina sp. indet., Ozarkodina n. sp?, Hindeodella sp... 2

2. Shale, greenish-gray, weathers lighter. Bedding indistinct. Weathers into small chips. Lower part partially concealed. Microgastropods, microcolumellae, and conodont Ozarkodina sp.. 22

1. Concealed. Probably green shale............................ 20

Total thickness of Dinwoody Formation.................. 1647

Paraconformable contact

Permian:

Gerster Formation.

Age and correlation. The age of the Dinwoody Formation as established by Newell and Kummel (1942), is Scythian (middle lower Triassic) because it contains ammonites belonging to the Otoceratan and Gyronitan faunal zones of the lower Eo-Triassic of Spath (1934). Several indeterminable ammonite impressions were found by the writer in the Dinwoody, in a stratigraphic position near that previously suggested by Clark (1957, p. 2198) to represent the *Meekoceras* zone, also on the basis of impressions. However, because of the presence of what is apparently the *Meekoceras* zone higher in the section, the writer feels that these lower impressions probably represent the Otoceratan or Gyronitan zone of the Dinwoody Formation.

Recognition by the writer of the *Lingula* and *Claraia* zones of Newell and Kummel (1942) lends support to his contention that the lower 1600 feet of Triassic strata in the Terrace Mountains should be assigned to the Dinwoody Formation, rather than to the Thaynes, to which latter formation the lower 900 feet was assigned by Clark and Stokes (1956, p. 1688). To further substantiate this contention, the writer obtained conodonts from limestone beds in both the Dinwoody and Thaynes Formations. The fossils were identified by, and their stratigraphic significance was discussed with Dwayne Stone (oral communication). Conodonts recovered from the lower 130 feet of the Dinwoody included *Ozarkodina* sp. and *Hindeodalla* sp. which are long ranging species (Stone, personal communication) and *Lonchodina mulleri* and *Hindeodella triassica* which latter two species are included in the *Gondolella planata* Assemblage-Zone of Clark (1960, p. 125) and which according to Clark have been found from about 10 feet above the base of the Triassic, up to and including the *Meekoceras* beds. These forms are not diagnostic of the Dinwoody as such, but neither are they diagnostic of the Thaynes.

Conodonts recovered from the *Meekoceras*-bearing limestone, unit 5 of the Thaynes Formation, include the long ranging forms *Hindeodella* sp., *Hibbardella* sp., *Lonchodina* sp., and *Spathognathodus* sp. and one species, *Neoprioniodus bicuspidatus*, which according to Clark (1960) ranges only up to and including the *Meekoceras* beds. The position of this form helps to substantiate the writer's interpretation that the *Meekoceras* zone of the Thaynes is 1760 feet above the base of the Triassic in the Terrace Mountains rather than about 350 feet as suggested by Clark (1957, p. 2198), and that underlying strata are properly assigned to the Dinwoody Formation.

The Dinwoody Formation in the Terrace Mountains is correlated with the Woodside Formation to the east on the basis of stratigraphic position and age. Kummel states (1954, p. 167) that the Dinwoody Formation in southeastern Idaho and the Woodside Formation at its type locality near Park City, Utah, have the same stratigraphic boundaries at their top and bottom, and that if the top of the Phosphoria is of the same age in southeastern Idaho as in northern Utah, the Woodside and Dinwoody Formations are probably time equivalents of each other and intertongue at their margins.

The presence of a few maroon shale beds in the *Lingula* zone of the Dinwoody in the Terrace Mountains suggests that thin tongues of the Woodside Formation may extend as far west as the study area. This would further suggest that the Terrace Mountain section lies on the western edge of the arcuate belt along which the Dinwoody and Woodside intertongue (Kummel, 1954).

Thaynes Formation

Definition and type locality. Boutwell (1907) first applied the name Thaynes to lower Triassic rocks exposed in Thaynes Canyon, Park City Mining District, Summit County, Utah. The formation was raised to group rank by Mansfield (1916), to comprise the Ross Fork limestone, the Fort Hall formation and the Portneuf limestone. Later, Kummel (1954), in differentiating seven lithologic units in the Fort Hall region of southeastern Idaho, rejected the names Ross Fork and Fort Hall, and incorporated the Portneuf Limestone and the Timothy Sandstone of Mansfield as members of the Thaynes Formation. His members include in ascending order: (a) Lower limestone, (b) lower black limestone, (c) tan silty limestone, (d) upper black limestone, (e) sandstone and limestone, (f) the Portneuf limestone member, and (g) the Timothy sandstone member. To the south, in the Bear Lake area, Kummel differentiated eight lithologic members, which group includes, among others changed from the Fort Hall area, a lower shale unit above the *Meekoceras* bearing lower limestone unit.

Distribution and exposure. The Thaynes Formation is exposed along the axial trace of the West Terrace syncline in secs. 31 and 32, T. 9 N., R. 12 W., where the surface outcrop area is approximately 1 square mile. Most exposures are poor but outcrops are present in dry washes cutting the west limb of the syncline and along the wave-cut terrace of the Provo level of Lake Bonneville.

Thickness and lithology. A 330-foot thickness of strata assigned to the Thaynes Formation is exposed in the West Terrace syncline. The upper contact is erosional, but is concealed by Quaternary sediments.

The lower contact is arbitrarily placed at the base of a 4-foot crystalline limestone bed, lithologically different from the subjacent Dinwoody and similar to overlying limestone beds, one of which 117 feet above, bears the *Meekoceras* fauna diagnostic of the Thaynes.

Thin-bedded silty limestone, similar to that of the Dinwoody *Claraia* zone, is present throughout the exposed section of Thaynes and makes up as much as 80 per cent of the rocks. The other 20 per cent is dark brown to gray bioclastic limestone similar to the lower *Meekoceras*-bearing limestone of the Thaynes Formation in other areas.

Measured section.

Section of the Thaynes Formation measured in
SE$\frac{1}{4}$ sec. 32, T. 9 N., R. 12 W., Utah.

Quaternary:

Surficial alluvium.

Angular unconformity

Triassic:

Thaynes Formation (incomplete):

UNIT	DESCRIPTION	THICKNESS (feet)
13.	*Concealed.* Float is dark-brown limestone	5
12.	*Shale,* calcareous, greenish-tan, weathers same. Brittle; fissile. Bedding surfaces have dendritic patterns of manganese oxide	70
11.	*Limestone,* brownish-gray, weathers dark brown. Upper part becomes platy and fissile; same color	3
10.	*Limestone,* yellow-tan, weathers lighter. Very thin-bedded; fissile; platy weathering	30
9.	*Concealed.* Float is limestone, medium- to dark-gray, weathers dark brown. Sandy and silty	17
8.	*Concealed.* Float is limestone, yellowish-tan. Very thin-	

bedded; platy weathering.. 28

7. *Limestone,* medium- to dark-gray, weathers dark brown. Poorly bedded; weathers into irregular wavy pieces. Exposure forms dark band.. 8

6. *Limestone,* greenish-yellow to tan, weathers same. Thin-bedded; platy weathering; current ripple-marked.............. 50

5. *Limestone,* bioclastic, brownish-gray, weathers dark brown. Considerable veining of white calcite. Fossils include *Dieneroceras* sp., *Paranannites* sp., *Meekoceras*? sp., and *Pseudosageceras*? sp. Preservation poor; very small exposure. Probably part of the "*Meekoceras*" zone. *Hindeodella* sp., *Hibbardella* sp., *Lonchodina* sp., *Spathognathodus* sp. and *Neoprioniodus bicuspidatus*.................................... 2

4. *Limestone,* silty, greenish-yellow to tan, weathers same. 116 Very thin-bedded; platy weathering. Current ripple-marked. Micaceous partings on bedding planes........................... 35

3. *Limestone,* medium-gray, weathers same. Brownish blebs and white crystalline calcite in veins. Irregular bedding. 81 Weathered surface rough, leaves no talus........................ 2

2. *Limestone,* greenish-yellow to tan, weathers same. Very thin-bedded; platy in part, shaley in part. Finely laminated. Very small scale ripple-marks. Fossils include casts that 79 are possibly ammonites, *Lingula borealis* (Bittner), undetermined pelecypod casts.. 75

1. *Limestone,* medium-gray, weathers same. Medium- to coarse-crystalline. Weathering surface rough. White calcite veining. Bedding irregular but resistant and well exposed... 4

Total thickness Thaynes Formation (incomplete).......... 329

Conformable contact

Triassic:

Dinwoody Formation.

Age and correlation. Unit 5 of the Thaynes Formation in the study are contains ammonites of the genera *Dieneroceras* sp., *Parannites* sp., and questionably of the genera *Meekoceras* sp. and *Pseudosageceras* sp. (Kummel, 1961, written communication), which genera are indicative of the *Meekoceras* zone of Smith (1932) or the Owenitan division of Spath

(1951), of Scythian age. The Terrace Mountains occurrence can be correlated by these fossils with *Meekoceras*-bearing strata elsewhere, an essentially world-wide correlation with the lower Triassic.

TERTIARY SYSTEM

Pliocene Series

Salt Lake Group

Definition. The name Salt Lake Group was first applied by Hayden (1869, p. 92) to Tertiary marls, sands, and sandstones in the Salt Lake and Weber Valleys. A comprehensive study of the group was recently made by L. W. Slentz (1955). In the studied area, deposits of Tertiary age are tentatively assigned to the Salt Lake Group on the basis of fossil content, lithology, and nature of occurrence.

Distribution and exposure. Deposits of the Salt Lake Group have been preserved on the east, south, and west sides of the western Terrace Mountains and in the Big Pass. The most extensive area of preservation is about one square mile in the embayment south of the eastern Terrace Mountains. Here, as at other occurrences of the Salt Lake Group in the mapped area that were covered by Lake Bonneville, the rocks are exposed only where streams have cut through the covering veneer of lake sediments and Quaternary alluvium. Exposures are, therefore, scattered, incomplete, and difficult to find.

Lithology and stratigraphic relationships. The Salt Lake Group comprises deposits of bentonitic clay, vitric tuff, and fresh-water limestone or marl. The bentonitic clay is a uniform brown, gray, or greenish-gray. Bedding in it is not discernable. The clay is found interbedded with marl and vitric tuff in two localities in the southern part of the Terrace Mountains.

The tuff is composed of fine- to medium-grained volcanic glass shards. It is gray-white, light- to medium-gray and buff, weathers to a slightly darker color. It is poorly indurated and friable. Much of the bedding in it is very indistinct and irregular. In some occurrences, where cross-bedding and scattered, rounded pebbles are present, the tuff appears to have been stream-deposited, but in most of the other deposits it is underlain by, or interbedded with, marl and was apparently deposited in a lake. This is further evidenced by some beds which have small-scale ripple-marks. Although each of the preserved tuff deposits is either fluviatile or lacustrine, the material was first probably a blanket deposit from ash falls over the entire area.

The marl is white to ivory or dark brown and gray, thin- to very thin-bedded, and well indurated. It is probably entirely of lacustrine origin. Most of it contains glass shards visible under a hand lens and some beds contain a sparse molluscan fauna.

The Salt Lake Group was apparently deposited on an irregular surface and has been preserved in only a few of the originally low places. This would indicate that a considerable amount of material has probably been eroded from the top of most, if not all, of the deposits, especially those covered by Lake Bonneville.

<u>Thickness</u>. Because contacts are irregular and not well-exposed, accurate thicknesses of the Salt Lake Group were not obtainable. The

preserved thickness of most deposits seems to be 20 to 30 feet, though several have greater thickness. A 190-foot thick sequence of interbedded brown bentonitic clays, conglomeratic marls, and tuffs is present in sec. 34, T. 8 N., R. 12 W. It has been tilted as much as 15 degrees to the north.

Age and correlation. Dwight Taylor identified the molluscan genera *Sphaerium* sp., *Bulimnea* sp., and *Planorbarius* sp. from white marl underlying tuff in the center E$\frac{1}{2}$SE$\frac{1}{4}$ sec. 19, T. 8 N., R. 11 W. (U.S.G.S. Cenozoic locality 23192). Taylor suggests (personal communication, 1962) that these fossils represent an assemblage which seems to range from early to middle Pliocene in many localities in southern Idaho and northern Utah.

On the basis of their age, as determined by mollusks, the Terrace Mountain deposits are correlated with the Camp Williams unit of Slentz (1955) and with the lower part of the Cache Valley Formation, with which latter formation the Terrace Mountain deposits are also lithologically similar.

The Salt Lake Group in the mapped area also corresponds lithologically to the tuff unit of the Salt Lake Formation as used by J. Stewart Williams (1962, p. 134) in southern Cache Valley. It seems significant that the tuff in both occurrences is underlain or associated with thin beds of buff to white fresh-water limestone.

QUATERNARY SYSTEM

Quaternary deposits are abundant in the study area. They comprise surficial alluvial deposits and colluvial scree and talus above the highest Lake Bonneville level. Below that shoreline, they comprise lacustrine Bonneville sediments, post-Bonneville fan deposits, lake-bottom clay and oolitic sand deposits, and minor eolian quartzose sand deposits. All of these are relatively unconsolidated except for some tufa-cemented conglomerate deposits of Lake Bonneville.

Deposits Above Bonneville Shoreline

Alluvial deposits. Alluvial deposits other than post-Bonneville fans occur abundantly only in the Big Pass and in an area south of Shelter Mountain Pass. The material of these deposits is largely derived from slope wash eroded from surrounding hills. Some alluvial material is ephemerally deposited along major streams, often as minor natural levees, but the amount is insignificant and the deposits were not mapped.

Colluvial deposits. Scree is usually present on slopes underlain by the Diamond Creek Sandstone, but is not restricted to that formation. Scree commonly fills gullies, as mentioned in connection with the Diamond Creek, and usually shows a color gradation from very dark at the base of a slope to light brown at the top where the blocks are more fresh.

Talus deposits are not abundant on other than cliffs formed from the Oquirrh Formation, but in those instances, deposits are large and outstanding. The best developed talus slopes are at the base of wave-cut cliffs along the east border of the eastern Terrace Mountains.

Deposits Below Highest Bonneville Shoreline

Lake Bonneville Group

General statement. Gravel, silt, diatomite, and clay deposits representative of the Alpine, Bonneville, and Provo Formations of the Lake Bonneville Group are present in the mapped area but were not differentiated. Future work on the lithologic and stratigraphic relationships and on the molluscan, ostracod, and diatom fossils of these deposits may provide basis for their differentiation in the study area.

Much has been written about the deposits of Lake Bonneville, and the reader is referred to U.S. Geological Survey Monograph 1 by G. K. Gilbert (1890) and to Professional Paper 257 by Hunt and others (1953) for specific information.

The lithologic character of Lake Bonneville sediments appear to depend largely on their location with respect to lake currents and sediment source. Thick gravel deposits were built up along shores where a large supply of detrital material was exposed to strong littoral currents, such as along the east slope of the eastern Terrace Mountains. The finer fractions bypassed or were washed out of these areas and were deposited in the more current-free embayments and behind current-restricting barriers. Although most of the material that filled in the lagoons behind the large bay-mouth bars at the Bonneville level was eroded from the alluvial cover in the range, the extreme fineness of some of the sediment suggests deposition from lake water spilling over the bars.

Distribution and exposure. Sediments deposited or modified by the waters of Lake Bonneville cover as much as three-quarters of the mapped area. Fine lacustrine sediments were deposited in all protected embayments below the highest lake level but are most abundant around the lower slopes of the ranges. Coarser sediments, mainly gravel, compose numerous current- and wave-built physiographic features in all parts of the study area that were covered by the lake.

Although lake sediments are at or near the surface wherever they occur in the area, very few stratigraphic sections of significant thickness are exposed. Stream erosion has dissected several large baymouth bars at the Bonneville shore line and has exposed limited sections of lake deposits below that level. The most complete, well-exposed section of sediments of the Lake Bonneville Group is in a small embayment on the southeast-facing slope of Kelton Butte, between the Stansbury and Provo shore lines, in the center E$\frac{1}{2}$SW$\frac{1}{4}$ sec. 13, T. 11 N., R. 12 W. (Fig. 11). This section was measured and described. It probably records a rise and fall of the lake indicated by the gravel units at the top and bottom.

Thick gravel deposits along the eastern side of the eastern Terrace Mountains have been partially dissected by torrential wash from the hills, but measurement of a complete section there was not possible.

A cut on the abandoned Southern Pacific Railroad in SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 33, T. 11 N., R. 12 W. provides an exposure of lacustrine conglomerate beds which are steeply inclined to the north, indicating that north-flowing currents swept across the bar (Fig. 12).

Measured section.

Section of the Lake Bonneville Group undifferentiated measured in
center E$\frac{1}{2}$SW$\frac{1}{4}$ sec. 13, T. 11 N., R. 12 W., Utah.

Erosional top

Quaternary:

Pleistocene:

Lake Bonneville Group (incomplete):

UNIT	DESCRIPTION	THICKNESS (feet)
5.	Gravel, silty. Dark-gray with buff silty matrix Fine- to medium-gravel. Medium sorting. No apparent fossils..	5+

Figure 11. Measured and described section of Lake Bonneville sediments on the southeast slope of Kelton Butte. Figure in right center gives scale.

Figure 12. Exposure of poorly indurated lacustrine conglomerate in a railroad cut through a bar at the Provo level of Lake Bonneville. View is to the northwest. Hills in background are capped by basalt flows of late Tertiary age. Road in foreground gives scale.

4. *Silt*, argillaceous. Buff to ivory white. Upper part more silty. Has high percentage of volcanic glass shards. Lower part more argillaceous. Slopes covered with gravel from overlying unit. Fossils include abundant ostracods (undet.), and sparse mollusca similar to those of unit 2.................. 28

3. *Silt*, argillaceous. Buff to ivory white, lighter overall than overlying unit. Very fine-grained. Indistinctly laminated. Abundant ostracods (undet.), sparse mollusca similar to those of unit 2... 23

2. *Silt* and *gravel*. Light-gray to buff. Argillaceous, calcareous. Very fine-grained silt with thin zones of gravel. Thin-bedded to lamellar. Ostracods and sparse mollusks throughout; one 6-inch thick bed of unconsolidated coquina composed of well-preserved mollusks, 17 feet above base of unit, includes *Fluminicola coloradoensis*, *Lymnaea bonnevillensis*, *Lymnaea* sp., *Valvata humeralis californica*, *Amnicola longinqua*, *Amnicola* sp., *Physa* sp., and *Pisidium compressum*, *Pisidium ferrugineum*.. 27

1. *Gravel*. Dark-gray. Medium- to fine; well rounded; well sorted. Thin-bedded to lamellar. Bedding steeply inclined toward basin, at an angle to bedding of overlying unit........ 9+

Total measured thickness Lake Bonneville Group (incomplete)........................... 92

Base concealed.

Bonneville fossils. In the interest of future investigation of Bonneville sediments, collections of mollusca and diatomaceous silt were made from the deposits whenever convenient. The mollusks were identified by Dwight Taylor of the U.S.G.S. and the diatoms by Anantha Setty in conjunction with his study of the diatoms of Lake Bonneville (Setty, 1963). Of the 126 diatom species found by Setty throughout the Bonneville Basin, 62 were present in the study area and three new species, *Surinella rostrata*, *Surinella rhomboides*, and *Surinella robusta*, named and described by Setty are only known, to date, from the mapped area.

Fauna and flora identified from the writer's collections are as follows:

Sample from Peplin Flats, center SW$\frac{1}{4}$ sec. 35, T. 11 N., R. 12 W., Elev. 4420 feet. A. P. Setty locality 9. Very fine white to buff silt, diatomite.

Ostracods: common - very thin-shelled, undet.

Diatoms: abundant -

Melosira granulata	R	*Gomphonema lalithaii*	R
Melosira varians	F	*Gomphonema naviculoides*	R
Cyclotella rotula	R	*Amphora ovalis*	F
Synedra pulchella	R	*Epithemia hyndmanii*	C
Rhoicosphenia curvata	R	*Epithemia argus*	C
Cocconeis lineata	A	*Epithemia zebra*	F
Navicula coarctata	F	*Nitzschia acicularia*	F
Navicula mormonorum	C	*Nitzschia linearis*	F
Navicula bohemica	C	*Denticula valida*	R
Navicula radiosa	C	*Surinella striatula*	F
Navicula brebissonii	R	*Surinella ovalis*	F
Navicula bombus	C	*Surinella ovata*	F
Navicula smithii	F	*Surinella utahensis*	F
Diploneis elliptica	F	*Surinella rostrata	F

Sample from Kelton Butte, center E$\frac{1}{2}$SE$\frac{1}{4}$ sec. 23, T. 11 N., R. 12 W. Elev. 4600 feet. U.S.G.S. Cenozoic local. 23195. A. P. Setty local. 10. Very fine silty and argillaceous material, light buff, soft and friable.

Ostracods: abundant, undet.

Mollusks: freshwater snails, rare -
cf. *Amnicola longinqua* Gould
Lymnaea bonnevillensis Call

Diatoms: abundant -

Melosira granulata	C	*Amphora proteus*	F
Melosira varians	R	*Epithemia hyndmanii*	R
Cocconeis lineata	F	*Epithemia argus*	C
Navicula bohemica	R	*Epithemia turgida*	C
Navicula bombus	F	*Epithemia zebra*	F
Navicula smithii	F	*Denticula valida*	F
Cymbella aspera	F	*Surinella striatula*	C
Cymbella turgida	F	*Surinella ovalis*	F

Sample from 100 feet below preceding sample. A. P. Setty local. 11.

Ostracods: abundant, undet.

Diatoms: abundant -

Melosira varians	F	Pleurosigma decorum	R
Fragilaria capucine	F	Cymbella turgida	C
Synedra pulchella	F	Cymbella tumida	F
Rhoicosphenia curvata	R	Amphora ovalis	F
Cocconeis lineata	C	Amphora proctus	F
Navicula bohemica	F	Epithemia hyndmanii	A
Navicula peregrina	F	Epithemia zebra	F
Navicula longa	F	Surinella striatula	F
Navicula impressa	F	Surinella ovalis	F
Navicula bombus	F	*Surinella rhomboides	F
Navicula smithii	F	*Surinella robusta	F
Pinnularia cardinalis	F		

Sample from northwest of Shelter Mountain, center W$\frac{1}{2}$NE$\frac{1}{4}$ sec. 8, T. 8 N., R. 12 W. Elev. 4950 feet. U.S.G.S. Cenozoic local. 23194, A. P. Setty local. 12. Medium silt, marly unconsolidated sediment, buff to gray.

Ostracods: abundant, undet.

Diatoms: generally rare -

Fragilaria capucine	R	Epithemia argus	A
Synedra lanceolata	R	Epithemia turgida	C
Cocconeis placentula	R	Epithemia zebra	A
Navicula bombus	R	Denticula lauta	R
Navicula smithii	R	Surinella striatula	R
Cymbella lanceolata	C	Surinella ovalis	C
Epithemia hyndmanii	A	Surinella regina	F

Sample from north of Tangent Peak, center E$\frac{1}{2}$NW$\frac{1}{4}$ sec. 11, T. 9 N., R. 12 W. Elev. 4820 feet. U.S.G.S. Cenozoic local. 23193, A. P. Setty local. 13. Fine silt, thinly laminated, white, overlain by thin gravel.

Ostracods: abundant, undet.

Mollusks: fresh water snails - common

Valvata humeralis
cf. Amnicola longinqua
Fluminicola coloradoensis
Lymnaea bonnevillensis
Physa sp.

Diatoms: abundant -

Melosira varians	A	Pinnularia viridis	F
Cyclotella striata	F	Cymbella turgida	A

Fragilaria capucina	C
Synedra pulchella	F
Cocconeis lineata	R
Navicula bohemica	C
Navicula radiosa	C
Navicula bombus	R
Navicula smithii	R

Cymbella tumida	F
Amphora hyalina	F
Amphora crassa	F
Epithemia hyndmanii	R
Surinella striatula	R
Surinella ovalis	F

Sample from southeast of western Terrace Mountains, NE$\frac{1}{4}$ sec. 32, T. 8 N., R. 11 W. Elev. 4800 feet. A. P. Setty local. 14. Fine, white, marly silt. White sediment shown in Fig. 14.

Ostracods: rare, undet.

Diatoms: generally rare -

Melosira varians	R
Melosira distans	R
Fragilaria capucina	R
Synedra lanceolata	R
Cocconeis placentula	R
Navicula acrospheria	F
Navicula dactylus	F
Navicula fischeri	F
Navicula radiosa	R
Navicula maculata	F
Navicula bombus	R
Navicula smithii	R
Diploneis interrupta	F

Campylodiscus hibernicus	R
Campylodiscus ehrenbergii	R
Surinella ovalis	F
Surinella striatula	F
Denticula valida	R
Cymbella turgida	C
Cymbella tumida	R
Amphora pellucida	F
Epithemia hyndmanii	A
Epithemia argus	A
Epithemia argus var. *alpestris*	F
Nitzschia punctata	R

Post-Bonneville fan deposits. Alluvial fans which post-date Lake Bonneville, also discussed briefly under geomorphology, are composed of fangravel and fansand (Blissenbach, 1954) derived both from hills above the Bonneville level and from Bonneville lacustrine sediments themselves. Although two periods of post-Bonneville fan building have been recognized elsewhere (Bissell, 1959, p. 182), they were not differentiated in the study area. Sets of braids and meanders older than those presently active are visible on the fan surfaces, but no attempt was made by the writer to separate stages of fan development.

Clay and sand deposits. Bottom clays of Lake Bonneville are present under a thin veneer of alkali salts and light-colored, surficial argillaceous material along the eastern and southwestern sides of the study area. The flats east of the study area are presently exposed above the Great Salt Lake water level, but would be flooded by a slight rise in the present lake. It has been postulated by Stifel and Stokes (1961) that an indefinite amount of material has been eroded from the clay surface in this area, so that the material now exposed may have been deposited at some earlier time than the Recent. Oolitic sand is abundant on the surface of the flats in some places.

Eolian deposits. Eolian dunes, composed largely of quartzose and oolitic sand, are present in the southern part of the study area, but are small and scattered and were not mapped.

IGNEOUS ROCKS

Intrusive Rocks

Dikes

Basic igneous dikes are exposed at two places in the study area. A single dike, isolated from surficial flows, trends east-west across the middle of the east Terrace Mountains ridge (center E$\frac{1}{2}$ sec. 29, T. 9 N., R. 12 W.). The dike is exposed for approximately 600 feet, is 10 feet wide at its widest place, and it dips 80-85 degrees to the south. Its western end intersects, and appears to cross a northwest-trending fault trace. Columnar jointing is slightly developed and is parallel to the dip of the dike.

The central part of the dike is olivine diabase, of subophitic texture, with phenocrysts of labradorite, augite, olivine and magnetite. Rock from the edge of the dike is fine-grained olivine basalt. It shows distinct flow banding and is of the same composition as the diabase. Olivine phenocrysts throughout the dike show marginal serpentinization.

Three dikes radiate from the south side of a basalt flow in the NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 30, T. 8 N., R. 12 W. They are fine-grained olivine-free basalt with phenocrysts of labradorite and augite and grains of magnetite; the same composition as the associated flow. A contact was not exposed between the dikes and the overlying flow, but the proximity of the two leaves no doubt that the dikes are related to, and probably feeders of the flow.

The age of the dikes is uncertain, but it is assumed that they are contemporaneous with surficial flows of late Tertiary age with which flows they are closely associated.

Extrusive Rocks

Basalt Flows

Surficial basalt flows are extensive in the northern part of the study area, covering about 11 square miles there (see Plate 1). To the south, in the Big Pass, a flow covers slightly less than one quarter square mile in the middle of the western side of the pass, and several small flows eminate from vents along the Big Pass fault near its southeast end. In addition to these, three flows, covering less than one-half square mile, are present on the southwestern side of the Terrace Mountains.

The flows in the studied area may be divided on the basis of olivine content into a tholeiitic or olivine-free group comprising those flows at the north end and in the southwest part of the area, and into an olivine-bearing group comprising those flows (and the dike) which occur in the vicinity of the Big Pass. There is little difference in these groups other than the amount of olivine present. In all cases, the rock is fine-grained with phenocrysts of labradorite and glomerophorphyritic augite and grains of magnetite in a fine intergranular ground mass.

In places in the northern part of the area, three stratified flows are distinguishable. They are all scoriaceous, the uppermost flow in particular. The fine magnetite in the uppermost flow has weathered, coloring the rock red-brown. A flow which caps a small butte three miles southwest of Kelton is more than 40 feet thick. The base of the flow is concealed by lacustrine tufa and scree blocks so that complete measurement is impossible. The upper surface of this flow dips two degrees to the south, and vesicular elongation and flow marks are alligned S. 20° E. Like the other flows in the northern part of the area, this one is part of a group probably originating at the eastern end of the Raft River Mountains 12 miles to the north.

Proctor and Bullock (1963) suggest a late Tertiary (Pliocene) age for the basalts exposed south of the Raft River Mountains, with which these flows are included.

Flows in the Big Pass are scoriaceous and are brecciated near the vents from which they emanated. Some are of porphyritic texture, and some are of intercertal texture with a glassy groundmass.

One of several small flows in the center sec. 17, T. 8 N., R. 11 W. which is closely associated with fresh-water marls of the Salt Lake Group is amygdaloidal, the vesicles being filled with secondary calcite. This flow may underlie deposits of the Salt Lake Group and therefore predate them, although exposures are very limited, and stratigraphic relationships are not clear. On the other hand, the Big Pass flows eminate from and apparently postdate faults, which in turn appear to have had displacement in the Pliocene because of their involvement with the Salt Lake Group sediments. Thus the faulting and emission of basalt are probably penecontemporaneous or closely related.

Welded Tuff

An exposure of rhyodacitic welded tuff covering about one-half square mile is present in sec. 12, T. 11 N., R. 12 W., four miles southwest of Kelton. The unweathered rock is mottled ivory buff and gray brown; is of well-developed vitroclastic texture; and is composed of quartz, sanadine, and oligoclase phenocrysts, in that order of abundance, in a groundmass of glass shards. Accessory biotite, hornblende, and magnetite are also present. The glass shards are partially devitrified, and the biotite is partially weathered to hematite.

The tuff is largely weathered to bentonite clay of mixed montmorillonite which is mostly green with some weathering gray and red. The expansive nature of the clay produces characteristic "popcorn" weathering on the surface of the bentonite. Mining of this material is discussed under economic geology.

STRUCTURAL GEOLOGY

General Statement

The eastern and western Terrace Mountains comprise two westerly tilted fault blocks, with outlying hills to the north and south including the Hogup Mountains, Crocodile Mountain, Kelton Butte, and others. The mountains are characterized, as are many of the surrounding ranges, by an abundance of faults and relatively few folds. Thrust faults were not discovered in the area, and minor overturning of strata is not structurally significant. High-angle reverse faults may be present, but stratigraphic exposures are not sufficiently definitive to separate them from the abundant high-angle normal faults.

Western Terrace Mountains Block

The western Terrace Mountains block, 13 miles long and 8 miles wide, is divided by the northeast trending outcrop belt of the Loray? Formation into eastern and western sides which are strikingly different structurally. Strata on the eastern side dip homoclinally, 35 to 40 degrees to the west and to the northwest. The eastern side of the block is very little faulted or folded in contrast to the western side which, though also only slightly folded, is considerably faulted. The faults in the western Terrace Mountains block can be grouped into a major north-south trending system, an east-west trending system of lesser importance, and a limited group of small arcuate faults with rotational movement. Three broad, open folds are present in the block.

Faults of the North-South System

Terrace Fault. The Terrace fault can be traced by the expression of its scarp for more than a mile along the east side of the western block south of the Big Pass. It probably extends further to the south as well as to the north under alluvium in the Big Pass. The fault appears to be normal, with the eastern side upthrown, although the relationship is difficult to determine because the fault trends nearly parallel to the strike of the enclosing strata. Several large masses of siliceous breccia are present about 200 feet west of the fault trace, but they do not seem to indicate a second fault and have no obvious relationship to the Terrace fault.

West Terrace Fault. The West Terrace fault is one of two large normal faults which extend for about seven miles along the west side of the block from its northern end to the vicinity of Shelter Mountain Pass. The east side is relatively upthrown, and the fault plane dips westerly at a high angle, as is indicated by its nearly straight trace. Outcrops are rare along the fault, especially on the downthrown western side which is composed of the Rex Chert throughout nearly the entire length of the fault. Although the Rex on the west side is opposed by Grandeur, Meade Peak and Rex on the east side, the amount of displacement is difficult to determine because of rotation of blocks on the east side. The fault was apparently active as recently as the Pliocene because its scarp has slight topographic expression, and vitric tuff deposits of the Salt Lake Group are preserved against the scarp on the downthrown side.

Shelter Mountain Fault. The Shelter Mountain fault is similar to, and probably related to, the West Terrace fault and extends parallel to it about half a mile to the west. Displacement is on the order of 400 feet where the fault passes through Shelter Mountain Pass, and relative displacement is down on the western side and up on the eastern side. Throughout most of its length the fault opposes Triassic and Rex on the west against Gerster and Rex on the east. The Shelter Mountain fault is assumed to be contemporaneous with the West Terrace fault. It has had movement along it since the Pliocene, as evidenced by the preservation of sediments of the Salt Lake Group along its scarp on the downthrown side.

Minor North-South Faults. Short faults of the north-south system are present on both limbs of the West Terrace syncline. They are most abundant on the eastern limb, especially on and to the south of Shelter Mountain. Most of them are of small displacement, but one in secs. 30 and 31 T. 8 N., R. 12 W. on the west limb of the syncline has an apparent throw of 2500 feet, with the western side relatively downthrown. Evidence for the amount of throw is displacement of the contact between the Rex Chert and the Gerster Formation. Most of the faults in the north-south system on the western side of the range are relatively downthrown on the west. An exception to this is present on the west slope of Tangent Peak where a normal fault of small displacement dips easterly and is relatively upthrown on the west.

Faults of the East-West System

West Shelter Fault. The West Shelter fault is the only one of more than 15 faults of the east-west system that has large throw and that has been given a name. It courses northwest from south of Shelter Mountain, across the axis of the West Terrace syncline, and is entirely concealed by alluvium and lake deposits. Its presence is indicated by an 1800-foot displacement of the Permian-Triassic contact on the axis of the West Terrace syncline relatively down to the south and by the rotation of the southern block so that it is tilted to the west. This fault apparently postdates the Shelter Mountain fault against which its eastern end terminates abruptly.

Minor East-West Faults. The axis of the syncline is displaced again by a smaller fault three miles south of the West Shelter fault. There the north side has been relatively downthrown and rotated to the west. The north side is the southern end of the block mentioned above.

In the northern part of the syncline (secs. 32 and 33, T. 9 N., R. 12 W.) the axis is offset laterally about a mile and a half to the east, north of an east-west trending fault. Displacement of the axis is apparently due to a combination of rotation and movement on the north-south trending Shelter Mountain fault. No lateral movement is indicated along the east-west fault as its eastern end terminates abruptly against the Shelter Mountain fault at an 80-degree angle.

Displacement on a similar fault a mile further to the north has opposed the Triassic Dinwoody Formation on the south to the Rex Chert on the north. The block north of this fault comprises only easterly dipping strata apparently representing the west limb of the West Terrace syncline. The east limb has apparently been omitted by displacement on the Shelter Mountain and West Terrace faults.

Faults of the Arcuate Rotational Group

Unnamed faults. This group comprises three unnamed normal faults of large displacement and the minor splinter or branch faults that are related to them. The major faults, equally spaced, are each slightly more than a mile apart, and the northernmost is one half mile south of Tangent Peak. The two more northerly faults are about three miles long and the southernmost is about two miles long. The fault traces are arcuate, concave to the south. The western ends trend slightly north of due west and terminate abruptly against the West Terrace fault, at nearly right angles to it. The eastern ends terminate in the outcrop belt of the Loray? Formation on the east side of the western Terrace Mountains drainage divide, and there they trend slightly west of north, approaching the direction of strike of beds in the Loray? Formation.

The fault planes dip to the south at high angles, probably greater than 75 degrees, and the southern side of each fault is down relative to the northern side, with greatest displacements at the western termini. The base of the Meade Peak provides a useful datum for determination of displacement near the middle of each fault, and in that part, the northernmost fault has an apparent displacement of 600-800 feet, the middle fault an apparent displacement of 2700-3000 feet, and the southernmost an apparent displacement of 900-1000 feet.

The northernmost of these three faults bifurcates near its eastern end, and the middle fault is actually a set, two faults whose adjacent ends are parallel, a quarter of a mile apart, and which overlap for almost a mile. The southernmost fault is single, with a minor branch fault to the south which meets it at about 70 degrees near the middle.

A quarter of a mile north of the middle fault is a minor east-west trending fault, whose plane dips to the north and is slightly concave in that direction. The fault cuts out the Meade Peak near its western end where it meets the West Terrace fault. It drops Rex Chert relatively down on the north, against Grandeur beds to the south, in small scale displacement opposite to that of the major arcuate faults.

Tangent Peak Fault. The Tangent Peak fault is similar to the arcuate faults described above. It courses around the southeastern side of Tangent Peak, and its southern end terminates against the northernmost of the previously described faults at a 50-degree angle. It is arcuate itself, is concave to the northwest and dips at a high angle, probably 80 degrees or more, in that direction. Its southern end is of small displacement, probably less that 100 feet because it only slightly thins the Meade Peak section by lowering the northwestern block with respect to the southeastern. The relation of this fault to others bordering the western edge of the Big Pass is uncertain. Its northern end serves as a border fault, with the Tangent Peak block dropped relatively down on the west.

Another fault, possibly related to the East Terrace fault, terminates against the middle of the Tangent Peak fault. It may have dropped the Big Pass block relatively down on the east and although the attitude of its plane is indeterminable, it dips at a high angle, as evidenced by its straight trace, and it is of reverse nature if the plane dips to the southwest.

Folds

West Terrace Syncline. A broad open synclinal fold, named the West Terrace syncline, extends for more than 10 miles along the western edge of the western Terrace Mountains. The axis of this fold, which traces a sinuous north-south course, is horizontal or plunges 10-15 degrees to the north, with the exception of the extreme southern end which plunges at a similar angle to the south. The axis of the fold is faulted in several places as mentioned above, and is offset to the east in the northern part of the structure. At the northern end of the syncline only the western limb of the fold is expressed.

This syncline may reflect the earliest structural deformation in the area. The axis has apparently been warped near the middle by the east-west trending Scorpio Peak anticline and has been displaced by later faulting. The syncline is of importance stratigraphically, not only for the good exposures along its western limb, but also for its preservation of Triassic strata in the northern part. Were it not for this structure, it is not likely that the Triassic rocks would have been preserved from erosion.

Tangent Peak Syncline. The Tangent Peak syncline, on which Tangent Peak is formed, is a broad fold, best developed on the northern end of the western Terrace Mountains, but reflected slightly in the successive fault blocks to the south. In the northernmost block the axis plunges north at 15-20 degrees and is apparently intersected by the Tangent Peak fault, or a related one, under the lacustrine sediments north of Tangent Peak.

The anticlinal flexure which would be expected between the West Terrace and Tangent Peak synclines has apparently been omitted by movement on the Shelter Mountain and West Terrace faults, although the relationship between the two synclines is not clear because of lack of bedrock exposures.

Scorpio Peak Anticline. A broad, sinuous, east-west trending anticlinal flexure is present in the southern part of the western Terrace Mountains block in the vicinity of Scorpio Peak, for which peak the structure was named. The axis plunges at an angle of 35-45 degrees to the west. The fold encompasses strata of the Wolfcampian Series of the Oquirrh Formation, the Diamond Creek, the Loray?, and the Grandeur. Laminated siliceous limestone units of the Oquirrh near the core of the flexure (sec. 24, T. 8 N., R. 12 W.) are compressed into sharp chevron folds (Fig. 13), and beds of the Loray? and Grandeur at the western end of the axial trace have joints which are slightly open due to tension. Because of tilting of the western Terrace Mountains block and erosion of the block to its present topography, surficial expression of the fold is that of a transverse section at about 45 degrees to the plunge of the axis.

Two minor flexures related to the Scorpio Peak anticline are present on the south flank of the larger fold. Their axes also plunge steeply to the west parallel to the axis of the Scorpio Peak anticline. They comprise a small anticline and complementary syncline which may correspond to two similar folds in a group of small hills a mile to the east, although they are not directly correlated with them because of lack of bedrock exposures in the intervening area.

Eastern Terrace Mountains Block

The eastern Terrace Mountains block is much less complicated structurally than the western block. It comprises uniformly northwesterly dipping strata of the Oquirrh and Diamond Creek Formations in the southern part, and complexly folded strata of these two formations and the Loray? Formation in the northern part, in which part the Hogup Mountains are included.

Faults

Big Pass Fault. The eastern Terrace Mountains structural block is

Figure 13. Right-angle chevron folds in the Wolfcampian Series of the Oquirrh Formation, near axial trace and core of Scorpio Mountain anticline in the southern part of the western Terrace Mountains. View is to the northwest.

defined along its west side by an apparently high angle, westerly-dipping normal fault named the Big Pass fault, whose nearly straight scarp courses for six miles along that side of the block. Its southern end may continue to the south under cover of lake sediments, and its northern end probably extends to the northwest under lake sediments.

Some displacement probably took place along the fault since the Pliocene as evidenced by sediments of that age preserved along its scarp, although major movement apparently occurred prior to that time. Late Tertiary basalt flows eminated from the fault zone at three vents near the southern end of the fault, the lava apparently having followed the fault plane to the surface. A similar basalt flow on the west side of the Big Pass also appears to originate from a fault trace, apparently a branch of the East Terrace fault or a related one.

East Border Fault. It is postulated that, because of the linearity of the eastern edge of the range, a fault of large displacement borders the eastern Terrace and the Hogup Mountains along that side, probably east of the improved road that follows the edge of the lake flats. Dr. Kenneth Cook (personal communication) agreed with the writer on the probability that a fault of large displacement is present in this vicinity because of the linearity of the range front, but he mentioned that a limited gravity survey indicates that unconsolidated material is less than 500 feet thick on the edge of the flats east of the Hogup Mountains, and further, that if a fault is present there, it has displaced bedrock against bedrock and would not be detected by a gravity survey. Because there is no direct evidence of the position of this fault, it is not shown on Plate I.

Minor Faults. Several minor faults trend northwest, parallel to the ridge and to the Big Pass fault, in the eastern Terrace Mountains. These appear to be of small displacement, to be very high angle or vertical because of their straight traces, and to have had movement along them since the Pliocene because their scarps have topographic expression. Two may be high angle reverse faults as they appear to be relatively upthrown on the west side, in contrast to the majority which are relatively downthrown on the west. Their fault planes dip at a very high angle but appear to dip to the west in harmony with those of the other faults.

Folds

Numerous small folds or buckles are present in the Hogup Mountains. Axes of both the anticlines and synclines trend northeast-southwest and plunge 15-25 degrees to the northwest. The folds are separated into three groups. The axes are evenly spaced about 700 feet apart in each group, and intervening beds dip steeply.

The smaller flexures are superposed on a larger, poorly defined synclinal fold which terminates the uniform northwesterly dip of strata in the eastern Terrace Mountains to the south.

Structure of Outlying Areas

Crocodile Mountain. The landmass herein called Crocodile Mountain is folded complexly and faulted to a lesser degree. Structural interpretation is difficult because of lack of exposures of bedrock. At the southern end of the mountain, rocks of the Permian Oquirrh Formation are folded on northeast-southwest trending axes, with the strata dipping steeply northwest and southeast.

Beds of the Virgilian Series of the Oquirrh Formation dip uniformly

10-20 degrees to the east on the northern half of the mountain, and are separated from strata of Wolfcampian age to the south by a concealed fault on which rotational movement took place. Small bedrock outcrops are separated here by almost one half mile of lacustrine sediments, so the exact position of the intervening fault can only be postulated.

Because of its linear western margin, a fault is postulated to border the western side of Crocodile Mountain under lacustrine sediments.

Kelton Butte. Structural interpretation on Kelton Butte is made difficult by the uniformity of lithology of the Virgilian and Wolfcampian Oquirrh Formation of which the butte is composed. Bedrock exposures are limited to the steep southeast-facing slope, the northwest side being concealed by lacustrine gravel. The butte is crossed by four north-trending faults, all of uncertain displacement, and the trace of a northwesterly trending anticlinal axis crosses the butte near its middle. Minor folding on north-south axes is present on both sides of the larger fold.

Hills South of the Terrace Mountains. Four groups of hills with exposed bedrock extend 12 miles southeast from the western Terrace Mountains to the southern end of the mapped area. Structures in the northernmost group, mainly in secs. 17 and 18, T. 7 N., R. 11 W., are anomalous to the structural attitude of strata extending to the south from the western Terrace Mountains block, giving evidence to the postulation that a concealed fault along the west side of the hills is responsible for the remarkable linearity of that western edge. Also, a northeasterly trending fault is present on the eastern slope of a small group of hills two miles to the north, in sec. 32, T. 8 N., R. 11 W., which fault may be, or may be related to, a more northerly part of this postulated border fault. That displacement has taken place on this northern fault in Pleistocene time is evidenced by the preservation of fine lacustrine sediments on the relatively downthrown western side (Fig. 14), but the amount of pre-Pleistocene movement, if any, is not determinable.

Similar linearity of the southwestern side of the next group of hills to the south, those mostly in sec. 33, T. 7 N., R. 11 W., suggests the probability of a concealed fault along that border also. Brecciation and disorganized attitudes on several small exposures around Hogup Siding to the south further suggest the presence of this fault and that it extends to the southwest. The hills are formed on a fault block composed of steeply northwest dipping strata of Virgilian and Wolfcampian age Oquirrh Formation.

A north-trending fault, apparently of small displacement, borders the eastern side of the southernmost group of hills, and a concealed fault may also border the western side, although there is little evidence for one other than the linearity of the border.

Preliminary gravity studies show that northwest-trending faults of large displacement are present under the mud flats on both sides of these southernmost hills, but the faults are as many as three miles east and west of the bedrock exposures (Kenneth Cook, personal communication). Dr. Cook explained to the writer that the structure on the west side lay between the hills south of Hogup Siding and the small bedrock exposures six miles south of Allen Siding on the Southern Pacific Railroad in sec. 34. T. 6 N., R. 12 W. This structure is a graben, which trends northwest, but which dies out before reaching as far north as the railroad. Dr. Cook further mentioned (personal communication) that bedrock was not far beneath the surface in the area between the northern New-

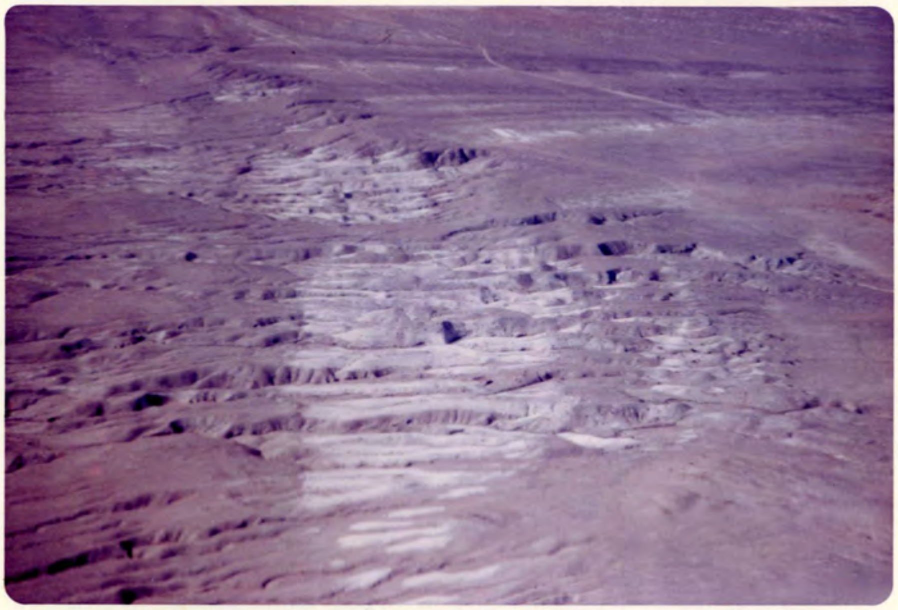


Figure 14. Oblique aerial photograph, looking southwest along a fault trace in sec. 32, T. 8 N., R. 11 W., showing Bonneville sediments preserved on the downthrown, uphill side of the fault (to the right).

foundland Range and the Terrace Mountains and that unconsolidated sediment was also shallow in the desert immediately west of the Terrace Mountains, indicating that a border fault of large displacement was not likely to be present there.

Structures in Unconsolidated Sediments

Preliminary investigation has disclosed two types of sedimentary structures developed in unconsolidated sediments related to Lake Bonneville.

Tension fractures. An isolated set of polygonal tension fractures has developed from the desiccation of fine lacustrine sediments in the northwestern part of the mapped area (W$\frac{1}{2}$ sec. 31, T. 11 N., R. 12 W.) (Fig. 15). The larger cells are about 300 feet in diameter, the smaller about 100 feet. Hexagonal, pentagonal, and orthogonal (rectangular) cells are present, developed from both triradial and biradial systems (Christiansen, 1963). The pattern of the fracture system is discernable because of more dense vegetation growing over the cracks. The fissures must either serve to store water or, as Christiansen suggests (oral communication), the sediments filling them may have higher capillarity than the enclosing beds, providing additional moisture for vegetation. Further investigation of these structures by trenching and coring might reveal the depth of the fissures and the nature of their formation and filling.

Depression structures. The second type of structures, previously described by Stifel and Stokes (1961, p. 131), is a group of distinct hemispheric depressions in the green bottom clay marginal to the Great Salt Lake between Dolphin Island and the eastern Terrace Mountains. The

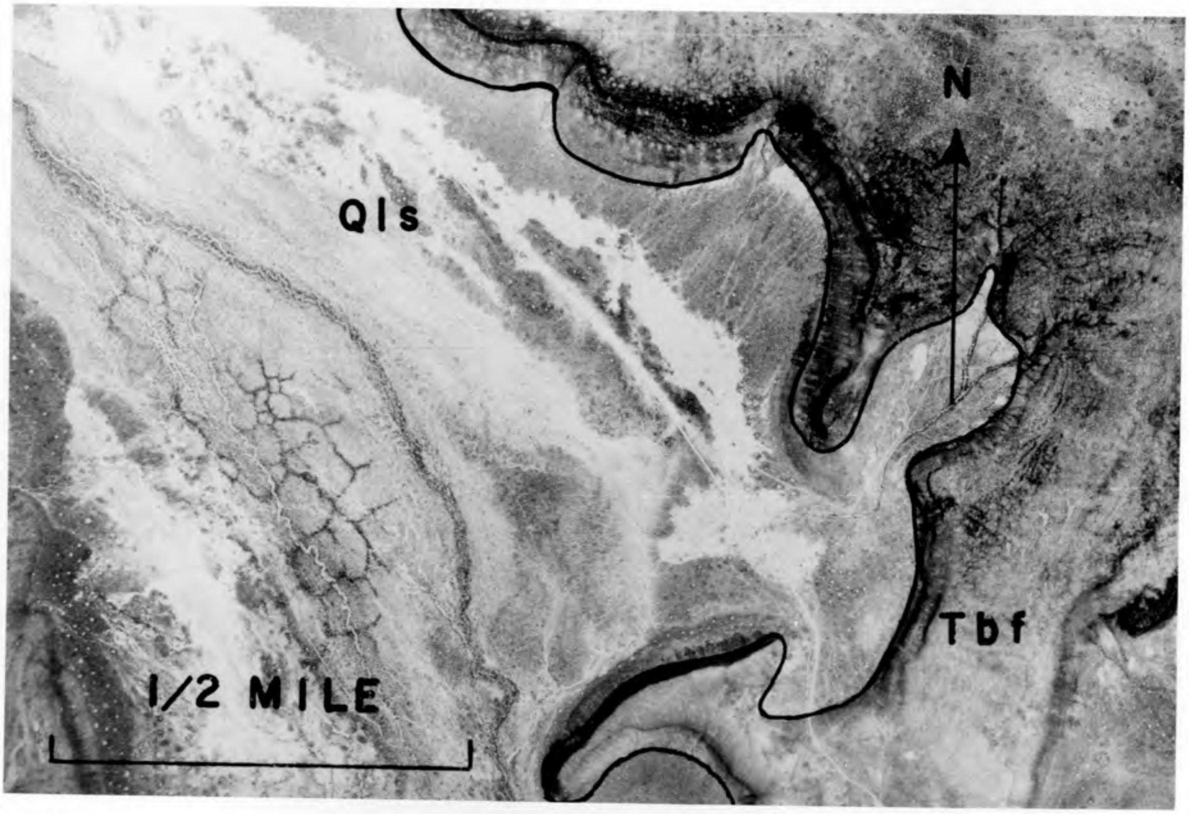


Figure 15. Vertical aerial photograph showing polygonal fractures developed in Lake Bonneville sediments in the northwestern part of the mapped area. Qls, Quaternary lake sediments; Tbf, Tertiary basalt flows.

depressions enclose concentric layers of gypsum crystals, white clay, and oolites (Fig. 16), which layers have been truncated by the horizontal plane of the clay-flat surface, on which surface the structures have circular, oval, or "dumbell" shaped outlines. Average surface diameter of the structures is approximately 6 feet, average depth 2 feet, and average separation 6 inches to several feet. Although in some places two structures intersect each other, the individual forms are very distinct and appear to have little influence on each other.

It was proposed by Stifel and Stokes (1961, p. 131) that the filling layers were originally a horizontal tabular body of gypsum and oolite beds which, after deposition, subsided locally with relatively little deformation. The clastic filling layers are of remarkably uniform thickness and show little or no lenticulation, indicating that they were probably at one time horizontally stratified at a level above the present erosional surface of the mud flats. The fact that the structures presently contain as much as 3 feet of filling material suggests that the entire system may have originally been on the order of 5-10 feet thick. Three to four feet of oolites and gypsum and 1-2 feet of clay have probably been removed from above the present surface. The stratified filling layers intersect the present surface at high angles (as much as 70-80 degrees), indicating the erosion of considerable overlying material since formation of the structures (Fig. 16). The outermost of the clastic filling layers is a tan, gray or greenish oolite zone, 1-2 inches thick. Inside or above it are beds of gypsum crystals mixed with white clay and oolites. This zone, 2-5 inches thick, is strikingly white and relatively competant, though very porous. It is filled in turn with concentric tan beds of oolites. Black pebbles of limestone and chert, moved across the flats by sheet wash, are caught on the structures by layers differentially resistant to erosion and slightly topographically high as a result, producing remarkably distinct concentric rings on the surface of each structure (Fig. 17).

Two cores, which reached depths of 8 and 16 feet, were taken from areas between depression structures. The interval of the cores between 3 and 10 feet below the present surface gave very incomplete cores due to high brine content, possibly indicating that a zone of salt may have been present in this interval. The major part of each core was composed of relatively uniform dark green clay, in places brown from organic material, and occasional thin zones of quartzose silt and oolites. A single shallow trench dug between two structures revealed that a silty bed extended horizontally across the interval, indicating that no deformation had taken place in the intervening clay, an important factor in consideration of proposed causes of formation of the structures.

Although not thought by the writer to be directly related to the depression structures, beds of clay, gypsum crystals, and oolites show evidence of penecontemporaneous slumping and irregular distortion in an area between the above described depression structures and gravel bars marking the former shoreline of the lake. These thin beds, slightly more resistant to erosion than the surrounding clay flats, dip at high angles and stand up an inch or two above the flats as low, sinuous and usually discontinuous ridges or miniature hogbacks. Erosional planation of the surface and a cover of alluvial gravel have largely obscured the structures, however, and investigation of them other than shallow trenching has not

Figure 16. Vertically sectioned depression structure on the clay flats between Dolphin Island and the eastern Terrace Mountains. Depression in green clay encloses concentric layers of white clay, gypsum crystals, and oolites.

Figure 17. Circular surficial expression of depression structures. View is to the southeast, Lakeside Mountains on the right horizon, Gunnison Island on the left horizon.

yet been carried out.

Planation of both the slump and the depression structures is attributed to the isostatic uplift of the region in post-Bonneville time (Crittenden, 1963) but their origin or origins are uncertain. The irregular distortions may be due to slumping by gravity sliding, although lakeward slope of the present surface is almost imperceptible. However, as strong earthquakes have occurred in Hansel Valley, a short distance to the northeast, in historical time (1934), similar quakes in the past may have triggered slumping in the surficial sediments.

The depression structures are present in an area of less than a square mile at this northern locality, but structures of somewhat similar nature and probably similar origin are present 18 miles to the southeast near Lakeside, and also within the Terrace-Lakeside threshold in T. 6 N., R. 10 W., south of the Southern Pacific railroad tracks. At the latter locality, brief investigation disclosed that beds near the surface were also composed of oolites, gypsum, and clay similar to those in the described area to the north, but here, distortion of the beds was more irregular. In most places, an upper bed of gypsum and clay was found to overlie layers of oolites and lower layers of gypsum crystals.

The internal structure of two trenched forms in this area was that of a truncated dome, the beds having quaquaversal dip from the center. The entire structures were upside down compared to those to the north. The surficial expression of the distorted beds is usually irregular, shapes being circular, oval, very elongate oval, and roughly linear. In some places circular structures are alligned in north-south trending rows. Further trenching of these structures and intervening areas may help explain their origin.

Hypotheses for the origin of the northern group of depression or ring structures suggested by and to the writer include: (1) synclinal depressions between mud volcanoes similar to those in the Gulf of California (Dorsey Hager, oral communication); (2) buckling, contorting or folding sediments on the clay flats; (3) deformation due to expanding clay minerals; (4) deformation due to ice blocks rafted to the area (Dorsey Hager, oral communication); (5) desiccation cracks widened by repeated freezing and filling (Dorsey Hager, written communication); (6) subsidence due to local solution of an underlying salt bed or interval; (7) local subsidence of an originally tabular gypsum and oolite interval due to its greater density than the underlying clay beds, the plastic clay being squeezed up between the centers of subsidence (A. J. Eardley, personal communication); and (8), deformation due to gypsum crystal growth (J. F. Shroder, personal communication). Unfortunately, most of the above proposals have been proven by the writer to be highly unlikely. It is hoped that planned future research may disclose the process or processes that were responsible for the formation of these structures.

GEOMORPHOLOGY

General Statement

Geomorphic features in the mapped area, other than those produced by Lake Bonneville, reflect the semi-arid conditions under which they formed. It is probable that most of the major drainage was established during the late Cenozoic uplifting of the mountains. At present, a few streams may flow for short periods from spring meltwater, but other than this seasonal runoff, the only stream flow in the area is from the relatively rare torrential rains.

Structure and lithology have affected topographic development to some degree in the mapped area, but it was Lake Bonneville that impressed the most striking geomorphic features on the region.

Peplin Mountain

Peplin Mountain, in the northwestern corner of the mapped area, consists of four small, nearly circular knolls which rise less than 200 feet above the Bonneville shoreline. Their topography is in a stage of late youth to early maturity, and each exhibits a marked radial drainage pattern (Fig. 18a). The relatively homogeneous siltstone and limestone of which they are formed seems to have had little or no influence on the topography.

The remainder of the mapped area north of the Hogup Mountains was covered and modified by Lake Bonneville and will be discussed under that heading.

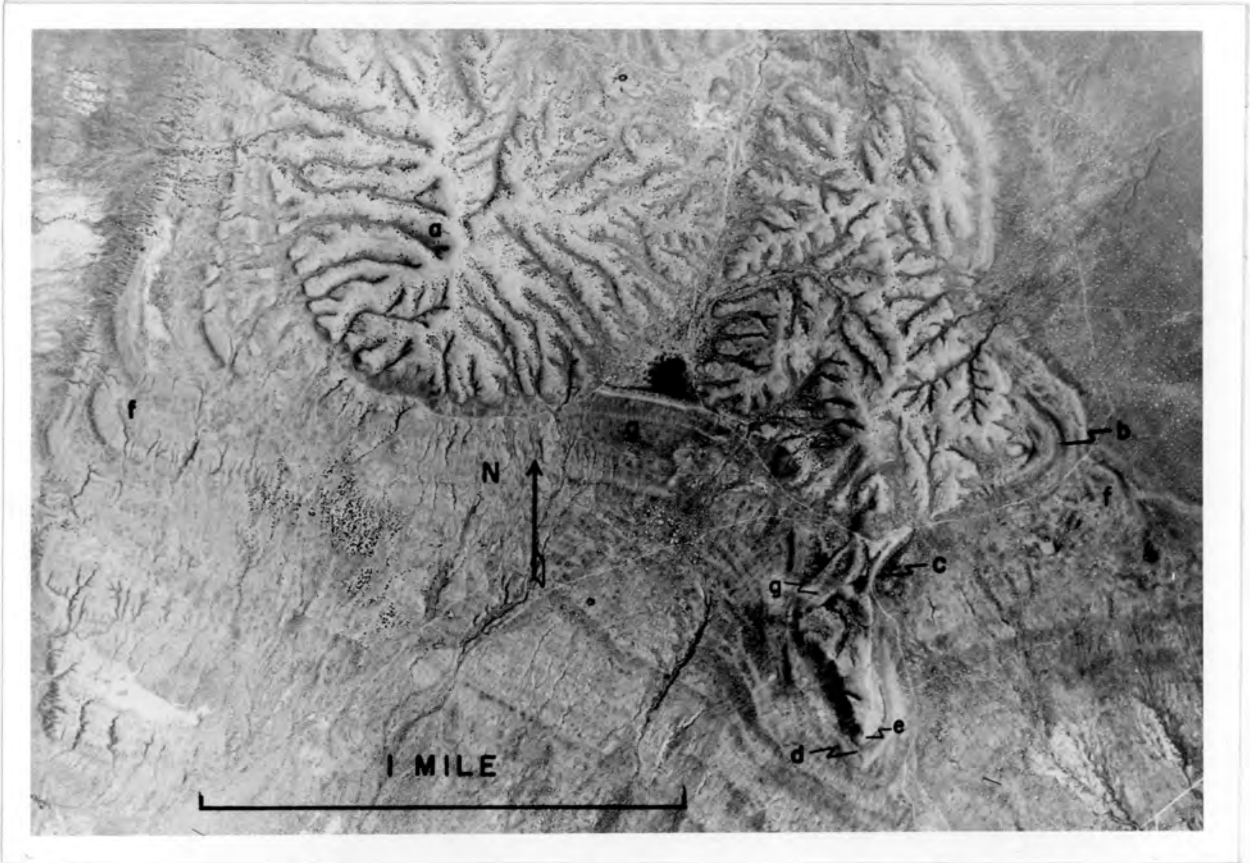


Figure 18. Vertical aerial photograph of Peplin Mountain showing: (a) development of radial drainage; (b) a cuspate bar at the Bonneville shore line: (c) a small tombolo; (d) a wave-cut terrace at the Bonneville shore line; (e) a sea-cliff; (f) cuspate forelands; and (g) bay-mouth bars.

Hogup Mountains

The Hogup Mountains comprise two low hills north of the eastern Terrace Mountains. The northernmost of the two hills was an island during the Bonneville stage of the lake, at which time the Hogup Spit was built from it to the south. The second hill, actually a small group of knolls, was connected as a tombolo to the northern end of the main ridge at the Bonneville level.

Eastern Terrace Mountains

The eastern Terrace Mountains comprise a single structural block. The block has a main slightly northwest trending ridge which is composed of uniformly northwest dipping strata of the Permian Oquirrh Formation and Diamond Creek Sandstone. The block is outlined by the Big Pass fault on the west and the wide Bonneville terrace on the east. The linear eastern border of the range is probably due to a major fault or fault zone, but neither the position nor actual existence of such a fault is demonstrable with available information.

Topography of the eastern Terrace Mountains is in the early mature stage, with well integrated drainage, sharp divides, and high relief. All surfaces are very steeply sloping. Most of the drainage is in a youthful stage and shows suggestions of lateral erosion or flood plain development only at the mouths of a few canyons in the northern part. Ephemeral gully development along the streams on the steeper eastern side of the ridge has produced a small scale pinnate drainage pattern (Fig. 20h). The major drainage, of poorly defined dendritic type, is divided east and west by the sharp ridge line of the structural block.

The ridge is straight in places but is angularly zig-zag over most of its length.

Western Terrace Mountains

The area of the western Terrace Mountains above the Bonneville shoreline is part of an elongate tilted block, roughly rectangular in outline, with a median drainage divide and a peak near either end; Tangent Peak at the north and Scorpio Peak at the south. The eastern slope of the western Terrace Mountains is underlain mainly by uniformly northwest dipping sandstones and limestones of the Oquirrh, Diamond Creek, and Loray? Formations, and has a well developed dendritic drainage pattern. Relative to that of the eastern Terrace Mountains, the topography is slightly subdued, and the dendritic stream pattern is finer, much better developed, and shows some structural control in places.

Although the higher parts of the western slope are similar topographically to those of the eastern slope, the several north-south border faults, the major east-west faults and the northwestern dip of the strata combine to somewhat alter the topography of the lower western slopes.

Major drainage is sub-parallel and gullied where bedrock has been faulted down and buried by alluvium to the extent that exposures are rare. The almost dip-slope nature of parts of the western side of the range has produced finer and more nearly parallel drainage than would otherwise have been developed.

In the southern part of the western Terrace Mountains, in the region of Shelter Mountain, an unusually fine-scale insequent and partially dendritic pattern has developed on extensively faulted shale of the Meade

Peak, chert and mudstone of the Rex, and carbonate rock of the Grandeur. The fine pattern is apparently due to considerable fracturing in the relatively weak strata and to numerous small faults. Bedrock exposures in the area are scarce.

Structural drainage control is apparent on both ends of the western Terrace Mountains. South of Scorpio Peak, sub-parallel subsequent valleys have developed on steeply but uniformly westerly dipping orthoquartzites and sandstones of the Diamond Creek. North of Tangent Peak, subsequent drainage partially follows the strike of the beds on both east and west limbs of the Tangent Peak syncline.

A topographically low region west of Scorpio Peak corresponds to the north-south trending exposures of the relatively incompetent Loray? Formation. The higher elevations bordering this depressed area are the result of the more resistant strata of the Diamond Creek Sandstone (largely orthoquartzite) on the east and of the dolomite and chert of the Grandeur on the west (Fig. 19). A similar valley was developed southwest of this area, in secs. 4 and 9, T. 7 N., R. 12 W., in pre-Lake Bonneville time on the north-south striking Meade Peak shale, between ridges of Grandeur on the east and Rex Chert on the west. Gravel deposits of the lake smoothed the contour of the valley, and it is now drained by sub-parallel consequential gullies, as is most of the area covered by the lake.

Big Pass

Uplift of both the eastern and western Terrace Mountain masses has produced a marked topographic contrast in the area of the Big Pass. The pass is formed by a structural block having relatively parallel border

Figure 19. View in the western Terrace Mountains looking north from Scorpio Peak. Outcrops of Diamond Creek Sandstone in the foreground, the valley developed on the Loray? Formation in the center, and Tangent Peak in the background. Raft River Mountains are on the horizon to the left.

faults along each side, approximately two-thirds of a mile apart, throughout its length. The Big Pass block has been largely buried by alluvial debris from the mountains on both sides of it. In contrast to the coarser dendritic, more permanent drainage pattern on the surrounding mountains, the drainage in the pass is fine, sub-parallel and gullied, closely resembling that of areas covered by sediments of Lake Bonneville.

Fault Scarps

Although there are no fresh scarplets in the mapped area, topographically expressed fault scarps are numerous. The most distinct of these scarps are on the western side of the eastern Terrace Mountains, on either side of the Big Pass, and on the west side of the western Terrace Mountains.

A normal fault near the southern end of the eastern Terrace Mountains is expressed by local reversal of the westerly slope and by local dislocation of drainage. Streams which originally flowed to the west across the later-faulted zone were diverted at right angles to the prevailing slope by the upthrown block. These streams now have north-south alligned segments which follow for short distances along the fault trace before turning again down slope to the west.

Fracturing and brecciation along another fault in the same area has caused piracy of drainage by a stream which eroded headward across several spurs (see Fig. 20g) along the weak, easily erodable fault zone.

The preservation of vitric tuff of the Salt Lake Group along a scarp of the Big Pass Fault indicates that movement has taken place along the fault since the deposition of that group during the Pliocene. Somewhat similar preservation of Lake Bonneville sediments, on the downthrown side of a normal fault southeast of the Terrace Mountains, indicates that a scarp there was topographically expressed at or shortly after the time of deposition of the lake sediments in the Pleistocene (Fig. 14).

Alluvial Fans and Bajadas

Pre-Bonneville alluvial fans are not easily distinguishable in the mapped area. Slight horizontal bowing of shorelines, which serve as topographic contour lines, reveal that a fan was probably present northwest of the north end of the Big Pass, at least below the Provo level, and several smaller fans were present along the east slope of the eastern Terrace Mountains. Very large fans are lacking in the area because streams are fed only from small drainage basins. Smaller fans present in pre-Bonneville time were so eroded and modified by the action of the lake that they no longer have topographic expression. Many are probably buried by post-lake fans and might be detectable by coring.

Post-Bonneville alluvial fans are numerous in the area, are frequently large, and in many cases, are extremely symmetrical and well developed (Fig. 20c). Because they cover a significant amount of the area below the Bonneville shoreline, they have been included on the geologic map. These fans are clearly distinguishable on aerial photographs because they usually mask the lake terraces they cover. Most of the smaller, more symmetrical fans have quite steep gradients. This is especially true of those which were formed by streams draining limited watersheds that debouch onto lake terraces, generally from between truncated spurs. Fanhead trenches commonly are well developed on such fans, and in places, deep

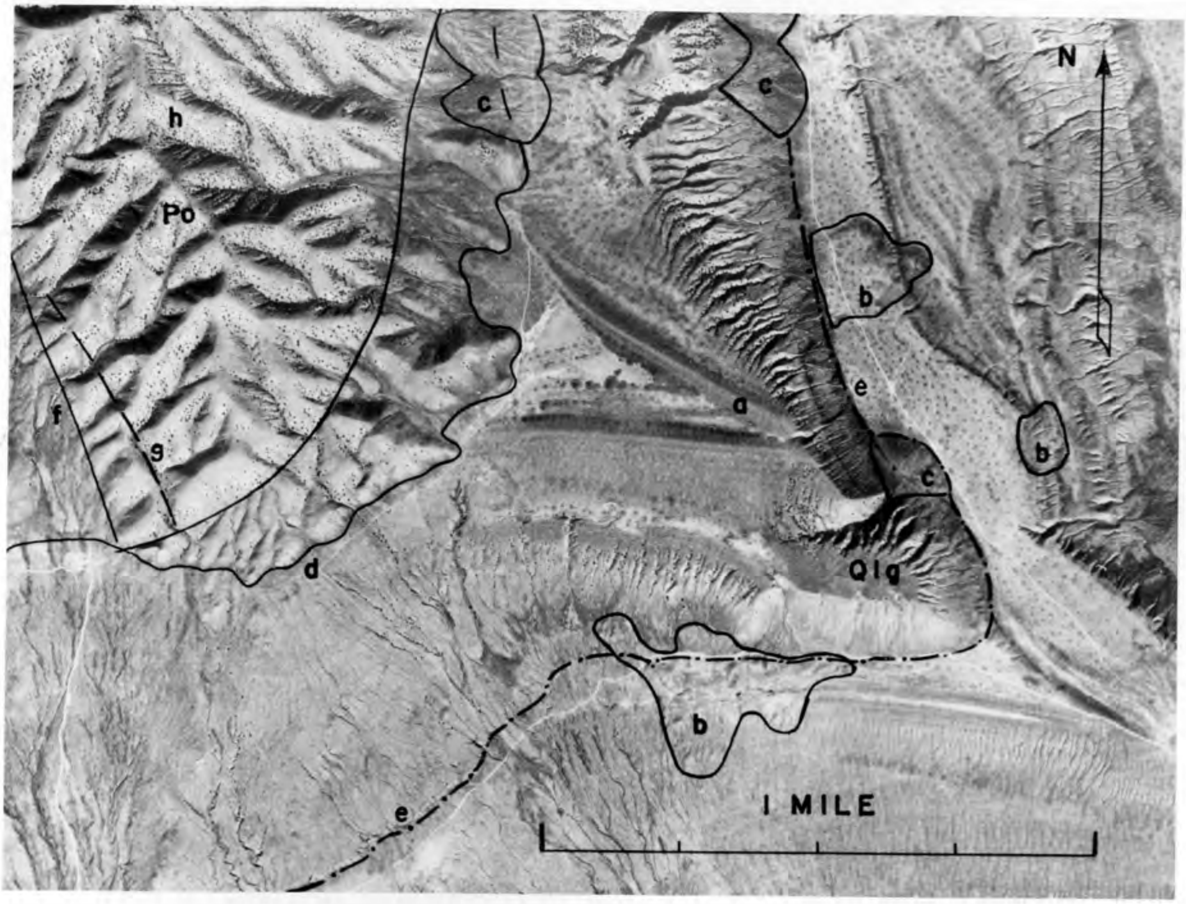


Figure 20. Vertical aerial photograph of proximal north end of the Terrace Spit and surrounding area showing: (a) horizontal V-shaped terrace at the Bonneville level; (b) post-Lake Bonneville gravel slides; (c) post-lake alluvial fans; (d) Lake Bonneville shore line and contrasting topography above and below it; (e) Provo shore line and terrace; (f) Big Pass fault and contrast of coarse rejuvinated topography east of the fault and buried topography with fine drainage west of the fault; (g) stream piracy by subsequent tributaries controlled by fault zone; and (h) ephemeral pinnate drainage.

channels have been cut entirely across fans formed on or between closely spaced terraces.

Although most of the fans are isolated, they coalesce in places to form minor bajadas. Pre-Bonneville bajadas have been obliterated by the lake, however, and post-Bonneville bajadas are of limited extent and rarely reach down to the present desert floor.

Pediments

A considerable part of the area below the Bonneville shoreline is of pediment nature. Because of extensive modification by the lake, especially in embayments where bedrock surfaces were buried by lake deposits, pediments are common, but their actual extent is difficult to determine.

Lacustrine Dunes

Two fields of dune-like structures of probable lacustrine origin are present on the flat desert floor which surrounds the southern end of the mapped area. The field on the southeast side of the bedrock exposures is in T. 6 N., R. 11 W. and is comprised of eight crescentic or barchan-shaped dunes. The dunes were formed and later modified by currents flowing to the southwest across a low spillway or threshold first mentioned by Eardley (1957) and later called the Terrace-Lakeside threshold by Stifel and Shroder (1964). It is postulated that during the later stages of Lake Bonneville (possibly the Gilbert Stage) currents flowed through this passage between the southern Terrace and northern Lakeside Mountains into the large western portion of the lake basin to compensate for evaporation. Marks of these currents are clearly visible on aerial photographs.

The dunes range in length from about 500-5000 feet and average approximately 3000 feet. Their widths (foreslope to backslope) range from 30-1000 feet, and they reach a maximum height of 10 feet, although the crests of most are only 6-7 feet above the surrounding mud flats. The horns of all the dunes point to the south and several horns have the form of recurved spits. The spit development on two of the dunes became so complex as to nearly obscure their original concentric shape.

The eastern end of one dune has been largely removed by currents, leaving a clearly discernable mark on the mud flats indicating its former extent.

The seemingly anomalous fact that the convex foreslopes are steeper than the concave backslopes was explained by Stifel and Shroder (1964) as being due to modification by currents after the water level had dropped below the crests of the dunes, material from the foreslope having been swept around the horns to form the recurved spits.

The dunes are composed of buff-colored oolitic sand which is bound with varying amounts of calcilutite and clay. In general the oolites average $\frac{1}{4}$-$\frac{1}{2}$ millimeter in diameter, although many zones have an admixture of larger sized aggregates composed of fecalites, oolites and odd-shaped concretionary pellets.

The dune sediments rest on a 1-2 foot thick bed of very clean, gray to buff oolitic sand and aggregates. This bed is in turn underlain by green-gray clay, silt, and calcilutite.

The dip of the internal bedding of the dune sediments does not exceed 2 degrees under the foreslope and no cross-bedding was detected in any of the dunes.

The dunes are located within the spillway where currents would have been the strongest and on the western side of the channel where sediment from areas of shallow water to the north would have been in abundant supply. The extremely large size and low height of the dunes, it is mentioned by Stifel and Shroder (1964), is suggestive of other than typical eolian origin. With respect to eolian dunes, it is stated by R. A. Bagnold (1941, p. 214), that although the relative length, width and height of barchans vary greatly, the maximum length and width of existing dunes is about 400 meters (1300 feet) and that the maximum height seems to be about 30 meters (90 feet). These figures are compared to the 5000 foot length and only 7-10 foot height of the dunes in the Salt Lake Desert.

L. V. Illing (1954, p. 89) described and illustrated similar subaequeous structures in the Bahama Islands as follows:

> "One of the gaps in the Exuma arc of cays . . . , shows an interesting development of underwater crescentic dunes. They measure 30-70 yards from tip to tip and are convex toward the ocean. They are formed in the central part of the channel by the 2-3 knot currents flowing onto the banks. . . . These submarine 'barchan' dunes are not reversed at each tide."

Illing also states that the dunes appear steep in both directions and that some do not have long drawn-out lateral tails, both conditions which are also true of the forms in the Salt Lake Desert. The only apparent difference between the Bahaman dunes and those in the Salt Lake Desert is that of size, the Utah structures being about 25 times as large.

→ The western group of dunes, a field of about 80 structures, lies between the southern Terrace Mountains and the northern Newfoundland Mountains to the west. Most of the dunes are within a belt about 4 miles long and a mile wide, although several large ones lie outside this area. Only one dune in the western group is barchan shaped. The others are oval, circular or slightly irregular in outline and all are roughly dome-shaped in section. Many have small spit-like projections extending from one or both ends, apparently due to modification by currents in water only a few feet deep.

The smaller dunes average about 600 feet in diameter and are nearly circular. The larger ones, are elongate ovals. They average 1700 feet in length, 800 feet in width, and have crests 15-20 feet above the surrounding desert floor. One of the largest of these, isolated from the rest of the field, and about four miles from the previous lake shore line, is 3900 feet long and 800 feet wide. The one barchan-shaped form, also large, is about 1400 feet from front to back, 3900 feet from horn to horn, and 30 feet high. All of the structures are stabilized and appear to have been so for a considerable time. At the present time they have a sparse cover of phreatophytes.

Dunes in the northernmost part of the field appear to be related to large banks or dune-like structures, composed of similar sediment, which were apparently attached to previous lake shore lines.

The southeasterly trend of these dune-like forms is due either to the effect of currents which may have formed the deposits or to the dissection of a former tabular body of sediments by post-Bonneville streams. One of these structures is present along the western edge of the belt of bedrock outcrops that extends southeast from the Terrace Mountains. It is 1/3 mile wide and about 4 miles long. It curves around the end of the bedrock outcrops and extends a mile and a half to the southeast onto the mud flats. The structure is separated from the shore by an undrained depression, the bottom of which is at about the same elevation as the mud flats to the west. The depression is about a quarter of a mile wide and it extends the length of the structure except where it skirts bedrock exposures near its southern end.

Lineation is present in the dune arrangement, with dunes alligned slightly northwest-southeast, in conformity with the apparent direction of currents in that region.

The dunes are composed of gypsum crystals and fragments thereof, ranging from a maximum of about 5 millimeters to less than 1/100th millimeter, and calcareous material, some of which is in the form of oolites, but most of which consists of calcilutite and small calcareous particles of undetermined origin. Very little other clastic material was detected.

Cores were taken across one small dune and a slit trench was cut in the large barchan dune in the middle of the Southern Pacific Railroad cut which bisects the dune. Bedding in each case was essentially horizontal, that in the large dune being uniform over several tens of feet through the central part of the structure.

It is remotely possible that these dune-like structures are residual, the erosional remnants of a former tabular body of sediment which covered the area where they now occur. A more likely possibility, however, is that they were variously shaped mounds of material accumulated by currents on the floor of Lake Bonneville during its later stages, which mounds were later modified by currents flowing around them, as evidenced by the small spit-like protruberances present on many of them.

Further research is planned into the origin of these structures.

Caves

A large cave is present in the SW corner, NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 31, T. 8 N., R. 12 W., in the southwestern part of the area. It was apparently formed by solution along a brecciated zone and was possibly uplifted by faulting to its present position. It is in one of the carbonate intervals in the Rex Chert and is at an elevation of about 4700 feet, midway between the Stansbury and Provo lake terraces. It has a large ante-room, about 50 feet deep, 15 feet wide and 10 to 15 feet high, connected by a foot-high crawl space to an inner room about 15 feet in diameter and 6 feet high. The floors of both rooms are composed of lake gravel and roof falls.

Three small caves, little more than overhangs, are present in the southern part of the area. Two are adjacent, at an elevation of 4400 feet, in the west $\frac{1}{2}$ sec. 3, T. 6 N., R. 11 W., formed at the base of unit 13 of the section of the Oquirrh Formation measured at that place. The third is located under a shell of tufa-cemented lacustrine conglomerate in sec. 10, T. 5 N., R. 11 W., at about 4300 feet. These three all appear to have been excavated by shore processes of Lake Bonneville.

Each of the caves mentioned was occupied as a shelter by Indians, as evidenced by artifacts found in and around them.

Dolphin Island

Dolphin Island was described by Stansbury during his survey of Great Salt Lake. Of it he said (1853, p. 191) that :

> "The summit is some 70 feet above the level of the water, and the island consists mainly of conglomerate in horizontal strata, and varying much in the size of the cemented stone."

Only a few details can be added to this description. The feature is not an island at the present time nor does the salt crust still exist that Stansbury mentions as lying immediately west of the island. The elevated part of the island is about three-quarters of a mile long, a third of a mile wide, and a spot elevation on the Army Map Service sheet indicates that the summit is 4235 feet above sea level. The island is formed essentially of calcareous tufa-cemented conglomerate (Fig. 21), the constituents of which are sub- to well-rounded, large-cobble to sand-sized clastics apparently derived from the sandstones and black limestones in the eastern Terrace or the Hogup Mountains. Wave action and south-flowing currents formed small cliffs on the north end of the island and produced two wing-like spits of gravel and sand which extend to the south on either side of the island. Oolitic sand is abundant immediately around the island and on the surrounding flats.

Lake Bonneville Features

General Statement

The magnificent development of lacustrine shore features in the mapped area was recognized early in the course of investigations of the region. They are first mentioned, though only briefly, by Howard Stansbury (1853) in his survey of the Great Salt Lake. They were paid considerable tribute some years later by Arnold Hague (*in* King, 1877, p. 427), who said of the northern part of the mapped area and adjoining areas, that probably no locality in the region of Salt Lake affords a better opportunity for observing the broader and more permanent lake terraces which mark the changes of level of the earlier bodies of water. G. K.

Figure 21. Tufa-cemented conglomerate of undetermined age which forms the elevated portions of Dolphin Island. View is of small cliffs at northern end of the island.

Gilbert visited the northern part of the mapped area in the late 1870's. He mentioned several important lacustrine features of the area, and measured and illustrated lake terrace levels on Kelton Butte (Gilbert, 1890).

In the present report, all lacustrine features are ascribed to shore processes active in Lake Bonneville, although the idea has been expressed by Jones and Marsell (1955, p. 116) that some of the shoreline features of the Bonneville basin conceivably were produced by predecessors of Lake Bonneville, because, as they further state (ibid., p. 117), ". . . it seems certain that Lake Bonneville was only the last of several Pleistocene lakes to occupy successively the same basin." With respect to previous occupations of the Bonneville basin, Eardley states (<u>in</u> Eardley and others, 1957, p. 1197) that lakes older than the Alpine existed but did not rise as high, and their deposits are not yet well understood.

Lacustrine shore features are so well developed and are such a dominant part of the landscape in the mapped area that brief descriptions of the more outstanding ones will be given here. The many different kinds present include both erosional features, such as sea cliffs and wave-cut terraces and constructional features, such as spits and hooks, cuspate or looped bars, tombolos, both longshore and V-shaped wave-built terraces and several types of bars.

Erosional Features

<u>Sea-cliffs</u>. Gilbert (1901, p. 34) felt the term sea-cliff should be retained over the more accurate term lake-cliff for such features in the Bonneville basin, because of the long established use of the former term. Except for a few isolated cases, sea-cliffs are limited to the highest,

or Bonneville shore line in the mapped area. An outstanding line of such cliffs, now partially obscured by post-lake alluvial fans, occurs along the east side of the eastern Terrace Mountains at the Bonneville level (Fig. 22). The base of this line of cliffs is markedly horizontal, a constant characteristic of such features according to Gilbert (1901, p. 34). The striking alignment of these cliffs may be due to the influence of an eastern range-bordering fault, but lake sediments have obliterated any trace of a fault and have concealed any key bedrock exposures that might have indicated the position of one. Other lines of sea-cliffs, of smaller size and less steepness occur along both sides of the western Terrace Mountains. In all of these places, wave action has truncated spurs which now form small aligned flatirons, now largely covered with talus.

Smaller, usually isolated wave-cut cliffs occur below the Bonneville level, especially in the southern part of the area.

Wave-cut Terraces. At many places, the nickpoint where the Bonneville level terrace meets the base of the cliffs is very probably wave-cut, but in most instances the cut bedrock surface is obscured by a veneer of gravel. Figure 23 illustrates one of several former islands in the mapped area which are surrounded by broad terraces at the Bonneville lake level, which terraces are partially wave-cut, having bedrock exposures on and around them, and are partially wave-built. Kelton Butte has another such terrace and was illustrated by G. K. Gilbert in his Bonneville monograph (1890, p. 108). Wave-cut terraces are found almost exclusively in association with wave-built terraces and are very few in number with respect to constructional terraces.

Constructional Features

Spits and Hooks. Perhaps the most conspicuous lake feature in the mapped area is the Terrace Spit (Fig. 24), which is attached to the southern tip of the eastern Terrace Mountains and extends for nine miles to the southeast. From its proximal or attached end at an elevation of about 5300 feet, it descends nearly 1100 feet to the level of the clay flats, at an elevation there of 4210 feet. Forming the proximal end of the spit is a spectacular V-shaped terrace, approximately 3300 feet long, very nearly horizontal and having a triangular depression 10 to 20 feet deep within marginal barrier bars (Fig. 20 a). The terrace and its pendant spit were built by two strong littoral currents, one flowing south along the east side of the Hogup and eastern Terrace Mountains and the other flowing east, an eddy current in the large embayment southwest of the spit. The two currents were of nearly equal strength when the lake was at the Bonneville level, but later, as the size of the embayment was reduced, the south-flowing current became dominant, aligning the spit to the southeast, parallel to the east side of the range. The distal end of the spit was recurved toward the bay forming a terminal hook.

A second large spit, herein called the Hogup Spit, was formed at the Bonneville level in the Hogup Mountains, by the same south-flowing current that formed the Terrace Spit. The current flowed from the north around what at the time was a small island, moving detritus from both sides to form the spit on the south or lee end. The Hogup Spit is straight, about 3000 feet long, several hundred feet wide, and nearly rectangular in plan view. The nearly flat surface of the spit slopes toward the distal end, and like the Terrace Spit, it has a small V-shaped depression where it is attached to the island.

Figure 24. Composite of vertical aerial photographs showing Terrace Spit extending to the southeast from the eastern Terrace Mountains.

Smaller spits are common in the mapped area, but none compare in size or degree of development to the two described.

Curved spits or hooks were formed at several places in the northern part of the area, especially where shore lines diverged abruptly landward away from the direction of littoral currents. The hooks usually form short extensions from larger gravel embankments.

Cuspate Bars. A cuspate, or looped bar was formed on the southeast side of northern Peplin Mountain in secs. 9 and 16, T. 11 N., R. 12 W., (Fig. 18, b). It was built either by littoral currents converging in the lee of a head or by a hook originating on one side of the head and rejoining it on the other.

Looped or cuspate bars enclosing V-shaped terraces were formed at the proximal ends of most spits or on headlands where currents converged. One looped or V-shaped bar formed at the Gilbert level off the southernmost bedrock in the mapped area, where south- and east-flowing currents built spits out from separate heads until they converged at the apex of the V. Both spits were curved into hooks at numerous times during their development by currents turning into the quiet medial lagoon. When the spits joined, the lagoon became entirely enclosed and is now an undrained depression.

Tombolos. At the Bonneville stage of the lake, numerous small islands were tied by bars as tombolos to the main Terrace Mountain mass, an island itself at the time. Two of these tombolos comprise the Hogup Mountains. Later, at the lower Provo stage, a chain of islands, all connected by gravel bars, joined the Hogup Mountains to Peplin Mountain and to the "mainland" to the north. An important one among many of the smaller tombolos is Crocodile Mountain which, though it was entirely submerged during high lake stages, was an island and was tied to the northeast side of the Hogup Mountains by the Hogup Bar when lake levels were below 4300 feet.

Figure 18 illustrates a short tombolo tying a small island to the southern side of Peplin Mountain (c), as well as showing two baymouth bars (g), a cuspate bar (b), a wave-cut terrace (d), sea-cliff (e), and cuspate forelands (f).

Wave-built Terraces. Constructional terraces occur in all parts of the mapped area that were covered by the lake. They are especially well developed at the Provo level, and on the western side of the Hogup Mountains they are outstanding for their breadth and flatness (Fig. 25). Parts of all terraces in the area are wave-built, especially those at the major lake levels recognized throughout the Bonneville basin.

Major Terraces and Elevations

Major lake terraces were developed at the Bonneville, Provo, and Stansbury levels of Lake Bonneville (Fig. 26). Because they were formed during relatively long periods of stable water level, they exhibit both wave-cut and wave-built terraces and numerous spits and bars. They are distinguishable anywhere within the mapped area and are easily traced on aerial photographs. They appear equally well developed throughout the region, as the fetch on the lake was long and nearly the same in all directions except to the north. As in most other areas of the Bonneville basin, the Provo level terrace is the best developed of the three, but the uppermost or Bonneville terrace is the most distinct because of the abrupt contrast in topography above and below it (Fig. 20, d and Fig. 26).

Figure 25. View to the southeast of broad, flat gravel terraces at the Provo level west of the Hogup Mountains, also showing the southern Hogup and eastern Terrace Mountains in the background to the left, separated by the Big Pass from Tangent Peak in the western Terrace Mountains to the right.

Figure 26. View to the southwest of the northern Hogup Mountains, two miles distant to the right, and the eastern Terrace Mountains to the left. First terrace below hilltops is Bonneville, second well developed terrace is Provo, third is Stansbury. Below and between these are intermediate terraces. Haystack is on Gilbert terrace.

The Bonneville shore line is nearly everywhere marked by a line of faceted spurs and baymouth bars, and on the east side of the eastern Terrace Mountains a terrace as wide as 800 feet was built at this level.

Attempts made by the writer to determine accurate levels of the major terraces in the mapped area consumed considerable time and met with little success. The work was done partly for this report and partly in conjunction with an investigation over the entire basin done by Max Crittenden of the U.S. Geological Survey (Crittenden, 1963). One of the purposes of these studies was to confirm G. K. Gilbert's proposal that the lake terraces showed concentric uplift due to isostatic rebound after unloading of the water from Lake Bonneville.

Lake terrace levels near Kelton were first measured during the Stansbury survey of the region in 1850 and later by Arnold Hague for the survey of the Fortieth Parallel under Clarence King. More complete measurements were made by A. L. Webster as part of G. K. Gilbert's survey of Lake Bonneville published in 1890. The figures listed by Webster (_in_ Gilbert, 1890, Appendix A) vary slightly, apparently because several methods of measurement were employed and different features were measured in the field. His measurements are of relative elevations above the Lake Shore Gauge Zero Datum which is 4208 feet above mean tide (Gilbert, 1890, p. 364).

Bonneville Terrace. Elevations of the Bonneville terrace were determined by the writer in the southern Hogup Mountains and on Kelton Butte about 10 miles to the north. In the Hogup Mountains, a spot elevation of 4855 given for the Provo shore line on the Army Map Service topographic sheet was used as a base. Adding to this the writer's figure of 393 feet (obtained by barometer traverse) which is the difference in elevation between the Provo and Bonneville terrace levels, the Bonneville shore line is 5248 feet above sea level in that area (sec. 1, T. 9 N., R. 12 W.). A barometric traverse made by the writer on Kelton Butte, (base was USC&GS BM L95, Utah Line 8) showed a 5216-foot elevation for the nickpoint of the Bonneville terrace there. This figure compares well with the 5225-foot elevation listed by Webster in Table XXIII (1017 feet above Lake Shore Gauge Zero Datum, _in_ Gilbert, 1890, p. 412), and with the best determinable figure from the Army Map Service topographic sheet. Crittenden mentions (1963, p. 6) that an elevation of 5300 feet in the eastern Terrace (Hogup) Mountains which he determined from aerial photographs and the above mentioned map, was believed too high and was ignored in his contouring on Fig. 3 (1963, p. 9). He mentioned his feeling (written communication, 1961) that this figure could well be 50 feet in error, and that 5275 or 5266 feet, determined from Webster's figures obtained near the former town of Matlin, several miles west of Kelton Butte, was probably nearer the true elevation. The writer concurs with this feeling, at least with respect to the eastern Terrace (Hogup) Mountains (sec. 3, T. 8 N., R. 11 W., Crittenden's location), but he suspects that the shore line may be as high as 5300 feet in the southern part of the western Terrace Mountains.

Provo terrace. The elevation obtained by Webster for the Provo terrace on Kelton Butte is approximately 4871 feet above sea level, which figure is at considerable variance from the apparently low determinations of 4829 and 4833 feet made by the writer and the less than 4855-foot elevation on the Army Map Service sheet. Again, the discrepancies may be due to the use of different datum levels and to the fact that readings were not taken on the same points in the field.

Stansbury Terrace. Using Webster's difference of 310 feet between the Provo and Stansbury levels at Matlin, the Stansbury shore line is 4518 feet above sea level in the northern part of the study area. This figure is compared to approximately 4500 feet for the Stansbury terrace level as determined from the topographic map.

Gilbert Terrace. Shore line features are present at the Gilbert level (Eardley and other, 1957), especially along the eastern side of the mapped area (Fig. 26), but are not extensively distinct, and no attempt was made to map or to measure this level.

Lack of control points prevented accurate measurement of terrace levels by altimeter in the southern part of the Terrace Mountains, but contour lines on the Army Map Service sheet indicate that terraces may be as much as 60 to 70 feet higher there than they are at Kelton Butte 20 miles to the north. The Bonneville terrace on the southern end of that range is 5280-5300 feet in elevation, the Provo 4880-4900 feet, and the Stansbury 4540-4560 feet above sea level.

The apparent difference in shore line elevations within the mapped area is compatible with Crittenden's contours (1963, p. 9) and supports Gilbert's hypothesis of isostatic rebound. The northern part of the area, formerly connected to a region of shallow water, would not be expected to rebound as much as the southern part, which was surrounded by deep parts of the former lake.

V-shaped Terraces. V-shaped terraces, as mentioned above, are present at the proximal ends of most spits in the mapped area and are usually bordered by slightly higher bars. They are also found as constructional extensions of headlands in the lee of current.

Storm Terraces. Intermediate terraces, especially storm terraces or beach ridges, are well developed in many parts of the mapped area. They are narrow, and although usually only faintly expressed topographically, they are detectable on aerial photographs because of variations in surficial sediment and vegetation. They are wave-built of gravel, or are erosional, having been cut slightly into gravel and fine lake sediments, and as a result are best developed in embayments and on gentle slopes where both fine sediments and gravel are abundant. The most clear and least obliterated examples of these terraces are on the western slope of the mapped area where they are very long, several sets being traceable individually for over six miles. In that region, 13 individual storm terraces are detectable on aerial photographs between the Bonneville and Provo levels, 34 between the Provo and Stansbury levels and 23 below the Stansbury level, a total of 70 minor terraces. A second very clear set is present on the southwest slope of the Terrace Mountains where a total of 63 terraces can be counted, 11 between the Bonneville and Provo, 31 between the Provo and Stansbury, and 21 between the Stansbury and the Gilbert (?) levels.

In some parts of the area, these minor terraces are markedly well developed below the Provo level and nearly obliterated above it, suggesting a relatively long period of time between recession from the high Bonneville stage of the lake and the last occupation of the Provo level, with the recession from that level leaving the present set of sub-Provo terraces. Eardley (1957, p. 1164) recognized this when he attributed differences in photographic tone of the three intervals between major terraces to the gaps in time between their successive abandonments.

Bars. Baymouth and barrier bars are outstanding geomorphic features in the mapped area. Most major drainages, such as those at either end of the Big Pass, and most smaller embayments and re-entrants, have baymouth bars at the Bonneville level. Some are single bars and some are multiple or compound. The embayments behind most of these bars were filled in with sediment, and in many cases the whole structure was later dissected by one or more streams, though several large bars have not been dissected and still have deep depressions behind them.

The longest baymouth bar in the area, built at the Gilbert level, extends in an arc from Kelton Butte southeast to Crocodile Mountain, closing off the embayment now called Peplin Flats. Though only a few feet higher than the enclosed flats, the bar is a mile and two-thirds long.

Numerous bars, especially those built as spits or headlands have marginal barrier bars behind which shallow lagoons were present.

Evidence of Currents in Lake Bonneville. Conformation of numerous gravel deposits in the mapped area strongly reflects current directions in Lake Bonneville. Spits and hooks are pendant from the lee sides of former islands, and the source directions for large gravel embankments are readily determined. Major currents flowed to the south along both sides of the Terrace Mountains but were locally affected by the islands and land masses around which they flowed (Plate XIV).

ECONOMIC GEOLOGY

A variety of non-metallic materials of potential economic significance is present in the mapped area. Diatomite, bentonite, vitric tuff, and gravel have been mined, and future development of phosphate deposits is a probability.

Diatomite

Diatomaceous lacustrine deposits occur in many of the protected embayments of Lake Bonneville, and although most are impure, thin, and of local extent, some are of possibly commerical grade. Such a deposit covers about nine square miles of Peplin Flats in the northern part of the mapped area. Claim to more than 180 acres of this material is held by Carl L. Cobia, presently operator of the Chevron service station in Snowville, Utah. The deposit was investigated for Mr. Cobia by a Colorado firm, but was apparently found to be too impure for economic production at present (Cobia, oral communication, 1961).

An abandoned loading platform stands in NW$\frac{1}{4}$ sec. 2, T. 10 N., R. 12 W., left from a previous mining operation, about which the writer was unable to obtain significant information.

As much as five feet of high grade diatomite was measured by the writer on the surface of Peplin Flats. This relatively pure diatomite is underlain in most places by several feet of impure, silty diatomite, which, in turn, is underlain by gravel. Accumulation of these deposits was apparently enhanced by restriction of the Peplin Flats embayment by the Hogup Bar and Crocodile Mountain when Lake Bonneville was lowered to about the Stansbury level, as the more pure deposits occur below 4500 feet.

Bentonite

Exposures of rhyolitic welded tuff in the northeastern part of the area have weathered to bentonitic clay of commercial quality and quantity. Surface mining of this material has been intermittent, and on a small scale, use of it apparently being to supply needs of local drilling operations. Future potential of this deposit was not investigated by the writer.

Vitric Tuff

A claim was established in 1954 on a deposit of lacustrine vitric tuff of the Salt Lake Group in the SE$\frac{1}{4}$ sec. 33, T. 9 N., R. 12 W. by the Nadir Mining Company of Sandy, Utah. Approximately $900.00 was spent in development at the site, but the project was abandoned after 1955. Intention was apparently to cut the material into small blocks to be sold in kits for figure carving.

No further exploitation of this material is known in the area. It could possibly be utilized as an abrasive, but uncontaminated material is not abundant in the region and, in any case, is probably more easily obtainable where the Salt Lake Formation occurs elsewhere.

Gravel

Large surficial gravel deposits are so abundant in the mapped area that discussing individual deposits is insignificant, other than to mention that the most important accumulations are on the west side of the Hogup Mountains, the east side of the eastern Terrace Mountains, and in the southern part of the area, mainly north of the railroad.

A large amount of gravel was used by the Southern Pacific Railroad in construction of the Lucin Cut-off and more recently as road metal for their service road along the tracks. The railroad's excavation for this gravel, extending along lake-shore bars, is 3 miles long, about 200 feet wide, and 10 to 15 feet deep, which dimensions indicate that nearly 2 million cubic yards of material was removed.

There is sufficient gravel locally for any conceivable project within the area, and there would be no need to transport gravel out of the mapped area because of its abundance in surrounding regions.

The dominantly fine clastic lithologies of the Pennsylvanian and Permian rocks, mainly Oquirrh, in the mapped area are apparently responsible for the development of the thick and extensive gravel deposits which occur there. Where similar lithologies are present in neighboring ranges, such as the Grassy Hills to the south, large gravel and silt deposits are usually present, and topography is subdued as it is in the mapped area. The lower Paleozoic limestones, dolomites, and quartzites present in such as the Newfoundland and Silver Island Ranges are more resistant, forming higher, craggy, well-exposed ranges with a much smaller amount of gravel around them. The Promontory and Lakeside Ranges are intermediate, having exposures of both general types of rock and having medium amounts of gravel.

Phosphate

Because spot samples taken from trenches by J. Stewart Williams in 1959 show relatively low percentage of P_2O_5 (Report by Williams to Utah State Land Board, December 1959), phosphatic shales of the Meade Peak Member of the Phosphoria Formation appear to have little potential commercial value in the Terrace Mountains. The writer feels, however, that neither the trenching nor sampling were adequate at that time, and that further investigation of the phosphate deposits may be warranted. Unfortunately, a complete and accurately controlled set of samples taken from a trench by the writer and Thomas Cheney of the U.S. Geological Survey were apparently misplaced and the information lost. Therefore, as they are the only data available at this time, figures from the report of Williams to the Utah State Land Board on the Terrace Mountain occurrences are included as follows (locations corrected by the writer):

1. Long trench in center E½NE¼ sec. 3, T. 8 N., R. 12 W.

	Approximate thickness in feet	Sample position	Analysis % P_2O_5
Rex Chert			
E. Shale	40	plus 2 feet	2.23
D. Limestone	40		
C. Shale	40	plus 40 feet	3.19
		plus 37 feet	6.38
		plus 17 feet	6.38
B. Limestone	100		
A. Shale	15	plus 13 feet	6.38
		plus 8 feet	15.19
Foot-wall limestone (Grandeur)			

2. Trench in east center E½NW¼ sec. 3, T. 8 N., R. 12 W., north of wash.

Two samples from 15-foot face plus black spots

	% P_2O_5
Selected black spots	3.19
Composite of 15-foot face No. 1	3.19
Composite of 15-foot face No. 2	3.19
3. Trench in same locations as above, across wash to south.	
Best looking material	6.38
4. Trench on foot-wall shale in SW¼SW¼ sec. 2, T. 8 N., R. 12 W.	
Shale at 12 feet above foot-wall	2.23
Shale at 8 feet above foot-wall	4.79
Shale at foot-wall	7.97
5. Trench on hanging-wall shale, short distance west of above.	
Top of 10-foot exposed thickness	15.95
Bottom of 10-foot exposed thickness	1.59

It seems somewhat anomalous to the writer that three samples from each of the first two trenches contain identical amounts of phosphate. It was also noted by the writer in the field that there was a considerable thickness of Meade Peak between the trench on the "foot-wall shale" and the base of the member, and that the trench on the "hanging-wall shale" is of dubious position within the section.

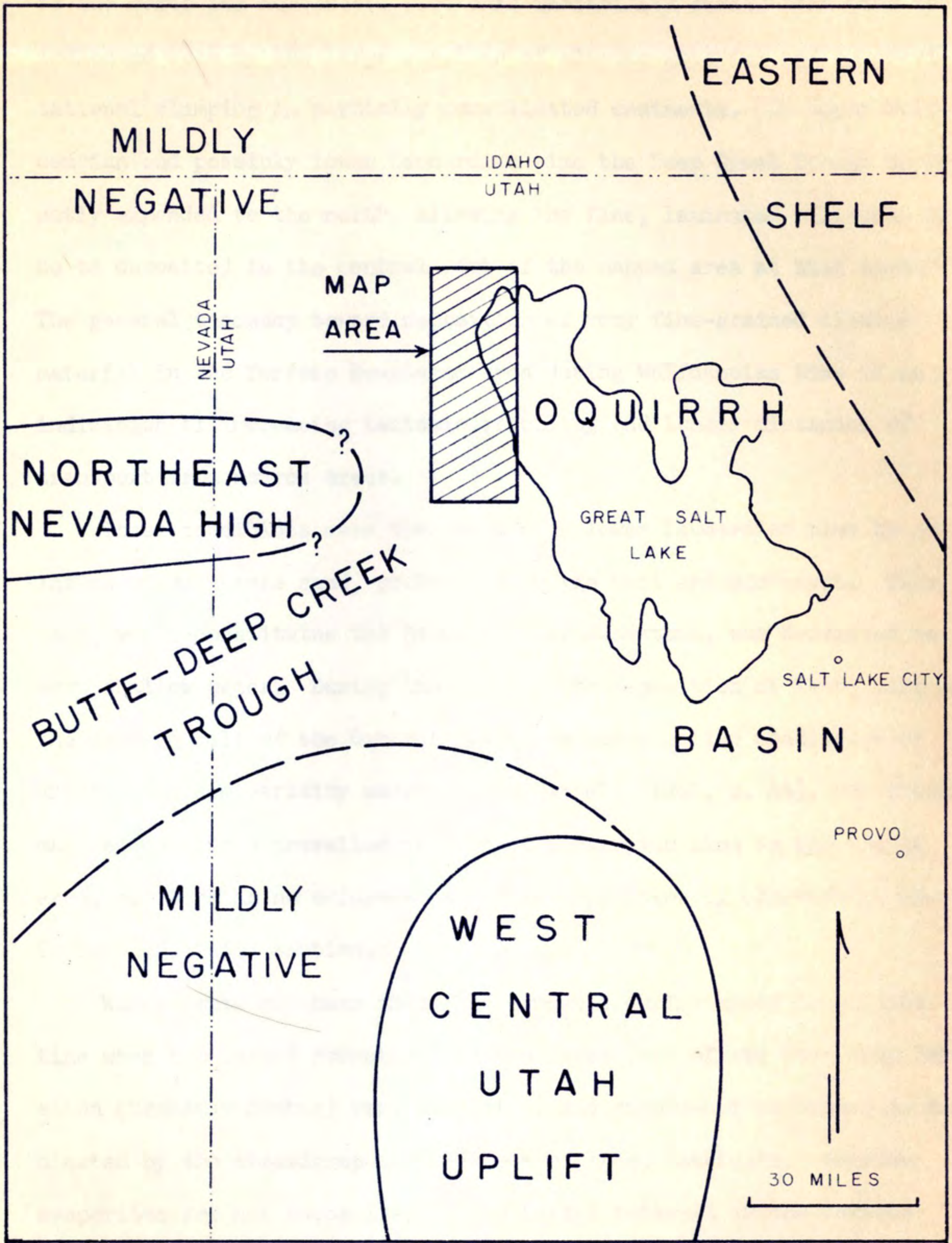
As Dr. Williams mentions (ibid., p. 4), open pit mining sites do not appear to exist in the region he investigated. It is suggested, however, that occurrences in secs. 4, 9, and 16, T. 7 N., R. 12 W., because of their low dips and large area of exposure, might be exploitable by open pit methods if the P_2O_5 content is high enough there. The presence of the Southern Pacific Railroad only four miles to the south may also be a considerable factor.

GEOLOGIC HISTORY

The area of the Terrace and Hogup Mountains was near the central part of the Cordilleran miogeosyncline during Paleozoic time. Evidence from the Promontory and Lakeside Ranges suggests that sediments of all Paleozoic systems were deposited in the studied area, although lack of exposures unfortunately prevents interpretation of events that took place before latest Pennsylvanian (Virgilian) time.

During late Pennsylvanian and early Permian time, the mapped area lay within the northwestern part of the Oquirrh Basin, and was partly north of and partly within the juncture of the Oquirrh Basin with the east-west trending Butte- Deep Creek Trough (Steele, 1960, p. 91) (Fig. 27). To the west lay the Northeast Nevada High (Steele, 1959, p. 1105). The great thickness of upper Pennsylvanian and lower Permian rocks in the mapped area indicates that the high or positive feature did not extend as far east into Utah as shown by Steele (1960, Plate 1) and by Bissell (1962, p. 43, Figs. 5 and 6), but it probably supplied much of the clastic material which constitutes the Oquirrh Formation in the Terrace Mountains area.

Sedimentation of the Oquirrh Formation was characterized by deposition of bioclastic and arenaceous limestones, silty limestones, calcareous sandstones, and orthoquartzites. Clastic material is conspicuously dominant. During middle Wolfcampian time water was apparently deep enough in the southern part of the mapped area to allow accumulation of thin-bedded, very fine-textured, siliceous mudstone and siltstone. Deposition of this lithology was periodically interrupted by influxes of coarse bioclastic and lithoclastic material from more shallow water



GENERALIZED MAP SHOWING TECTONIC FEATURES OF THE NORTHEASTERN GREAT BASIN DURING LATE PENNSYLVANIAN AND EARLY PERMIAN TIME

Figure 27 after Steele, 1959

to the north and northwest. Tectonic instability during this time is indicated both by the large supplies of clastic material and by gravitational slumping in partially consolidated sediments. In upper Wolfcampian and possibly lower Leonardian time the Deep Creek Trough apparently expanded to the north, allowing the fine, laminated siliceous beds to be deposited in the central part of the mapped area at that time. The general tendency toward deposition of very fine-grained clastic material in the Terrace Mountains area during Wolfcampian time is an indication of increasing tectonic stability and longer distances of transport from source areas.

These conditions were interrupted in lower Leonardian time by an influx of quartzose sand, probably from the east and northeast. This sand, which constitutes the Diamond Creek Sandstone, was deposited in very shallow water. During the time of its deposition at least part of the eastern half of the Oquirrh Basin was under eolian conditions of aridity and semi-aridity according to Bissell (1962, p. 46), but shallow marine conditions prevailed throughout Leonardian time in the mapped area, as there is no evidence of eolian deposition of clastics in the Terrace Mountains section.

Water depth may have increased somewhat during upper Leonardian time when the Loray? Formation and the lower part of the Park City Formation (Grandeur Member) were deposited, and subsidence continued as indicated by the stratigraphic thickness of these intervals. Because evaporites are not recognized in the Loray? interval in the Terrace Mountains, the writer feels that water depth was deeper, and that the depositional basin was less constricted in the Terrace Mountains area than it was to the west and southwest where the Loray Formation contains gypsum and anhydrite. Gypsiferous siltstones may be present in the Terrace Mountains section, but if so, they are concealed. Units of "punky," friable, calcareous siltstone, common in the Terrace Mountains section, may represent locally the evaporitic conditions which prevailed to the west.

Slight deepening and broadening of the depositional basin is indicated by the increase of chert and dolomite in the Grandeur Member overlying the Loray? Formation. Quartzose clastic material was occasionally supplied to the area throughout Grandeur time (upper Leonardian-lower Guadalupian), but it was very fine-grained. Fine-scale, high-angle, irregular cross-bedding in the Grandeur is indicative of current action in relatively shallow water, probably in the epineritic zone.

There probably was little tectonic change in the Terrace Mountains area when Meade Peak deposition was initiated during Wordian time. It has been generally concluded (McKelvey, <u>in</u> McKelvey and others, 1959, p. 25) that the phosphatic sediments of the Meade Peak probably accumulated on a gently shoaling bottom that received cold phosphate-rich waters from an open ocean. Temperature, pH, and the presence of certain mineral ions were apparently the most important factors in control of of the deposition of the phosphatic sediments. The extreme fineness and high organic content of the sediment suggests that deposition was not close to shore, and that it was in water deep enough to allow reducing conditions near the bottom.

The cherty mudstone intervals in the lower part of the overlying Rex Chert possibly indicate maximum water depth in the Park City-Phosphoria sequence, if they are assumed to represent a basinward facies of the Rex as suggested by McKelvey (<u>in</u> McKelvey and others, 1959, p. 29), but the physical conditions of Meade Peak time persisted through lower Capitanian time while the Rex Chert Member was being deposited. As with the phosphate in the underlying Meade Peak, the supply of siliceous material and the chemical environment was probably more responsible for the deposition of the Rex Chert than was the physical environment. During deposition of the upper Rex and the overlying Gerster carbonates the depositional basin became continuously more shallow. The occurrence of thick Park City and Phosphoria sections in northwestern Utah and eastern Nevada indicates that the upper Permian seas were extensive in that area as well as in the shelf areas to the east and northeast where these stratigraphic intervals have long been known and studied.

As has been mentioned previously, the nature of the Permian-Triassic boundary is uncertain, but a paraconformable or possibly disconformable relationship may be present at the contact. The sharp lithologic change from carbonate rocks to shale suggests that a hiatus may be present, but there is no other stratigraphic evidence in the area.

The homogeneous shales and limestones of the lower Dinwoody Formation indicate an influx of fine clastic material over the Gerster limestones and probably indicate slightly more shallow water. The upper part of the Dinwoody section, silty and wave ripple-marked, indicates continued shallowing of the water, although the thickness of the Dinwoody also attests to continued subsidence of the basin in lower Triassic time. The Thaynes Formation represents the last marine deposition preserved in the mapped area. Some additional Triassic sediments may have been deposited, but it is likely that sedimentation was interrupted in middle to late Triassic time by the influence of the medial Cordilleran geanticline (Schuchert, 1924) which became a positive area to the west in Triassic time. The upper contact of the Thaynes Formation, although concealed, is erosional and any sedimentary evidence of tectonic activity to the west has probably been removed.

Sediments that may have been deposited in the Terrace Mountains area during the time between the lower Triassic and the late Tertiary have been removed by erosion or concealed under range-bordering alluvium.

Tectonic activity took place in the studied area between the Triassic and the late Tertiary. Initial folding occurred during either the Nevadian orogeny (late Jurassic and early Cretaceous) or the Laramide orogeny (late Cretaceous through Eocene), or both, there being no direct evidence for differentiation between the two orogenies. Orogenic deposits which serve so well to date tectonic events in the Wasatch Mountains to the east are completely lacking in the Terrace Mountains and in surrounding ranges as well. Folding can only be dated as post lower Triassic and previous to block faulting of the range.

Two phases of folding are distinguishable. One phase comprises the broad north-south trending West Terrace syncline and Tangent Peak syncline, and the other comprises east-west trending folds which include the broad Scorpio Peak anticline with its associated minor flexures and the folds in the Hogup Mountains and Crocodile Mountain to the north. That the north-south trending folds were formed before the east-west trending ones is suggested on the meager grounds of the flexure or undulation of the axis of the West Terrace syncline, an apparent effect of later north-south compression. The axis of the Tangent Peak syncline is too much affected by later faulting to indicate deformation by folding.

A major phase of block faulting and rotation of the fault blocks apparently took place after folding and may have begun in the early

Tertiary. Tilting of the Terrace Mountains blocks was accompanied by rotational faulting of the Permian strata along the west side of the mountains. The possibility is recognized that the east-west trending folds may also be related to the later tilting of the major fault blocks, although this relationship seems unlikely.

Block faulting of the Basin and Range type apparently took place in the Miocene and has continued on a minor scale at least to Pleistocene time.

Relief ancestral to that of the present developed before deposition of the late Tertiary (Pliocene), Salt Lake Group, but renewed Basin and Range-type faulting has increased dissection since that time. In probable contemporaneity with deposition of the Salt Lake Group and late stages of block faulting, small basalt flows emanated from fault planes at several places within the studied area.

Most of the mapped area was greatly modified geomorphically by Lake Bonneville and has been rising isostatically as a result of the desiccation of that lake during the latter part of the Pleistocene. Sediments of the Bonneville Group are common in the studied area, and their displacement locally indicates that faulting has been active until very recent time.

Post Bonneville erosion is evidenced by numerous and extensive alluvial fans which conceal and largely eradicate shore-line terraces that they cover.

BIBLIOGRAPHY

Arnold, Dwight E., 1956, Geology of the Northern Stansbury Range, Tooele County, Utah: unpublished Masters thesis, Univ. of Utah.

Bagnold, R. A., 1941, The physics of blown sand and desert dunes: London, Methuen.

Baker, A. A., Huddle, J. W., and Kinney, D. M., 1949, Paleozoic geology of north and west sides of Uinta Basin, Utah: Am. Assoc. Petroleum Geologists Bull., v. 33, p. 1161.

Baker, A. A., and others, 1947, Stratigraphy of the Wasatch Mountains in the vicinity of Provo, Utah: U.S. Geol. Survey Oil and Gas Inv. Prelim. Chart no. 30.

Baker, A. A., and Williams, J. Steel, 1940, Permian in parts of the Rocky Mountain and Colorado Plateau regions: Am. Assoc. Petroleum Geologists Bull., v. 24, p. 617-35.

Bissell, Harold, 1962, Pennsylvanian-Permian Oquirrh Basin of Utah: <u>in</u> Brigham Young Univ. Geol. Studies, v. 9, part 1, p. 26-49.

Bissell, Harold, 1959, Stratigraphy of the Southern Oquirrh Mountains, Pennsylvanian System: <u>in</u> Utah Geol. Soc. Guidebook No. 14, H. J. Bissell, ed.

Blackwelder, E., 1918, New geological formations in western Wyoming: Washington Acad. Sci. Jour., v. 8.

Blissenbach, E., 1954, Geology of alluvial fans in semiarid regions: Geol. Soc. America Bull., v. 65, p. 175-89.

Boutwell, J. M., 1907, Stratigraphy and structure of the Park City mining district, Utah: Jour. Geol., v. 15, p. 434-58.

Christiansen, F. W., 1963, Polygonal fracture and fold systems in the salt crust, Great Salt Lake Desert, Utah: Science, v. 139, no. 3555, p. 607-09.

Clark, D. L., 1957, Marine Triassic stratigraphy in eastern Great Basin: Am. Assoc. Petroleum Geologists Bull., v. 41, n. 10.

Clark, D. L., 1960, Triassic biostratigraphy of eastern Nevada: Intermountain Assoc. Petroleum Geologists 11th Ann. Field Conf.

Clark, D. L., and Stokes, W. L., 1956, Preliminary survey of Triassic rocks in eastern Great Basin: Am. Assoc. Petroleum Geologists, Bull., v. 40, p. 1686-92.

Crittenden, Max D., 1963, New data on the isostatic deformation of Lake Bonneville: U.S. Geol. Survey Prof. Paper 454-E.

Dibble, C. E., 1947, The Mormon Mission to the Shoshoni Indians: Utah Humanities Review, v. 1, no. 1, p. 53-57.

Dunbar, and others, 1960, Correlation of the Permian formations of North America: Geol. Soc. America Bull., v. 71, p. 1763-1808.

Eardley, A. J., 1951, Structural geology of North America: New York, Harpers Brothers, 624 p.

Eardley, A. J., Gvozdetsky, V., and Marsell, R. E., 1957, Hydrology of Lake Bonneville and sediments and soils of the Basin: Geol. Soc. America Bull., v. 68, p. 1141-1202.

Gilbert, G. K., 1890, Lake Bonneville: U.S. Geol. Survey Mon. 1, 438 p.

Gilluly, James, 1932, Geology and ore deposits of the Stocton and Fairfield quadrangles, Utah: U.S. Geol. Survey Prof. Paper 173, 171 p.

Hose, R. K., and Repenning, C. A., 1959, Stratigraphy of Pennsylvanian, Permian, and Lower Triassic rocks of Confusion Range, west-central Utah: Am. Assoc. Petroleum Geologists Bull., v. 43, No. 9, p. 2167-96.

Hunt, C. B., Varnes, H. D., and Thomas, H. E., 1953, Lake Bonneville--geology of northern Utah Valley, Utah: U.S. Geol. Survey Prof. Paper 257-A, p. 1-99.

Illing, L. V., 1954, Bahaman calcareous sands: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 1-95.

Jennings, J. D., 1953, Danger Cave: Univ. of Utah Anthropological Papers, no. 27.

Jennings, J. D., Smith, E. R., and Dibble, C. E., 1959, Indians of Utah; past and present: Univ. of Utah, Dept. of Anthropology.

Jones, D. J., and Marsell, R. E., 1955, Pleistocene sediments of lower Jordan Valley, Utah: in Utah Geol. Soc. Guidebook No. 10.

King, Clarence, 1877, Geological explorations of the Fortieth Parallel: Prof. Paper of the Engr. Dept. U.S. Army, v. 2, no. 18.

Kummel, B., 1954, Triassic stratigraphy of southeastern Idaho and adjacent areas: U.S. Geol. Survey Prof. Paper 254-H.

Mansfield, G. R., 1916, Subdivisions of the Thaynes Limestone and Nuggett Sandstone, Mesozoic, in the Fort Hall Indian Reservation, Idaho: Washington Acad. Sci., Jour., v. 6, p. 31-42.

McKelvey, V. E., and others, 1956, Summary description of Phosphoria, Park City, and Shedhorn Formations in western phosphate field: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 12, p. 2826-63.

McKelvey, V. E., 1949, Geological studies of the western phosphate field: Mining Eng., v. 1, p. 270.

Miller, A. K., and Cline, L. M., 1934, The cephalopods of the Phosphoria Formation of northwestern United States: Jour. Paleontology, v. 8, p. 281-302.

Miller, A. K., Furnish, W. M., and Clark, D. L., 1957, Permian Ammonoids from western United States: Jour. Paleontology, v. 31, no. 6, p. 1057-1068.

Moritz, C. A., 1951, Triassic and Jurassic stratigraphy of southwestern Montana: Am. Assoc. Petroleum Geologists Bull., v. 35, p. 1781-1814.

Newell, N. C., and Kummel, B., 1942, Lower Eo-Triassic stratigraphy, western Wyoming and southeast Idaho: Geol. Soc. America Bull., v. 53, p. 937-955.

Newell, N. D., 1948, Key Permian section, Confusion Range, western Utah: Geol. Soc. America Bull., v. 59, p. 1053-58.

Nolan, T. B., 1935, The Gold Hill mining district, Utah: U.S. Geol. Survey Prof. Paper 117, 172 p.

Olson, R. H., 1960, Geology of the Promontory Range, Box Elder County, Utah: unpublished Ph. D. thesis, Univ. of Utah.

Proctor, P. D. and Bullock, K., 1963, Igneous rocks of Utah: in Oil and Gas Possibilities of Utah, Re-evaluated, Utah Geol. and Mineral. Surv. Bull. 54, 564 p.

Richards, R. W. and Mansfield, G. R., 1912, The Bannock overthrust; a major fault in southeastern Idaho and northeastern Utah: Jour. Geology, v. 20, p. 681-709.

Rigby, J. K., 1958, Geology of the Stansbury Mountains: in Utah Geol. Soc. Guidebook, no. 14.

Schuchert, Charles, 1924, Historical geology: John Wiley & Sons, Inc.

Setty, A. P., 1963, The paleontological and ecological study of fresh-water diatoms of Lake Bonneville Basin, Utah: unpub. Ph. D. thesis, Univ. of Utah.

Slentz, L. W., 1955, Salt Lake Group in lower Jordan Valley, Utah: in Utah Geol. Soc. Guidebook 10, p. 23-36.

Slentz, L. W., 1955, Tertiary Salt Lake Group in the Great Salt Lake Basin: unpublished Ph. D. thesis, Univ. of Utah.

Smith, J. P., 1932, Lower Triassic ammonoids of North America: U.S. Geol. Survey Prof. Paper 167.

Spurr, J. E., 1895, Economic geology of the Mercen mining district, Utah: U.S. Geol. Survey 16th Ann. Rept., pt. 2, p. 374-76.

Stansbury, Howard, 1853, Exploration and survey of the valley of the Great Salt Lake of Utah, including a reconnaissance of a new route through the Rocky Mountains: Corps. of U.S. Army Engineers, Washington.

Steele, G., 1959, Basin and Range structure reflects Paleozoic tectonics and sedimentation [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 43., p. 1105.

Steele, G., 1959, Stratigraphic interpretation of the Penn-Permian Systems of the eastern Great Basin: Ph. D. thesis, Univ. of Washington.

Steele, Grant, 1960, Pennsylvanian-Permian stratigraphy of east-central Nevada and adjacent Utah: in Intermountain Assoc. Petroleum Geologists Guidebook 11th Ann. Field Conf., p. 91-113.

Stifel, P. B., and Shroder, J. F., Jr., in press, Barchan-shaped dunes of probably subaequeous origin in the Great Salt Lake Desert [abs.]: Proceedings, Utah Academy of Sciences, Arts, and Letters, v. 42, part 1.

Stifel, P. B. and Stokes, W. L., 1961, Some unusual sedimentary structures along the shore of Great Salt Lake [abs.]: Proceedings, Utah Acad. of Sciences, Arts, and Letters, v. 38, p. 131.

Thompson, M. L., 1954, American Wolfcampian fusulinids: Kansas Univ. Paleont. Contr., no. 14, Protozoa, art. 5.

Tooker, E. W., and Roberts, R. J., 1961, Stratigraphy of the north end of the Oquirrh Mountains, Utah: in Utah Geol. Soc. Guidebook to the Geology of Utah, no. 16, p. 17-35.

Utah Writers' Project, 1941, Utah, a guide to the state: New York, Hastings House.

Welsh, J. E. and James, A. H., 1961, Pennsylvanian and Permian stratigraphy of the central Oquirrh Mountains, Utah: in Utah Geol. Soc. Guidebook to the Geology of Utah, no. 16, p. 1-16.

Williams, J. Steele, 1943, Pennsylvanian and Permian rocks: in Intermountain Assoc. Petroleum Geologists 4th Ann. Field Conf., p. 38-40.

Williams, J. Stewart, 1962, Lake Bonneville: geology of southern Cache Valley, Utah: U.S. Geol. Survey Prof. Paper 257-C, 150 p.

APPENDIX

The following is a list of geographic names used for location within the study area, approved in May, 1964 by the Board on Geographic Names of the U.S. Department of the Interior:

Big Pass: generally north-south trending valley dividing the Terrace Mountains just east of Tangent Peak; Box Elder County, Utah; 41°30' N., 113°09' W. [north end], 41°26' N., 113°07' W. [south end].

Peter B. Stifel, Brigham City 1:250; the pass is very large and distinct, thus the name; not in a USNF; name reported in local usage by stockmen.

Crocodile Mountain: north-south trending mountain about 2.5 miles long, with an elevation of about 4,700 feet, about 2 miles northeast of the Hogup Mountains and 8 miles west of the northwest end of the Great Salt Lake; so named because the mountain profile resembles a crocodile's head; Box Elder County, Utah; 41°38' 30" N., 113°07'30" W.

Peter B. Stifel, Brigham City 1:250; name proposal for an unnamed feature; not in a USNF.

Hogup Bar: ridge about 1.5 miles long with an elevation of about 4,380 feet, between Crocodile Mountain, on the northeast, and the Hogup Mountains, on the southwest; Box Elder County, Utah; 41°37'15" N., 113°08'00" W.

Peter B. Stifel, Brigham City 1:250; name proposal for an unnamed feature; not in a USNF.

Kelton Butte: butte on the southeast end of Peplin Mountain just northwest of Peplin Flats and about 7 miles southwest of Kelton; Box Elder County, Utah; 41°40'05" N., 113°10'40" W.

Peter B. Stifel, Brigham City 1:250; to establish the name; first used by G. K. Gilbert in USGS Monograph no. 1, 1890; not in a USNF.

Peplin Flats: basin about 3 miles across; it is bounded on the east by Crocodile Mountain and Hogup Bar, on the south by the Hogup Mountains, and on the northwest by Peplin Mountain; Box Elder County, Utah; 41°39'00" N., 113°09'00" W.

Peter B. Stifel, Brigham City 1:250; name proposal for an unnamed feature; the name "Peplin" is common to the area; not in a USNF.

Scorpio Peak: mountain peak with an elevation of about 6,560 feet, in the southern part of the Terrace Mountains about 10 miles southwest of Dolphin Island in the Great Salt Lake; so named because of the numerous scorpions found on its slopes; Box Elder

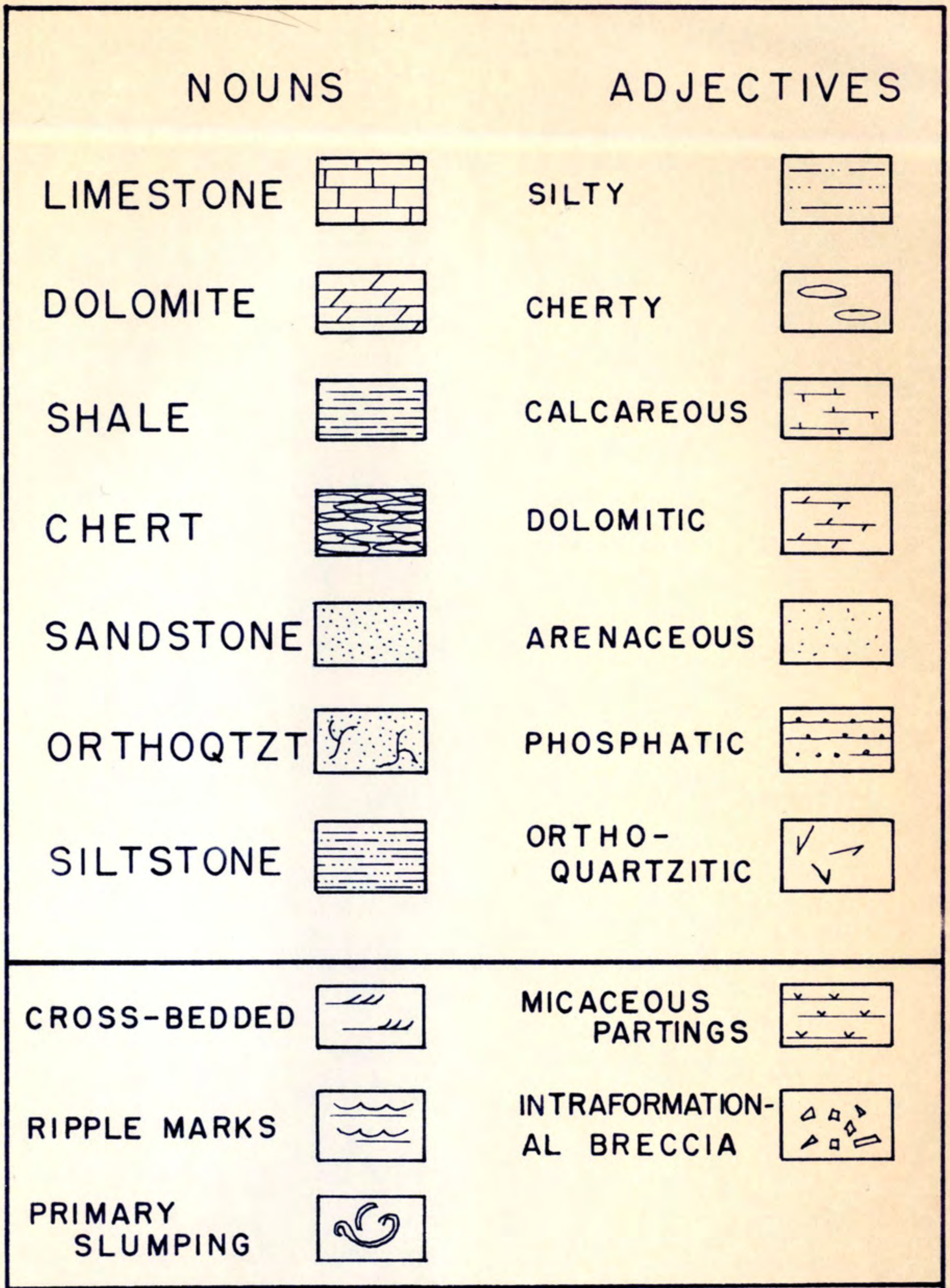
County, Utah; 41°24'20" N., 113°10'15" W.
Peter B. Stifel, Brigham City 1:250; name proposal for an unnamed feature; not in a USNF.

Shelter Mountain: mountain with an elevation of about 5,900 feet, on the west side of the Terrace Mountains about 3 miles west-northwest of Scorpio Peak; Box Elder County, Utah; 41°25'30" N., 113° 13'00" W.
Peter B. Stifel, Brigham City 1:250; name proposal for an unnamed feature; not in a USNF.

Shelter Mountain Pass: pass on the west side of the Terrace Mountains just east of Shelter Mountain; Box Elder County, Utah; 41°25' N., 113°13' W.
Peter B. Stifel, Brigham City; name proposal for an unnamed feature; not in a USNF.

Tangent Peak: mountain peak with an elevation of about 6,750 feet, in the Terrace Mountains about 9 miles west-northwest of Dolphin Island in the Great Salt Lake; named by the Clarence King Expedition (1877); Box Elder County, Utah; 41°28'50" N., 113°10'25" W.
Peter B. Stifel, Brigham City 1:250; to establish the name; unused on maps but used first by A. Hague in King's Exploration of the 40th Parallel; not in a USNF.

Terrace Spit: arcuate ridge about 9 miles long, extending southeastward from the east side of the Terrace Mountains along the west shore of the Great Salt Lake; Box Elder County, Utah; 41°26'30" N., 113°05'30" W. [northwest end], 41°20'00" N., 113°00'10" W. [southeast end].
Peter B. Stifel, Brigham City 1:250; name proposal for an unnamed feature; not in a USNF.



GRAPHIC SYMBOLS USED IN COLUMNAR SECTIONS

TABLE I