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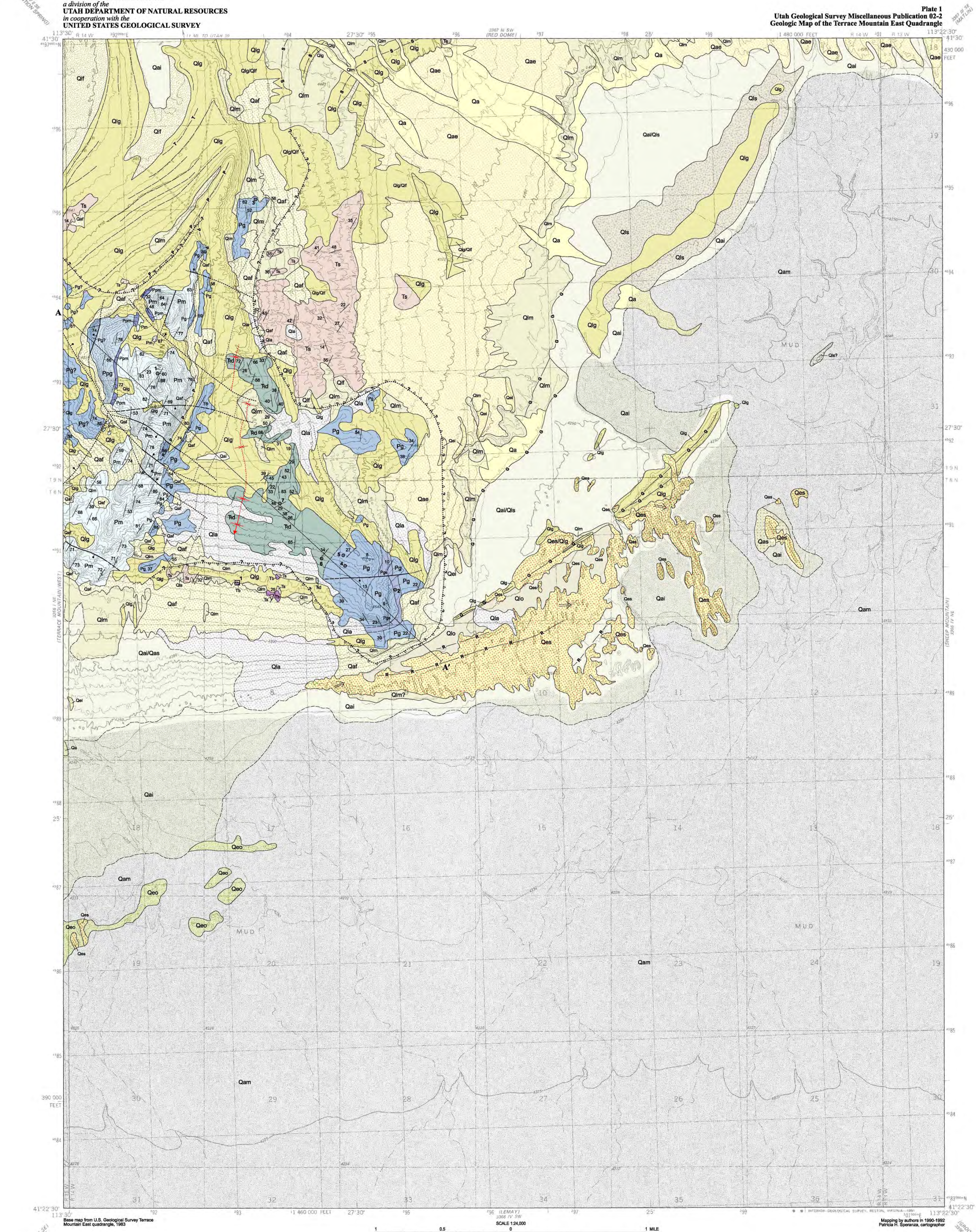


Base map from U.S. Geological Survey Terrace Mountain East quadrangle, 1983

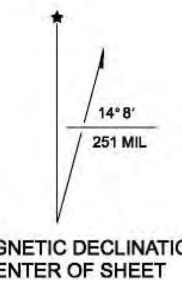
Mapping by authors in 1990-1992
Patricia H. Speranza, cartographer

SCALE 1:24,000

1 0.5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0.5 0 1 KILOMETER



2002 MAGNETIC DECLINATION
AT CENTER OF SHEET

GEOLOGIC MAP OF THE TERRACE MOUNTAIN EAST QUADRANGLE, BOX ELDER COUNTY, UTAH

by
Padhrig T. McCarthy and David M. Miller
U.S. Geological Survey

2002

QUADRANGLE LOCATION

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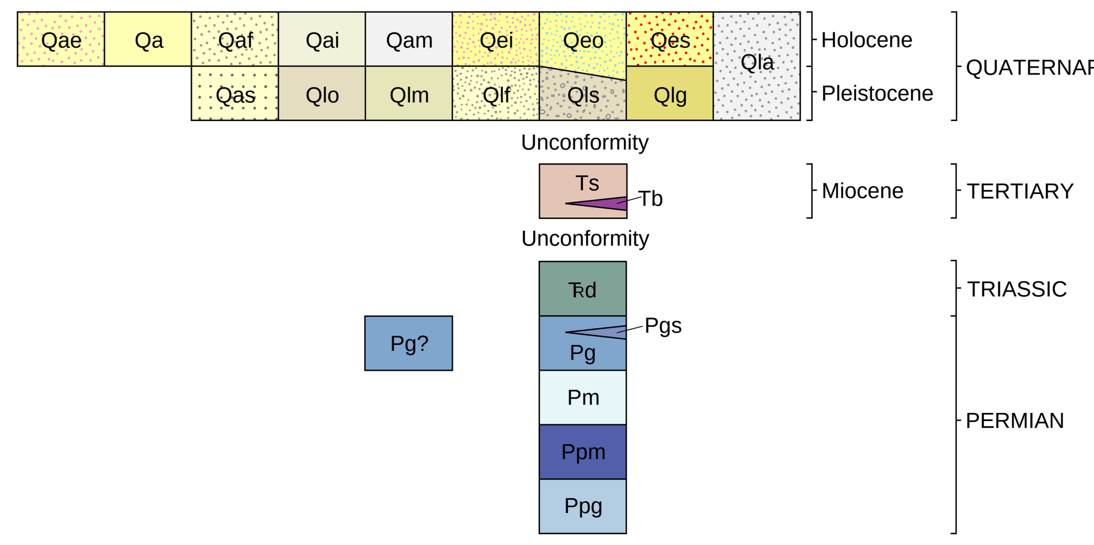
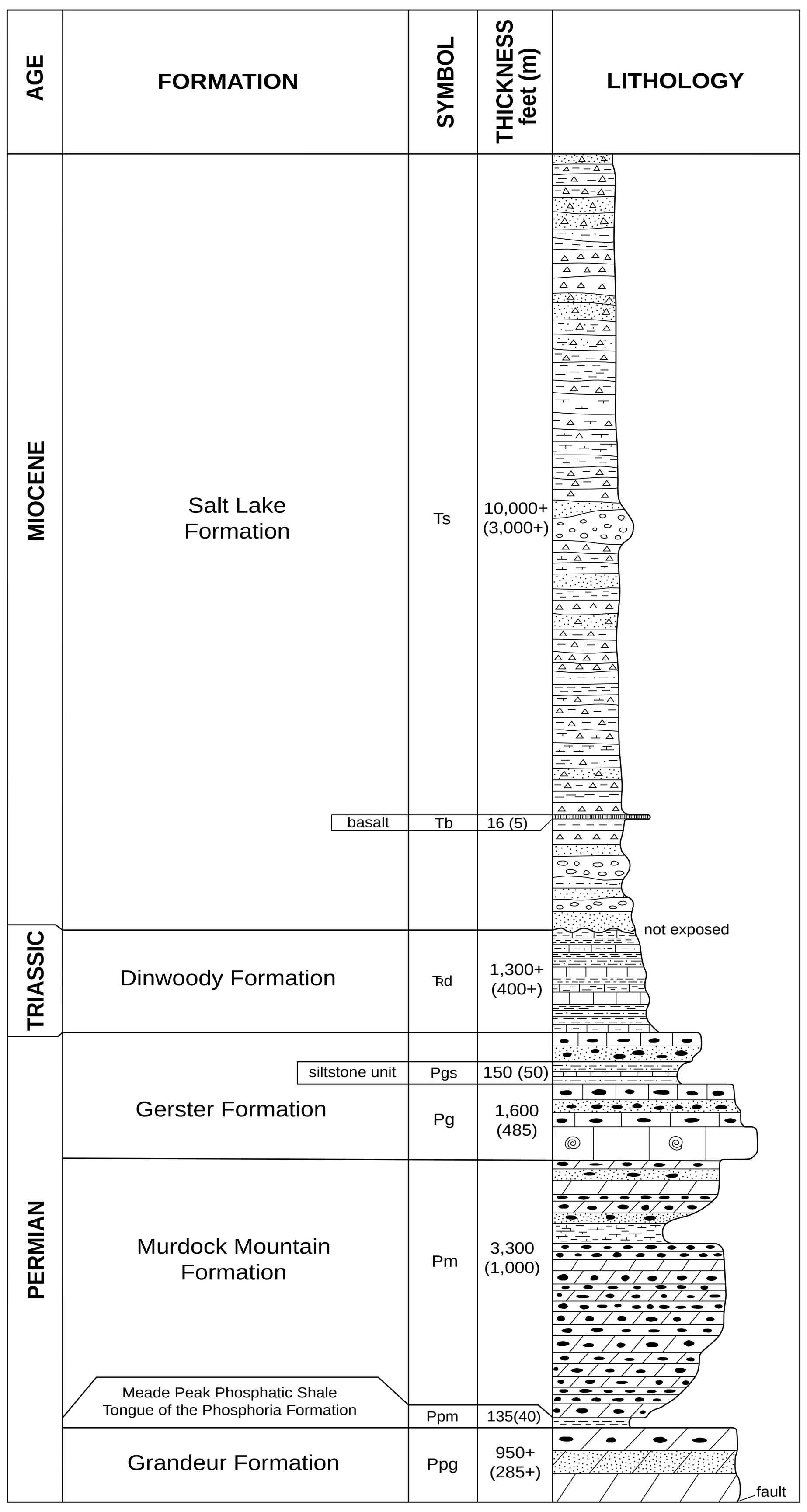
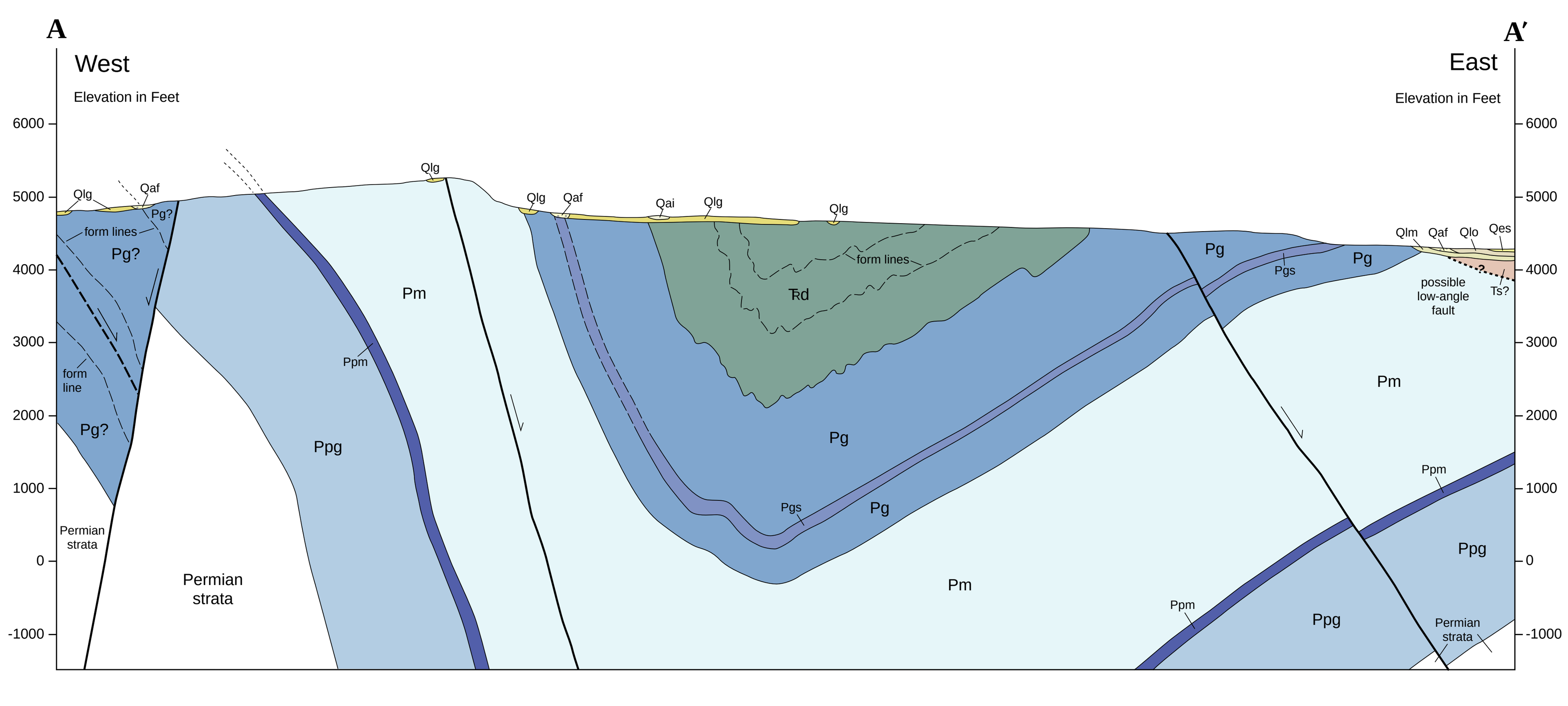
DESCRIPTION OF MAP SYMBOLS

- CONTACT–Dashed where gradational or approximately located, dotted where covered
- HIGH-ANGLE FAULT–Dashed where approximately located, dotted where concealed; queried where location uncertain; bar and ball on downthrown side; arrows show sense of movement on cross section
- LOW-ANGLE FAULT–Concealed and location uncertain; teeth on upper plate
- STRIKE AND DIP OF BEDDING
  - 27 Inclined
  - Vertical
  - 74 Overturned
- TRACE OF AXIAL SURFACE OF SYNCLINE–Showing direction of plunge; dotted where concealed
- DIRECTION OF SEDIMENT TRANSPORT
- 1 LOCATION OF GEOCHRONOLOGY SAMPLE
- 4 LOCATION OF PALEONTOLOGY SAMPLE
- SHORELINE–uncertain timing
- P PROVO SHORELINE
- S STANSBURY SHORELINES
- G GILBERT SHORELINES
- R REGRESSIVE SHORELINES
- T TRANSGRESSIVE SHORELINE
- Qlf/Qlg THIN DEPOSITS RESTING ON OLDER DEPOSITS

CORRELATION OF MAP UNITS







DESCRIPTION OF MAP UNITS

Qae Alluvial and eolian deposits, undivided (Holocene)--*Brown silt of alluvial and eolian origin, interbedded as thin sheets.*

Qa Alluvium (Holocene)--*Sand, silt, clay, and minor gravel deposited along active washes.*

Qaf Alluvial-fan deposits (Holocene)--*Gravel, sand, and silt forming alluvial fans, most of which issue from steep slopes of Terrace Mountain.*

Qai Alluvial silt (Holocene)--*Silt, fine sand, and clay deposited as broad sheets on plain flanking Terrace Mountain; transitional to alluvial mud flats. Deposited by streams and sheet floods. Also present in depressions bounded by lacustrine beaches.*

Qam Alluvial mud (Holocene)--*Medium-brown mud with minor sand and silt. Underlies alluvial mud flats in southern and eastern part of quadrangle.*

Qei Eolian silt (Holocene)--*Dunes of brown silt and fine-grained sand. Deposits lie on lacustrine marl east of Terrace Mountain.*

Qeo Eolian ooid sand (Holocene and Pleistocene)--*Ooid sand and minor quartz sand and mud pellets. Deposits formed along linear features on mud flats that probably represent ground-water seepage zones.*

Qes Eolian sand (Holocene)--*Dunes consisting of brown sand and silt of various compositions: ooids, gypsum, quartz, lithics, and mixtures of these. Sand varies in composition from dune to dune. Deposits primarily lie along Gilbert spit extending east from south tip of Terrace Mountain.*

Qla Lacustrine and alluvial deposits, undivided (Holocene and Pleistocene)--*Thinly interbedded silt and sand deposits of lacustrine and alluvial origins. In most areas, unit consists of thin sheets of fine-grained alluvium on erratically exposed lacustrine marl.*

Qas Alluvial sand and silt (Pleistocene)--*Medium-brown, interbedded fine-grained sand, silt, and mud. Deposits are finer grained at lower altitudes. Predates Gilbert shoreline of Lake Bonneville.*

Qlo Lacustrine ooid sand (Pleistocene)--*Coarse- to medium-grained sand composed mostly of ooids. Exposed below Gilbert spit at southeast part of Terrace Mountain.*

Qlm Lacustrine marl (Pleistocene)--*White and gray marl and clay, locally containing silt.*

Qlf Lacustrine fine-grained deposits (Pleistocene)--*Fine-grained sandy mud and sandy marl deposited as thin sheets in northwest part of quadrangle.*

Qls Lacustrine sand (Pleistocene)--*Fine- to medium-grained sand, well sorted and well rounded. Associated with spits and bars east of Terrace Mountain.*

Qlg Lacustrine gravel deposits (Pleistocene)--*Cobble- and pebble-gravel and subordinate sand. Forms prominent barrier beaches, spits, and bars.*

Ts Salt Lake Formation (Miocene)--*White, yellow, yellowish-brown, green, and gray, moderately lithified siltstone, sandstone, mudstone, and conglomerate, commonly tuffaceous. Locally contains boulders of rhyolite lava. Contains basalt (Tb) mapped separately.*

Tb Basalt--*Dark brown to black massive to nodular basalt and red vesicular basalt lying on tuffaceous sandstone. K-Ar date on sample is about 18 Ma.*

Ŧd Dinwoody Formation (Triassic)--*Gray and brown, thin- to medium-bedded, impure limestone, and tan, green, and brown, calcareous shale, and siltstone. Limestone beds typically highly fossiliferous.*

Pg Gerster Formation (Permian)--*Dark-gray, fossiliferous limestone, chert, sandstone, and siltstone. Base marked by thick beds of productid-bearing limestone. Locally containing:*

Pgs Siltstone subunit of Gerster Formation--*Tan to orange siltstone interbedded with gray limestone. Chert forms nodules.*

Pg? Gerster(?) Formation (Permian)--*Thick sequence of chert rock containing traces of bedded fossiliferous limestone, sandstone, and siltstone. Correlation uncertain (queried) because rocks are highly fractured. Exposed on west side of Terrace Mountain.*

Pm Murdock Mountain Formation (Permian)--*Dark-brown to tan, thick- to thin-bedded chert, dolomitic sandstone, and cherty dolomite. Middle part composed of distinctive silty limestone. Typically highly fractured.*

Ppm Meade Peak Phosphatic Shale Tongue of the Phosphoria Formation (Permian)--*Light-gray to black, calcareous shale and fissile, yellow-brown siltstone, with minor gray limestone. Thin-bedded, poorly exposed.*

Ppg Grandeur Formation of the Park City Group (Permian)--*Light-gray sandy dolomite and medium-brown dolomitic sandstone. Medium to thick bedded.*

Note on mapping conventions: Where a Quaternary map unit is present as a thin veneer, the unit label of the veneer is above the line (/) and the underlying unit is below the line. For instance, Qai/Qls indicates that a thin sheet of Qai overlies Qls.

McCarthy, Miller
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Utah Geological Survey MP-02-2

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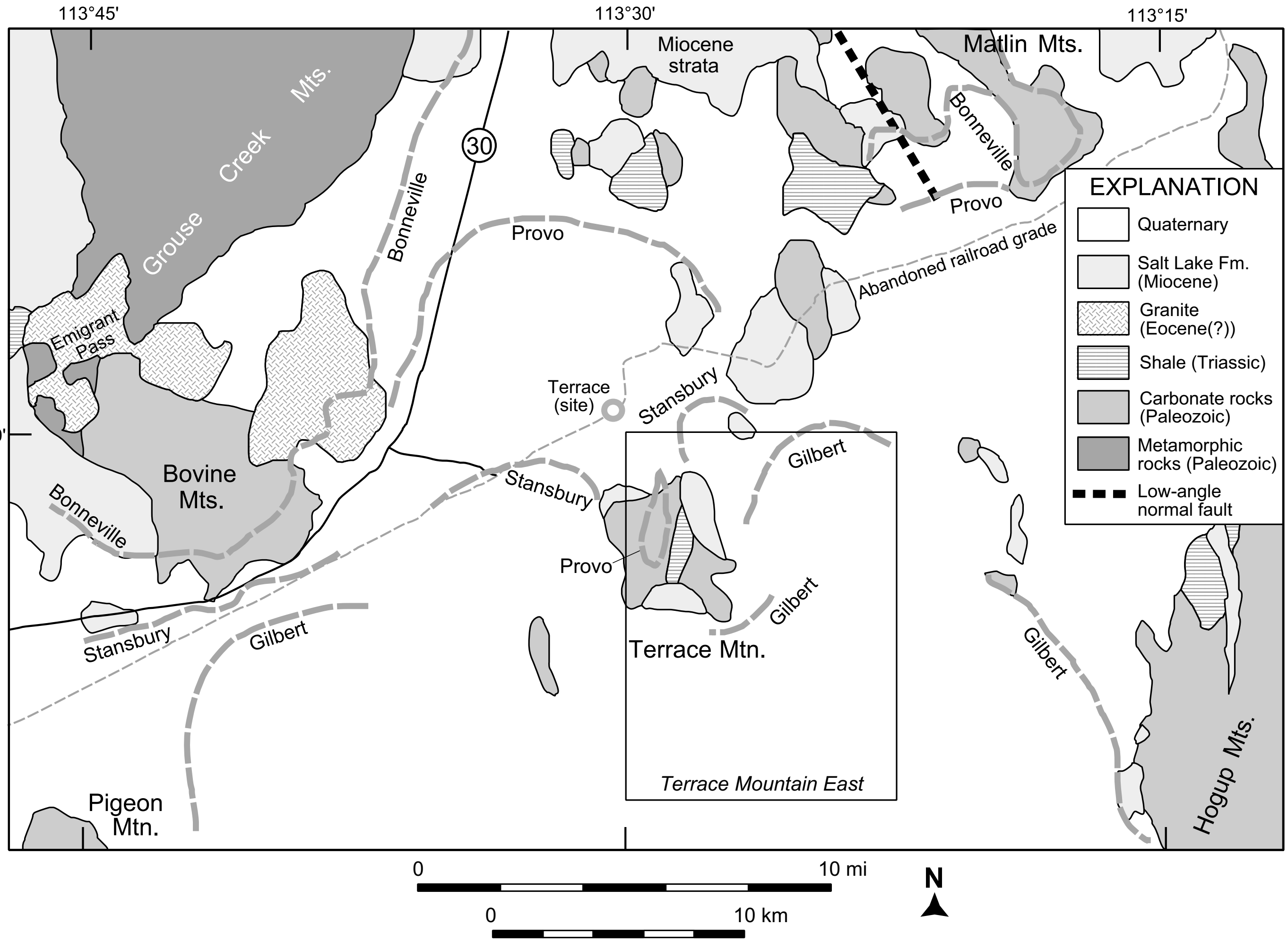

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UTAH GEOLOGICAL SURVEY

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GEOLOGIC MAP OF THE TERRACE MOUNTAIN EAST QUADRANGLE, BOX ELDER COUNTY, UTAH

by

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U.S. Geological Survey

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ABSTRACT

Much of Terrace Mountain, an isolated small mountain on the north edge of the Great Salt Lake Desert, is within the Terrace Mountain East quadrangle. Permian and Triassic rocks that were folded into a large north-trending syncline underlie the mountain. Faults cutting these rocks are typically marked by altered breccia, which is prospected at one place. Miocene strata overlying these older rocks dip westward, either as a result of emplacement as a low-angle, fault-bounded sheet across the older rocks or by deposition against and subsequent tilting with the older rocks. Relations in the adjacent Terrace Mountain West quadrangle point to the low-angle fault interpretation. Quaternary alluvial, lacustrine, and eolian sediments blanket much of the quadrangle. In particular, lacustrine deposits display the many shorelines of late Pleistocene Lake Bonneville.

INTRODUCTION

The Terrace Mountain East quadrangle is located in northwestern Utah, southeast of Utah State Highway 30 (figure 1) and about 25 miles (40 km) south of Park Valley. Rocks in the quadrangle are of Permian, Triassic, and Miocene age; these rocks were eroded and then partly buried by deposits of late Pleistocene Lake Bonneville and younger alluvial sediments. The resistant Permian and Triassic rocks form Terrace Mountain. Terrace Mountain was named, along with a siding of the Southern Pacific Railroad at the townsite of Terrace, 3 miles (5 km) northwest of the mountain and outside the quadrangle, for the gravel terraces on the north side of the mountain (figure 2).

The high point of the quadrangle is Terrace Mountain's peak, which, at 5,361 feet (1,634 m), rose about 80 feet (25 m) above the surface of Lake Bonneville at its high stand. Roughly three-fourths of the quadrangle is composed of Quaternary lacustrine and reworked lacustrine deposits of Lake Bonneville. Most of these deposits form a terrain of low relief (less than 50 feet [16 m]) surrounding the mountain. The lowest elevation, 4,222 feet (1,288 m), is located at the quadrangle's southern edge.

Tertiary rocks of the Salt Lake Formation crop out around the perimeter of Terrace Mountain and probably underlie much of the Quaternary cover. These rocks include tuffaceous lacustrine sandstone and pebbly sand, tuffaceous sandstone and siltstone, basalt, and sparse coarse conglomerate.

A small-scale geologic map of Box Elder County by Doelling (1980) was the first map to show the rock units at Terrace Mountain and in the surrounding region. The Terrace Mountain East quadrangle lies adjacent to the Terrace Mountain West quadrangle, geologically mapped by Miller and McCarthy (2002); southwest of the Matlin Mountains, which were mapped by Todd (1983); and east of the Bovine Mountains, which were mapped by Jordan (1983) (figure 1). The Hogup Mountains, where the stratigraphy is similar to that at Terrace Mountain, lie directly to the east about 12.5 miles (20 km). Stifel (1964) described the geology of the Hogup Mountains in detail.

DESCRIPTION OF MAP UNITS

Permian Rocks

Grandeur Formation (Ppg)

The Grandeur Formation of the Park City Group underlies a small area on the west flank of Terrace Mountain, where it crops out through thin gravel deposits as large light-gray and tannish gray blocks of sandy dolomite and medium-brown dolomitic sandstone. Although greater thicknesses of the unit are observed in nearby mountain ranges, only the uppermost 950 feet (285 m) are exposed at Terrace Mountain due to a fault that truncates the base.

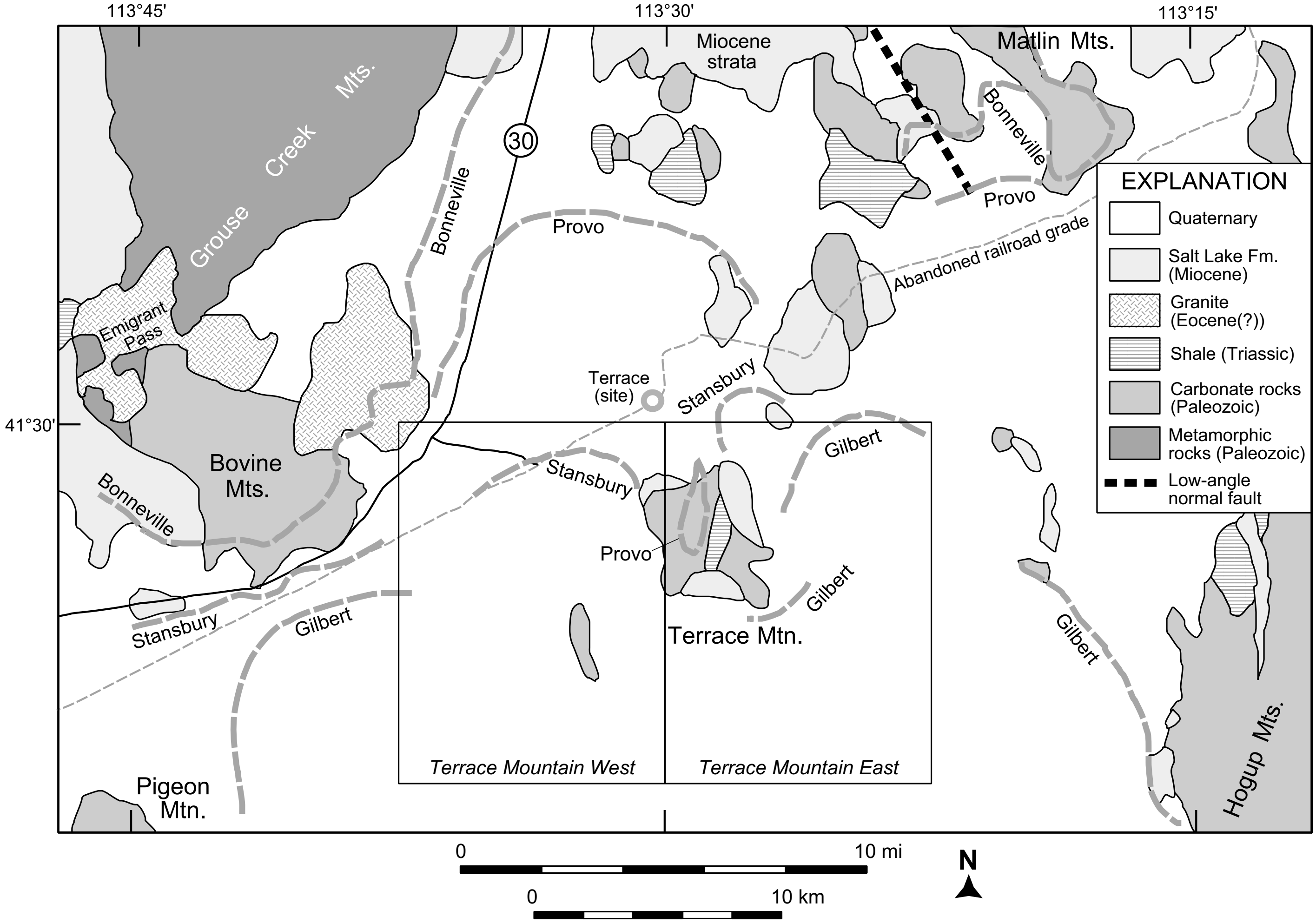

Figure 1. Location map showing general geologic features in vicinity of Terrace Mountain. Terrace Mountain West and Terrace Mountain East 7.5-minute quadrangles are outlined by boxes. Prominent Lake Bonneville shorelines are indicated by broad patterned lines. Thick dashed line in Matlin Mountains represents boundary between detached (west) and rooted (east) terranes of Todd (1983). Geology modified from Doelling (1980), Todd (1983), Jordan (1983), and D.M. Miller and P.T. McCarthy (unpublished mapping, 1992).

Figure 2. Photograph of Terrace Mountain viewed to the east. Gravel terraces extend left (north) from the crest. Alluvial mud flats extend to the south. In the foreground are Quaternary alluvial and lacustrine deposits.

The Grandeur Formation is mostly thick-bedded, light-gray, coarse-grained dolomite with medium-grained bioclastic beds. Brown sandy zones and chert lenses 0.5 to 2 inch (1.25-5 cm) thick, which are laterally continuous for no more than a few tens of feet (3-10 m), are present in the lower part of the section present at Terrace Mountain. No bedding is preserved in these siliceous zones, in contrast to common cross-bedding displayed in sandstone in the lower part of the Grandeur at the Hogup Mountains (Stifel, 1964). Dolomite that makes up the uppermost 200 to 300 feet (60-90 m) contains less sand than lower in the unit, but distinct brown sandstone beds are present within this interval. The uppermost part of the Grandeur is marked by a zone with vertical features that appear to be worm burrows replaced by chert. The Grandeur appears to be in conformable contact with the overlying Meade Peak Phosphatic Shale Tongue of the Phosphoria Formation.

A complete section of the Grandeur Formation is present in the nearby Hogup Mountains (figure 1). There, the unit is 1,838 feet (556 m) thick and consists of interbedded silty dolomite and chert with occasional limestone and sandstone beds (Stifel, 1964). Stifel (1964) assigned a late Leonardian age to the Grandeur of the Hogup Mountains. We assign the rocks at Terrace Mountain to the Grandeur Formation on the basis of lithology and stratigraphic position. At the Matlin Mountains to the north, Todd (1983) described a section lying stratigraphically above the Oquirrh Formation as a lower interbedded limestone and sandstone unit overlain by the Kaibab(?) Limestone, both of Leonardian age. Todd described vertical chert pipe features in the middle part of her Kaibab(?) Limestone, which may correlate with the distinctive chert in the uppermost part of the Grandeur Formation. If so, the lower half of Todd's (1983) Kaibab(?) and much or all of her interbedded limestone and sandstone unit at the Matlin Mountains are the Grandeur Formation. This equivalence is strengthened by the similar stratigraphic position of the Kaibab Limestone and Grandeur Formation (Wardlaw and others, 1979b).

Meade Peak Phosphatic Shale Tongue of the Phosphoria Formation (Ppm)

The Meade Peak Phosphatic Shale Tongue of the Phosphoria Formation is present in northwestern Utah as a thin shale unit (Wardlaw and others, 1979b; Miller and others, 1984). At Terrace Mountain it is exposed in gullies that incise gravel above the Provo shoreline on the west side of the mountain. The unit consists of yellow-brown calcareous siltstone, light-gray to black calcareous shale, fissile yellow siltstone, and minor gray limestone. The rock commonly appears as chippy float, but there are a few solid outcrops. Phosphatic nodules were not observed.

The Meade Peak Phosphatic Shale Tongue is about 135 feet (40 m) thick at Terrace Mountain, similar to thicknesses at Lemay Island about 28 miles (45 km) to the southwest (194 feet [59 m]; Miller and Glick, 1986) and in the Leach Mountains 47 miles (75 km) to the west (130 feet [40 m]; Miller and others, 1984). The Meade Peak is much thicker in the Lucin NW quadrangle about 25 miles (40 km) to the west, where 442 feet (135 m) are exposed, but rocks from overlying units may be included there (Miller and Oviatt, 1994). The Meade Peak is also much thicker in the Hogup Mountains (Stifel, 1964), where 397 feet (121 m) of section allotted to this unit consists of upper and lower zones of siltstone and shale separated by about 161 feet (49 m) of siliceous carbonate rocks. One of the siltstone-shale intervals may pinch out between Terrace Mountain and the Hogup Mountains. The Meade Peak was not identified by Todd (1983) in the Matlin Mountains. The Meade Peak Phosphatic Shale Tongue is late Leonardian (late Early Permian) in age in the region (Miller and others, 1984; Wardlaw and others, 1979b).

Murdock Mountain Formation (Pm)

The resistant Murdock Mountain Formation was defined by Wardlaw and others (1979a) as a transitional facies between the Plympton Formation in central Utah and the Rex Chert Member of the Phosphoria Formation in Idaho. The Murdock Mountain underlies the high ridge of Terrace Mountain. It consists of thin- to very thick-bedded chert and dolomitic sandstone that range in color from dark brown to tan. Parts of the section contain as much as 30 percent dolomite, present both as distinct beds and as large irregular blocks surrounded by chert matrix. The lower part of the unit consists mostly of dark chert, bedded on a 2- to 6-inch (5-15 cm) scale, as well as common dolomite interbeds. The middle part of the unit is distinctive silty limestone that is not described in most parts of the region. The upper part of the unit is mainly chert that is lighter in color and more massively bedded than that in the lower part. Limestone beds are uncommon, but present within all parts of the Murdock Mountain.

The silty limestone interval is about 250 feet (80 m) thick and forms the middle part of the Murdock Mountain Formation. This interval consists of 1- to 4-inch-thick (2.5 to 10 cm) beds of silicified dark-gray and brown limestone separated by zones of silty limestone that weather orange and purple. A few yellow, silty shale beds and fine-grained brown sandstone beds are present in this interval, sandstone being more common in the lower half. This silty limestone interval is very distinctive due to its thin-bedded appearance, lack of chert, abundance of fine-grained limestone, and unusual weathering colors. It is exposed just west of the highest part of Terrace Mountain and extends south-southwest from that point (center N$^1/_2$ section 31, T. 9 N., R. 14 W.). Sample M92TM-25 (table 1, number 1), taken from this interval, yielded conodonts that range in age from Middle Pennsylvanian to earliest Triassic. The silty limestone interval is folded near this fossil locality and may also be internally faulted, but seems to be concordant with upper and lower parts of the Murdock Mountain Formation.

The thickness of the Murdock Mountain Formation is about 3,300 feet (1,000 m) at Terrace Mountain. This thickness is greater than that of the laterally equivalent Rex Chert Member of the Phosphoria Formation in the nearby Hogup Mountains (Stifel, 1964). Stifel measured 1,157 feet (350 m) of Rex Chert in the Hogup Mountains and Wardlaw and others (1979a) measured 873 feet (266 m), but unpublished mapping by the authors shows the area to be structurally complex and both measured sections to be incomplete. However, the Murdock Mountain Formation is also thinner at its type section in the Leach Mountains (1,263 feet [385 m]). At the Lucin NW quadrangle, Miller and Oviatt (1994) reported a thickness of 1,378 feet (420 m) for the Murdock Mountain Formation, but the overlying rocks (335 feet [102 m] thick in an incomplete section) that they correlated with the Triassic Dinwoody Formation are very similar to the silty limestone interval forming the middle part of the Murdock Mountain Formation at Terrace Mountain. We favor the interpretation that only the lower and middle parts of the Murdock Mountain Formation are exposed at the Lucin NW quadrangle. The Murdock Mountain Formation may encompass the upper part of the Kaibab(?) Limestone and the Plympton(?) Formation as used by Todd (1983) at the Matlin Mountains, for a total thickness of roughly 3,940 feet (1,200 m). The Murdock Mountain Formation is latest Leonardian and early Guadalupian (late Early Permian) in age in northwestern Utah and adjacent Nevada (Wardlaw and others, 1979a), an age consistent with the fossils contained in the Murdock Mountain Formation at Terrace Mountain (table 1).

Gerster Formation (Pg)

The Gerster Formation crops out along the base of the steep east flank of Terrace Mountain, near the Provo shoreline, and in the most southeasterly bedrock exposures. The Gerster consists primarily of fossiliferous limestone and light-colored chert that are less resistant than the underlying Murdock Mountain Formation. The lower part of the Gerster is best exposed near the Provo shoreline (figure 1) and the upper part of the section is best exposed at the southeastern part of Terrace Mountain. The lower part is distinguishable from underlying chert of the Murdock Mountain Formation by the presence at its base of a productid-bearing limestone bed, 40 to 60 feet (12-18 m) thick. The lower part consists of beds of coarse, medium-gray, fossiliferous limestone containing disarticulated crinoid, bryozoan, and brachiopod fragments alternating with beds of light-brown, fine-grained sandstone and siltstone, which in most places are largely altered to chert. The upper part of the Gerster Formation consists of thick beds of chert interbedded with bioclastic limestone and siltstone on a 6.5- to 10-foot (2-3 m) scale. The intertonguing of chert and limestone was noted by Roberts and others (1965) and Wardlaw and others (1979b) as part of a north-to-south facies change. Massive chert in the upper part of the Gerster encloses a siltstone subunit, which is described below.

Table 1. *Paleontology data for the Terrace Mountain East quadrangle.*

Map no.	Field (USGS) number	Rock unit	Fossil age	Date of report	Paleontologist	Faunal description and other information [Latitude and Longitude]
1	M92TM-25 (31771-PC)	Murdock Mountain Formation	Pennsylvanian to earliest Triassic	12/8/92	A.G. Harris	2.4 kg processed for conodonts; a few conodont elements were recovered: 1 Pa element fragment of *Hindeodus* sp. indet.; 1 juvenile Pa element of *Neogondolella*? sp. indet. Age is Middle Pennsylvanian to very earliest Early Triassic (earliest Griesbachian). Conadont Alteration Index (CAI) = 4, indicating that rock reached at least 200°C. [41°27'52" 113°29'12"]
2	M92TM-23	Gerster Formation	Pennsylvanian to Permian	12/8/92	A.G. Harris and W.V. Sliter	3.0 kg sample processed; no conodonts were recovered but the residue yielded: 2 phosphatized steinkern clusters of bryozoan zooercial fillings; 4 ichthyoliths; 2 phosphatized steinkerns of a high-spired gastropod; 3 phosphatized steinkerns of foraminiferans including a *Lingulonodisaria* genus, a nodosariid and an irregularly coiled morphotype. Nodosariids extend into the Permian, and *Lingulonodisaria* range in age from the Early Pennsylvanian to the middle Early Cretaceous. [41°26'27" 113°27'12"]
3	M90TM-166	Gerster Formation	Late Permian	4/21/92	R.K. Paull	Sample yielded the following conodonts: 1 Pa element of *Merrilina galeata* (Stauffer); about 50 indet. fragments. *Merrilina* is common to the Gerster Formation, as well as the Franson and Ervay Members of the Park City Formation. Age is Guadalupian (Late Permian). CAI = 3.5 to 4.0 [41°28'58" 113°28'22"]
4	M91TM-139	Gerster Formation	Late Permian	4/21/92	R.K. Paull	Brachiopods in the sample included *Timaniella* sp., which is common to the upper part of the Gerster Formation. It is associated with the *Neogondolella bitteri* (Zone 6), and also associated with the Retort Phosphatic Shale Member of the Phosphoria Formation in Wyoming, the Franson Member and lower part of the Ervay Member of the Park City Formation of Wyoming, and the Edna Mountain Formation of Nevada. Age is middle to late Wordian. [41°26'38" 113°27'35"]
5	M91TM-140	Gerster Formation	Permian(?)	4/21/92	R.K. Paull	This sample contains phosphatic tubes and abundant bryozoan and crinoid debris. The tubes are common in the Permian, but represent infillings of something (bryozoans?) rather than actual fossils. Barren of conodonts. Fillings suggest a Permian age. [41°26'42" 113°27'37"]
6	M91TM-141	Dinwoody Formation	no information	4/21/92	R.K. Paull	This extremely insoluble sample yielded 3 fish teeth and several broken gastropod steinkerns. No information on their age is available. [41°26'41" 113°27'48"]
7	P90TM-147	Dinwoody Formation	Early Triassic	4/21/92	R.K. Paull	Sample yielded the following conodonts: 2 Sb elements and 10 fragments of *Ellisonia triassica*; 1 Sb element of *Furnishius*. Age is Early Triassic. CAI = 2.5 to 3.0. [41°27'02" 113°28'08"]

The Gerster Formation (including its enclosed siltstone subunit) is about 1,600 feet (485 m) thick at Terrace Mountain. The approximate thickness results from its poorly exposed upper contact. Stifel (1964) described 903 feet (274 m) of the Gerster in the Hogup Mountains to the east, where the section lacks the siltstone subunit, but otherwise is very similar lithologically. The Gerster Formation also is present in the Leach Mountains 46 miles (75 km) west of Terrace Mountain (1,690 feet [514 m] thick; Miller and others, 1984), and in the Matlin Mountains (figure 1) to the north (>2,300 feet [>700 m]; Todd, 1983), and a partial section is present at Lemay Island, 28 miles (45 km) to the southwest (>790 feet [>240 m] thick; Miller and Glick, 1986). Brachiopods collected by V.R. Todd (written communication, 1991) at Terrace Mountain were examined by Bruce Wardlaw, who stated that they belonged to the lower part of the Gerster Formation. Conodonts collected from the upper part of the Gerster Formation yielded a Guadalupian age (table 1, number 3), which agrees with the late Guadalupian age assigned by Stifel (1964) to the formation in the Hogup Mountains, and is in accord with the Early Permian age established by Wardlaw and others (1979b).

Siltstone subunit of the Gerster Formation (Pgs)

The upper part of the Gerster Formation at Terrace Mountain contains a distinctive siltstone interval, informally referred to here as the siltstone subunit. The siltstone subunit is exposed in the southeast tip of Terrace Mountain. The siltstone subunit may be present in the northernmost exposures of the Gerster Formation in the west limb of the syncline below the Provo shoreline, but poor exposures there make this determination inconclusive. The lack of well exposed siltstone subunit outcrops is probably due to the non-resistant quality of the subunit. The siltstone subunit is about 150 feet (45 m) thick and consists of tan to orange siltstone interbedded with gray limestone, all with variable amounts of nodular chert. Limestone within the subunit bears phosphatized foraminifera thought to be Permian in age (table 1, number 2). Permian brachiopods (productid, composite, and spirifer) and crinoid fragments are also present in the subunit.

Gerster(?) Formation (Pg?)

The Gerster(?) Formation crops out along the western part of Terrace Mountain and mostly is massive chert, with lesser cherty sandstone and cherty limestone beds. Although some marker beds can be traced to illustrate faults and folds, detailed stratigraphic correlation was not possible because the rocks are highly fractured.

Triassic Rocks

Dinwoody Formation (TRd)

The Dinwoody Formation crops out on the southeast side of Terrace Mountain below the level of the Provo shoreline in the hinge area of a large syncline. The Dinwoody Formation consists of 3.3- to 6.6-foot-thick (1-2 m) packages of thin- to medium-bedded, fossiliferous, gray and brown limestone interlayered with tan, brown, and green calcareous shale and siltstone. Limestone is well exposed and locally cherty. Intervals of shale and siltstone are poorly exposed and commonly are marked by chippy float. Siltstone is parallel-laminated and weathers dark brown, whereas calcareous siltstone is chocolate brown and ripple-laminated.

The base of the unit appears to be conformable with the underlying Gerster Formation. Though the contact is indistinct, no obvious change in the attitude of bedding occurs across the zone where rocks change from those typical of the Gerster Formation to those typical of the Dinwoody. However, some workers described the contact between the Gerster Formation and Triassic strata as an unconformity that developed during Late Permian-Early Triassic erosion (e.g., Collinson, 1968; Wardlaw and others, 1979b; and Paull and Paull, 1982). At Terrace Mountain, we did not observe a basal conglomerate like that described by Paull and Paull (1982) at the Hogup Mountains. The evidence at Terrace Mountain only rules out an angular unconformity. Careful paleontologic studies are necessary to determine how much, if any, of the rock record is missing in this area. Although the upper part of the Dinwoody Formation and any overlying rocks are missing, at least 1,300 feet (400 m) of the Dinwoody appears to be present at Terrace Mountain. Conodonts from the lower part of the formation at Terrace Mountain yielded Early Triassic ages (table 1, number 7). In the Hogup Mountains, a complete section of the Dinwoody is 1,670 feet (506 m) thick (Stifel, 1964). The contact of the Dinwoody with the overlying Thaynes Formation is commonly taken as the *Meekoceras* zone in northern Utah (e.g., Stifel, 1964; Collinson, 1968). We did not find any remnant of the *Meekoceras* zone at Terrace Mountain and therefore do not consider the Thaynes to be present in this area.

Tertiary Rocks

The early Tertiary in northwest Utah was marked by the deposition of thin sequences of non-marine sedimentary and volcanic rocks during extensional tectonics (e.g., Miller, 1991; Dubiel and others, 1996). Intrusive rocks of Eocene and Oligocene age are exposed in some mountain ranges. The late Tertiary was marked by the formation of thick sedimentary sequences and interbedded bimodal-composition volcanic rocks. Deposits accumulated during this later event are generally considered to represent Basin-and-Range extensional tectonism (Best and others, 1989; Christiansen and Yeats, 1992) and are strictly Miocene in age in this part of Utah. Scattered outcrops of a thick tuffaceous sedimentary sequence in the Terrace Mountain area are similar to Miocene strata in nearby mountains. We assign the strata to the Salt Lake Formation, a thick, diverse, and poorly dated late Cenozoic unit of western Utah (Heylmun, 1965).

Salt Lake Formation (Ts)

The Salt Lake Formation at Terrace Mountain consists of mostly sedimentary rocks deposited in a lacustrine environment. Most rocks include a component of reworked volcanic ash. The Salt Lake Formation is composed mainly of tuffaceous sandstone and siltstone, thick-bedded tuffaceous mudstone and diamictite, calcareous siltstone and mudstone, altered tuffaceous mudstone, siliceous siltstone, marl, and fine-grained quartz sandstone. Basalt is a minor but distinctive component of the Salt Lake Formation and is described as a separate map unit. Fine-grained deposits typically weather yellow-brown, gray, and green. Altered ashy beds are white, with local hues of red and purple. Mineralogy of the altered beds was not determined, but the colors are not characteristic of zeolitization. Thick-bedded mudstone and diamictite are brown and generally consist of muddy ash, sometimes with gravel suspended in fine materials; they are interpreted as debris-flow deposits. Much of the unit is very fine grained and thin bedded or laminated, indicating a lacustrine depositional environment. Tuffs are composed entirely of glass shards, with no crystals or lithics.

The lowest beds of the Salt Lake Formation east of Terrace Mountain are unusual in that they consist of interbedded (on a scale of 1 to 2 inches [2.5-5 cm]) calcite-cemented conglomerate, gravelly diamictite, and ashy brown mudstone. Opaline pumice fragments as large as 2.4 by 0.6 inches (6 by 1.5 cm) are present in some altered mudstone beds. Clasts are matrix-supported, angular to subrounded, and mostly as large as 1.6 inches (4 cm). Clasts are lithologically similar to nearby Permian and Triassic rocks. The depositional setting for these coarse deposits was probably a low-gradient alluvial fan. This terrestrial section is overlain by lacustrine rocks, including oolitic sand, but deposits, interpreted as beach gravel, recur intermittently and a few alluvial deposits also are present. The strata seem to become finer grained and contain more lacustrine material southward. One sandstone, about 33 feet (10 m) thick, contains boulders of quartz-sanidine-biotite-hornblende rhyolite. The large size of boulders suggests local derivation, but no outcrops of rhyolite are known in the area. The mineralogy of this rhyolite is unusual for Miocene igneous rocks of the area, which generally contain little biotite and hornblende.

Relatively resistant conglomerate of the Salt Lake Formation crops out at the north edge of the Terrace Mountain East quadrangle. The conglomerate is bright red due to hematite staining and contains subangular clasts derived from Pennsylvanian and Permian rocks. It is very thick- to thick-bedded with crude layering shown by imbricate elongate clasts. Pebbles are mostly 2 to 8 inches (5-20 cm) in diameter. The conglomerate overlies marl and fine-grained ash, as well as a few thin beds of arkosic muscovite-bearing sandstone.

The Salt Lake Formation at Terrace Mountain is Miocene in age on the basis of lithologic similarity with dated Miocene strata in the northern Pilot Range 25 miles (40 km) to the west (Miller, 1985) and Matlin Mountains to the north (Todd, 1983). The thickness of the Salt Lake Formation is unknown due to poor exposures, but probably exceeds 10,000 feet (3,000 m) east of Terrace Mountain. Tuff and rhyolite in the lower part of the Salt Lake Formation east of Terrace Mountain contain igneous minerals that are unusual, but not rare, for the Salt Lake Formation. These lower beds possibly are older and may actually correlate with Eocene tuffs and sedimentary rocks in the Pilot Range (Miller, 1993). However, until the rhyolite clasts are dated, this possibility remains remote.

Basalt (Tb)

Basalt is present within the Salt Lake Formation in three small exposures along the south flank of Terrace Mountain, forming a distinctive, mappable unit. The basalt is dark brown to black where massive or nodular and red where strongly vesicular. It is aphanitic with fine-grained phenocrysts of olivine and plagioclase and contains sparse feldspar xenoliths about ½ inch (1.25 cm) in diameter. It overlies coarse-grained sandstone containing reworked tephra; overlying rocks are not well exposed.

One sample of basalt was dated by whole-rock conventional K-Ar methods as 18.4 ± 0.5 Ma (table 2, average). Although this age is older than other published ages for basalt in northwestern Utah (Miller, 1991), the excellent replication for two spectrometer runs of the whole rock powder suggests that the age is valid. This basalt is interbedded with a part of the Salt Lake Formation that contains abundant tephra, much of which in this area is only known to span a relatively short time interval from 14 to 8 Ma (Perkins and others, 1995). The date on the basalt might be older than the age of extrusion, possibly because of incorporated xenolithic material, or the tephra-rich part of the Salt Lake Formation extends back to at least 18 million years.

Quaternary Units

Lacustrine and alluvial deposits are the most common Quaternary sediments in the Terrace Mountain East quadrangle, but eolian deposits are also prominent. Pleistocene alluvial fans were overlapped by lacustrine sediments deposited during the rise of Lake Bonneville, the youngest and deepest of the large Pleistocene pluvial lakes in northern Utah. The lake rose across the Terrace Mountain area starting at about 28,000 years ago and left a prominent series of beach gravels at the Stansbury shoreline at about 25,000 years ago (all Quaternary ages in this report are C^{14} ages). It reached a maximum depth at about 15,000 years ago (Oviatt and others, 1992), forming the Bonneville shoreline (figure 1). Shortly thereafter, the overflow threshold in southern Idaho

Table 2. *Geochronology data for the Terrace Mountain East quadrangle.**

Map no.	Sample no.	Sample site Latitude	Longitude	Rock unit	Material dated	% radiogenic Ar	K-Ar age (Ma)
1	M90TM-197	41°26'32"	113°28'32"	basalt (Tb)	whole rock	76	18.5±0.5
				replicate analysis	whole rock	77	18.3±0.5

* All data analyzed by John K. Nakata at the Menlo Park laboratories of U.S. Geological Survey. Constants conform to Steiger and Jäger, 1977.

catastrophically failed (Bonneville flood) and the lake lowered to a stable threshold, forming the Provo shoreline (figure 1) until about 14,000 years ago. From about 14,000 years to 12,000 years ago, the lake level fell to very low altitudes, leaving the Terrace Mountain area blanketed by marl, sand, and gravel. A small transgression of the lake formed the Gilbert shoreline (figure 1) between 10,900 years ago and 10,300 years ago. In addition to these regionally recognized shorelines, the lake formed many local shorelines on Terrace Mountain. Subsequent erosion and alluvial and eolian deposition has modified the landscape only slightly.

Lacustrine gravel deposits (Qlg)

Coarse-grained lacustrine deposits were widely deposited in shorezones of Lake Bonneville. In general, the coarsest and thickest deposits are beach gravel that lie close to bedrock or to fluvial sources of coarse material; they are less than 20 feet (6 m) thick. The coarse-grained deposits define many temporary shorelines of Lake Bonneville, as shown on plate 1 by transgressive and regressive shorelines, where the proper combination of wave energy and sediment supply occurred. Many long narrow gravel bars represent gravel reworked from fluvial and alluvial sources. The highstand (Bonneville shoreline) is represented by a wave-cut bench at about 5,220 feet (1,591 m) altitude near the crest of Terrace Mountain (not depicted on the plate 1). Shorelines intermediate between the Bonneville and Provo lake levels are not well represented at Terrace Mountain. An abrasion notch cut at the Provo shoreline lies at 4,840 feet (1,475 m) altitude (NE1/4 section 30, T. 9 N., R. 14 W.), whereas gravel beaches and a spit at the Provo level are at about 4,850 feet (1,478 m) altitude (SE1/4 section 31, T. 9 N., R. 14 W.). Lower altitude shorelines, probably mostly transgressive (overlain by marl), are preserved at 4,795, 4,730, 4,715, 4,700, 4,690, 4,680, 4,665, 4,645, 4,625, 4,615, 4,480, 4,460, and 4,425 feet (1,461, 1,442, 1,437, 1,433, 1,430, 1,427, 1,421, 1,416, 1,410, 1,407, 1,366, 1,359, and 1,349 m). The shorelines at 4,480, 4,460, and 4,425 feet (1,366, 1,359, and 1,349 m) altitude are barrier beaches developed across a small drainage at the northern edge of the quadrangle, and represent part of the Stansbury oscillation (Oviatt and others, 1990). The Gilbert beaches and a spit are at about 4,255 to 4,265 feet (1,297 to 1,300 m) altitude but wave-cut notches created by the Gilbert lake stand are at 4,265 to 4,270 feet (1,300 to 1,302 m) altitude (sections 27, 34, and 35, T. 9 N., R. 14 W.). The Gilbert spit gains altitude eastward in the direction of clast transport, suggesting that it was built during the rise of the lake. Regressive shorelines below the Gilbert are at 4,250 feet (1,295 m) and lower altitudes, where they occur as shoreline scarps draped by younger eolian and alluvial materials.

Shorelines also are represented by notches cut into fine-grained materials. An example is the notch cut into lacustrine marl of Lake Bonneville (unit Qlm) by the Gilbert lake stand (section 34, T. 9 N., R. 14 W.). Other notches, somewhat obscured by eolian sand deposits, are evident as step-like benches in the otherwise smoothly sloping surface below the Gilbert highstand. Gravel in the Gilbert-stand spit is 5 feet (1.5 m) thick and has a sand and mud matrix. Clasts in the Gilbert gravel deposits include lineated green quartzite, derived from the Grouse Creek or Raft River Mountains, and plates of cemented ooids possibly formed near the Gilbert shorezone during the rise of the lake.

Lacustrine sand (Qls)

Lacustrine sand deposits consist of well-sorted and well-rounded, fine- to medium-grained sand. The deposits flank gravel bars (Qlg) at low altitudes and apparently represent elutriated fines deposited in low-energy waters adjacent to the gravel deposits. Some lacustrine sand is covered by a thin alluvial silt cover (mapped as Qai/Qls). Lacustrine sand is generally less than 10 feet (3 m) thick.

Lacustrine fine-grained deposits (Qlf)

Fine-grained lacustrine deposits consisting mainly of poorly sorted, calcareous fine sand, mud, and sandy marl are exposed between gravel beaches northwest of Terrace Mountain. The fine-grained lacustrine deposits contain reworked ostracodes. These deposits overlap gravel beach deposits (Qlg) in places, demonstrating deposition in quiet waters of the lake and that these beaches are transgressive. East of the Provo-level spit extending north from Terrace Mountain, thick lacustrine fine-grained deposits are mantled by lacustrine gravel deposits (Qlg/Qlf) that may represent a lag deposit that formed as the lake fell from the Provo shoreline.

Lacustrine marl (Qlm)

Lacustrine marl overlies coarser-grained lacustrine deposits. It forms sequences of laminated marl, deposited in shallow water, grading upward into dense gray marl, deposited in deep water, which in places is overlain by sandy marl. The laminated marl is conspicuous from a distance because it weathers to a white color, in contrast to the grayer marl above it. Bedding in the gray marl is indistinct. Matrix-supported pebbles in the marl are interpreted as dropstones. Ostracodes are abundant throughout the marl. Thickness ranges from less than 3 feet (1 m) to over 20 feet (6 m).

We interpret the lacustrine marl in this area as the product of open-water to deep-water deposition in Lake Bonneville. It overlies near-shore facies, such as lacustrine sand (Qls) and gravel (Qlg), that mark the initial transgression of the lake. Following the highstand of the lake, sandy marl was deposited as the lake level fell; this regressive marl forms the upper part of the marl unit in a few places.

Lacustrine ooid sand (Qlo)

These deposits lie southeast of Terrace Mountain and consist of dark-brown ooid sand and platy-cemented ooid sand, which is coarse to medium in size. The ooid sand may be extensive beneath alluvial mud (Qam), but is only exposed near the east-northeast-trending Gilbert spit in the central part of the quadrangle, and is overlain by eolian sand (Qes).

Alluvial sand and silt (Qas)

Alluvial sand and silt deposits underlie a veneer of alluvial silt (Qai) south of Terrace Mountain near the edges of the mud flats. The alluvial sand and silt deposits consist of medium-brown, thin-bedded, fine-grained sand, silt, and some mud. The unit is greater than 13 feet (4 m) thick in the Terrace Mountain West quadrangle (figure 1). There, it coarsens upslope with increasing sand and decreasing mud.

Mud is laced with networks of white calcite veins. This unit probably is time equivalent to red beds described by Currey and others (1988) that postdate the decline of Lake Bonneville and predate the rise of the Gilbert-stage lake.

Lacustrine and alluvial deposits, undivided (Qla)

Thinly layered sand and silt deposits of lacustrine and alluvial origin are mapped as an undivided unit along the flanks of Terrace Mountain. In most places, this unit consists of thick, sandy (regressive), lacustrine marl that is overlain by thin Holocene alluvial-fan deposits.

Eolian sand (Qes)

Eolian sand is present as small (1 mile^2 [2.56 km^2]) dune fields and less common sand sheets, mostly less than 7 to 20 feet (2-6 m) thick, near the Gilbert spit in the central part of the quadrangle. The unit is composed of reworked sand and silt derived from lacustrine deposits. The sand is composed of variable amounts of lithic grains, quartz, gypsum, and ooids, and is brown and medium to fine grained. Composition of the sand varies from dune to dune. Dune morphology indicates sediment transport to the east and east-northeast. The sand is draped over Lake Bonneville shorelines at and below the Gilbert spit.

Eolian ooid sand (Qeo)

Eolian ooid sand forms a few large dunes and subdued vegetated zones, all aligned roughly east-northeast, in the southwestern part of the quadrangle. The sand is brown, fine grained, and composed of ooids and minor quartz sand and mud pellets. Spherical ooids greatly exceed rod-shaped ooids in abundance. The deposits are at least 7 feet (2 m) thick, but no bases are observed. The deposits serve as hosts for abundant vegetation, including greasewood, halogeeten, and grasses, and in places the sand is black and organic-rich as a result. Wind-borne ooids may have been trapped at ground-water seepage zones along cracks to anchor these deposits.

Eolian silt (Qei)

Eolian silt and fine-grained sand, brown in color, is present as five small dune fields 3 to 6 feet (1-2 m) high resting on lacustrine marl east of Terrace Mountain and on the west margin of the quadrangle (section 7, T. 8 N., R. 14 W.). The deposits probably are reworked regressive marl.

Alluvial mud (Qam)

Alluvial mud underlies extensive low-gradient surfaces south and east of Terrace Mountain, labeled "mud flat" on the topographic map. The deposits consist of medium-brown to tan mud and minor sand and silt with reflective clay coatings, and are generally devoid of vegetation. The alluvial mud unit grades into the alluvial silt unit (Qai) near alluvial sources, such as Terrace Mountain. Gullies as deep as 3 feet (1 m) incise the flats underlain by alluvial mud.

Alluvial silt (Qai)

Thin sheets of brown alluvial silt with subordinate fine sand and clay overlie lacustrine marl, lacustrine sand, and alluvial sand and silt at low altitudes east and south of Terrace Mountain. The unit is so thin that Lake Bonneville shoreline scarps are visible through the unit. Blades of gypsum crystals as large as 2 inches (5 cm) long are common in the unit. The alluvial silt was probably deposited by stream and sheetflow floods and is gradational, with a decrease in grain size, into alluvial mud (Qam) of the mudflats. Alluvial silt also is present in depressions bounded by barrier beaches, such as in the northwest part of the map.

Alluvial-fan deposits (Qaf)

Alluvial-fan deposits consisting of poorly sorted gravel, sand, and silt postdate the development of the Bonneville and younger shorelines. These deposits are at the bases of drainages on steep slopes of Terrace Mountain. Typically, they are small fans and broad coalesced fans that locally contain floodplains. The fans are probably less than 20 feet (<6 m) thick. Thin and discontinuous alluvial-fan deposits over lacustrine deposits are mapped as undivided lacustrine and alluvial deposits (Qla).

Alluvium (Qa)

Alluvium consists of sand, mud, and minor gravel, with grain size generally decreasing downstream. As mapped, alluvium floors the wash at the north-central edge of the quadrangle and extends in discontinuous thin sheets of fan alluvium downstream along that stream course. Unmapped sandy alluvium lies in incised drainages on the mud flats.

Alluvial and eolian deposits, undivided (Qae)

Thin sheets of intermixed alluvial and eolian brown silt are designated as undivided alluvial and eolian deposits. The unit includes subordinate lacustrine sand and marl deposits and a discontinuous, thin lag gravel that forms a pebble pavement. The deposits lie on the east flank of Terrace Mountain below bedrock outcrops and above the mud flats. Where eolian deposits form thicker sheets, ripple and dune morphology indicates sediment transport by wind to the east.

STRUCTURE

The Terrace Mountain East quadrangle is located between mountains in northwestern Utah that have extensive exposures of complexly deformed rocks, and some deformation affected rocks within the quadrangle. The Matlin Mountains to the northeast (figure 1) have been interpreted by Todd (1983) as a series of structurally juxtaposed sheets consisting of Paleozoic, Triassic, and Tertiary strata resting on rooted Paleozoic and Tertiary sequences. Mesozoic thrust faults, folds, and normal faults are described south of Terrace Mountain in the Newfoundland Mountains (Allmendinger and Jordan, 1984) and west of Terrace Mountain at the Bovine Mountains (Jordan, 1983; Miller and McCarthy, 2002). The Grouse Creek Mountains to the northwest exhibit complex structure that apparently includes Mesozoic metamorphism, folding, and faulting, as well as Cenozoic intrusion, metamorphism, and ductile shear (Compton and others, 1977; Todd, 1980; Snoke and Miller, 1988). A deep Tertiary(?) basin to the north of the Terrace Mountain West quadrangle is evident on gravity maps (Cook and others, 1989; figure 3). The extensive Quaternary cover surrounding Terrace Mountain makes direct correlation with nearby structures difficult.

The Matlin Mountains contain the nearest outcrops of Paleozoic rocks, some of which were displaced along low-angle normal faults in Tertiary time. Todd (1983) described the eastern part of the Matlin Mountains as a rooted section of unmetamorphosed Pennsylvanian and Permian rocks depositionally overlain by Tertiary sedimentary rocks. The rooted section is structurally overlain by five displaced sheets consisting of Mississippian through Triassic(?) sedimentary rocks and Tertiary fanglomerates that were transported with the sheets. Displaced sheets make up the western part of the Matlin Mountains, and are separated from the rooted section by a low-angle normal fault with a roughly north-south trace. If the trace of the normal fault is projected south, Terrace Mountain is located well within the area of displaced sheets. Also, on the basis of brief reconnaissance, Todd (1983) stated that Permian strata at Terrace Mountain may be part of the displaced sheets. Our detailed field work at Terrace Mountain and interpretation of gravity data lead us to favor the interpretation that Permian strata at Terrace Mountain are rooted, but there are a few observations that could be used to argue that the rocks are displaced.

Two sets of observations support a displaced-sheet interpretation. First is the generally fractured state of rocks throughout Terrace Mountain. However, other exposures of cherty Permian strata in the region (the Hogup Mountains, Pigeon Mountain, and Lemay Island) are also highly fractured. Second, contact relations between Permian and Tertiary rocks suggest that a low-angle fault juxtaposes the two sets of rocks. Along the northwest side of Terrace Mountain (Terrace Mountain West quadrangle), tuffaceous rocks of the Salt Lake Formation are brecciated and altered to an orange color. A few meters away is an exposure of orange and red brecciated jasperoid derived from Permian chert and dolomite. It seems likely that a sinuous fault lies between these exposures, and its orientation is low angle. Another exposure of brecciated Tertiary rocks at the northwest side of Terrace Mountain (Terrace Mountain East quadrangle) may indicate the presence of the same fault. The low-angle fault may be the means by which displaced Permian strata were transported, but lack of exposure makes it impossible to demonstrate its existence.

There is strong evidence at Terrace Mountain to suggest that the Permian rocks are rooted. The outcrops at Terrace

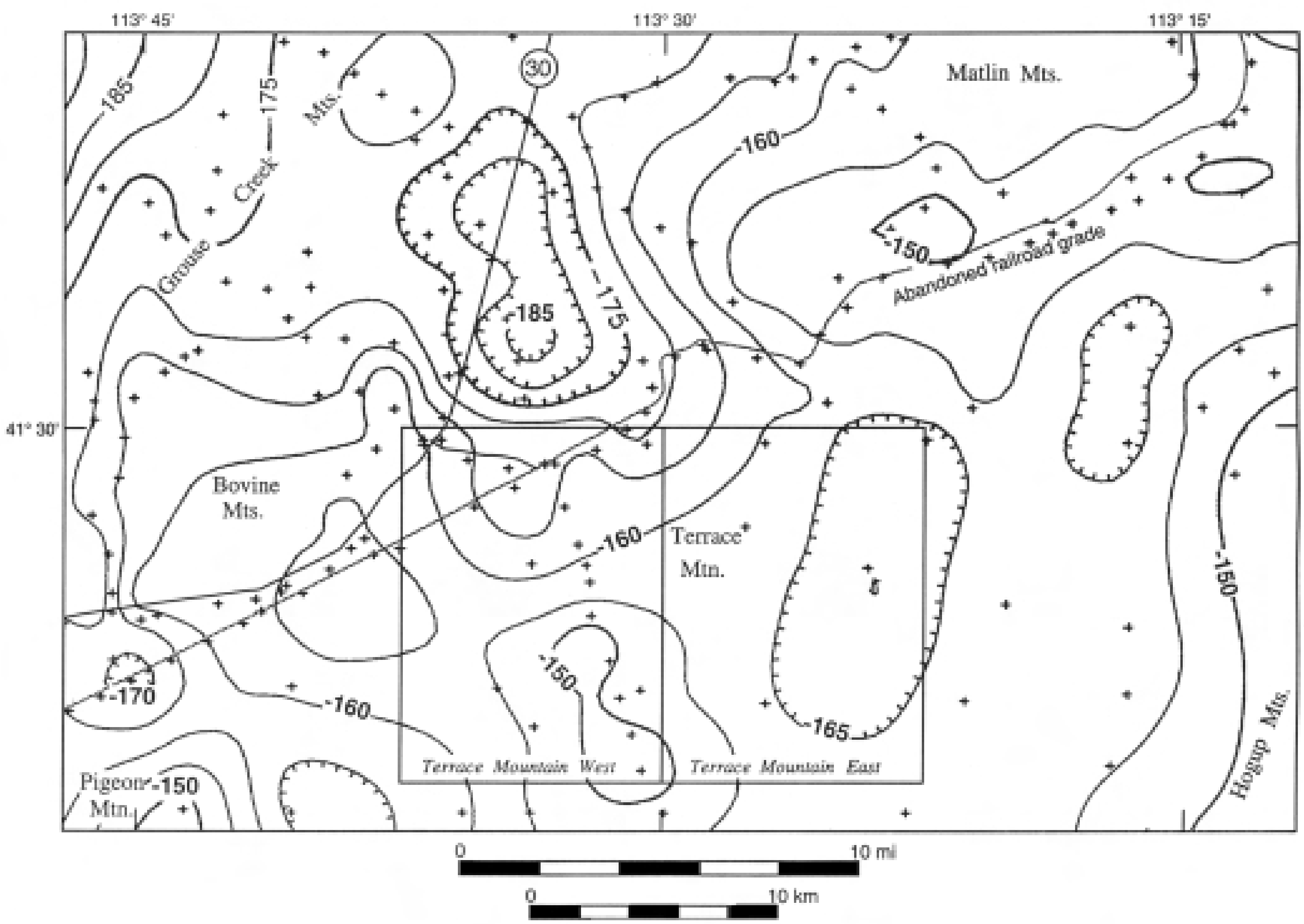

Figure 3. *Map of Bouguer gravity in Terrace Mountain area, redrawn from Cook and others (1989). The area shown is the same as in figure 1. Crosses represent gravity stations; contour interval is 5 mgal. Higher (less negative) gravity values tend to coincide with mountain ranges underlain by Paleozoic rocks, including the rooted part of Matlin Mountains. Note relatively scant stations in Terrace Mountain quadrangles, particularly the Terrace Mountain East quadrangle.*

Mountain exhibit a high degree of structural integrity. Bedding and stratigraphic units are continuous and consistent throughout the mountain and a large syncline that affects the entire section of Permian and Triassic rocks is relatively undisrupted. Although outcrops typically display several fracture sets, the strata are coherent on a large scale and lack major disruption. This degree of structural coherence would not be expected in a relatively thin sheet of rocks that traveled several miles along a flat fault with little overburden. Structural coherence is not present in displaced sheets in the western part of the Matlin Mountains (Todd, 1983).

Sparse gravity data indicate that there is no significant thickness of low-density material underlying Terrace Mountain. Tertiary strata that are exposed around Terrace Mountain dip to the west at angles averaging 30 degrees. Assuming that there has been no structural duplication of the sequence, these strata represent a thick section of Tertiary sediments tilted into their present position. If the Permian strata of Terrace Mountain represent an allochthonous sheet emplaced on a package of tilted Tertiary strata, then the area would appear as a gravity low relative to the rooted section of the Matlin Mountains or other nearby rooted bedrock. However, gravity data (figure 3) show that this is not the case. Terrace Mountain has nearly the same gravity signature as the eastern (rooted) Matlin Mountains and the Bovine Mountains, suggesting that the low-density Tertiary materials are thin and overlie rooted bedrock at Terrace Mountain. This gravity signature and the presence of breccia between tilted strata of the Salt Lake Formation and Permian rocks are best explained by a low-angle fault, down to the east, that places Salt Lake Formation over the Permian rocks. This explanation also provides a mechanism for tilting the Miocene section across the region. However, breccia is not present between Permian and Tertiary strata on the east side of Terrace Mountain, where apparent local sources are present for cobbles in the Miocene conglomerate. Both of these observations are weak support for an intact depositional sequence along the east side of Terrace Mountain. In opposition, an intact depositional sequence would represent a buttress unconformity, which is unlikely given the lacustrine and shoreline facies. We conclude the Miocene strata are probably faulted; poor exposures of the contact and presence of widespread Permian strata in the region that can be potential sources for the conglomerate explain the observations appearing to support an intact depositional sequence.

Tertiary Basins

Western Utah has been subjected to pervasive extensional normal faulting that has divided the terrain into distinct mountain ranges separated by deep sediment-filled basins. Faulting associated with basin formation has caused rotation of large fault blocks, as displayed by Tertiary lacustrine sedimentary deposits at Terrace Mountain. These sedimentary materials were deposited in a nearly horizontal geometry in a low-energy environment and now dip west at an average of 30 degrees. Remnants of the basin exposed along the flanks of Terrace Mountain are probably in fault contact with underlying Permian strata, as explained above. The original size, area, and depth of this basin are not known.

Gravity data for the Terrace Mountain East quadrangle (figure 3) are sparse, but show a broad low-amplitude low in the eastern part of the quadrangle. We interpret this low as a shallow structural basin filled with low-density material, most likely the Salt Lake Formation, which is exposed just west of the basin in the Terrace Mountain East quadrangle and north of the basin (Todd, 1983).

Folds

Pre-Tertiary rocks at Terrace Mountain are folded into a large asymmetric syncline with a roughly north-northeast trending axis. Bed thinning has occurred in fold limbs. The limbs of this fold are over 2 miles (3 km) wide perpendicular to the axis. Dips in the western limb increase from west to east; dips from 60 to 75 degrees eastward change gradually to vertical and locally overturned (westward), and then steep and upright to vertical near the fold axis. Dips in the eastern limb vary due to undulations and small folds, but overall this limb dips west about 10 to 30 degrees (cross section A-A'). Relative widths of the limbs are not discernible because a complete fold train is not exposed, but we consider vergence to be to the east on the basis of asymmetry of bedding attitudes in the limbs. A stereonet plot of poles to bedding (open and sold circles, and crosses on figure 4) illustrates the grouping of bedding orientations on the nearly planar limbs. A cylindrical best fit to Permian and Triassic bedding measurements yields a calculated fold axis trending 200 degrees and plunging 10 degrees south (shaded square on figure 4).

Small folds in Triassic carbonate rocks and shale exposed near the hinge of the large syncline consistently plunge gently south, but are variable in geometry. Some folds are broad, open, and upright; others are tight and upright, and many exhibit geometries similar to that of the large syncline with steeply east-dipping and gently west-dipping limbs. Axial plane cleavage in a few of these small folds dips steeply east (solid squares on figure 4), essentially parallel to bedding in the steep western limb. Cleavage data is not shown on plate 1 due to lack of space. A stereonet plot of poles to bedding in Triassic rocks measured near the hinge (crosses on figure 4) yields two groups of points, suggesting that the folding geometry is kink-style. These small fold axes in Triassic rocks trend about 180 to 210 degrees and plunge about 10 degrees to the south (stars on figure 4). Minor fold axes plot parallel to the axis of the large syncline, which indicates that these folds have not been refolded and that there is continuity between the two scales of structures. Folding postdated deposition of Triassic strata, probably predated Miocene deposition, and probably was Mesozoic in age, similar to that of other folds in the area (Snoke and Miller, 1988). Folds south of Terrace Mountain in the Newfoundland Mountains are associated with thrusting of Jurassic age (Allmendinger and Jordan, 1984).

High-Angle Faults

High-angle faults with displacement large enough to show on the map cut folded Permian and Triassic rocks at Terrace Mountain. Smaller, unmapped faults cut Miocene and older strata. Faults exposed in the cherty Permian rocks generally consist of breccia zones 10 feet (3 m) wide that contain a calcite matrix.

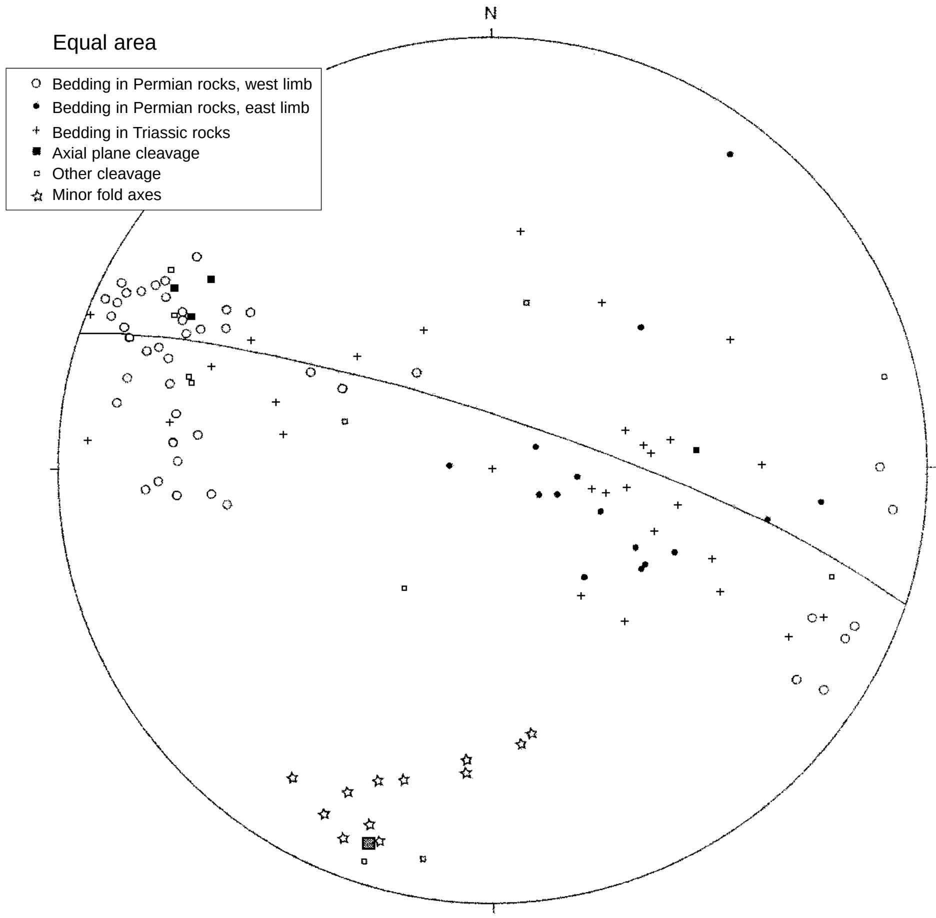

Figure 4. *Stereonet plot of poles to bedding for Permian and Triassic strata at Terrace Mountain, as well as other structural data. Cylindrical best fit to bedding is shown as line (representing a plane) and its pole (shown as large square) represents best-fit fold axis for bedding. Bedding from unit Pg? not included. Cleavage measurements include several taken near possible faults that place Tertiary strata on Permian strata.*

Nearly all of the high-angle faults that cut Permian rocks strike west to northwest, have a normal sense of separation, and are marked by orange and red alteration. Normal separation (throw) of the strata along these faults ranges from 200 to 1,800 feet (60-550 m). Because strata dip steeply east, the apparent separation of contacts is smaller than the throw on the faults. Both throw and sense of lateral separation on the faults are not systematic. A single slickensided surface on a minor (unmapped) vertical fault striking N. 47° W. had a rake of 25 degrees to the south, suggesting a large component of right-lateral separation. The faults appear to be normal with a component of right-lateral separation. Minor faults in Permian and Triassic rocks (not shown on the map) are similar to the larger faults shown on the map; they strike about N. 40° W. to N. 70° W. and dip nearly vertically.

Three faults in the south 1/2 of section 31, T. 9 N., R. 14 W. appear to bend and join westward, because they are not exposed along projected strike to the west and a single narrow valley (concealed fault) is present to the west. These faults have a cumulative left-lateral separation of contacts of about 1,200 feet (365 m). A parallel fault, whose trace is inferred between the high point of Terrace Mountain and the knob to the north (border of sections 30 and 31, T. 9 N., R. 14 W.), is a complex structure with unknown offset. This fault offsets the Gerster Formation/Murdock Mountain Formation contact in a left-lateral sense, yet apparently offsets the Murdock Mountain Formation/Meade Peak Phosphatic Shale tongue contact in a right-lateral sense. North of the fault, the Murdock Mountain Formation appears dramatically thinned - probably by a combination of faulting along a bedding-parallel normal fault and by apparent folding accommodated by the complex fault.

Two exceptions to the fairly systematic west to northwest fault orientation are exposed in the northwest part of Terrace Mountain. One fault, located at the west side of the mountain, strikes north-northeast and places carbonate rocks, mapped as the queried Gerster Formation (Pg?), against dolomite of the Grandeur Formation. These two units normally lie 4,300 feet (1,300 m) apart stratigraphically, requiring at least that much throw on the fault that juxtaposes them. South of the west- to northwest-striking three-fault system, a north-northeast-striking fault places the lower part of the Murdock Mountain Formation against the upper part(?) of the Gerster Formation; the juxtaposition indicates about 3,300 to 4,900 feet (1,000 to 1,500 m) of stratigraphic throw. The second north-northeast-striking fault, whose trace is mapped in breccia north of the high point of Terrace Mountain, is a complex structure. This fault lies nearly parallel to bedding in the Murdock Mountain, and apparently eliminates part of the Murdock Mountain section. It may represent a bedding-parallel normal fault that possibly formed at the time of folding.

Minor faults cutting Miocene strata, as well as older rocks, strike about north to N. 15° W., dip moderately to steeply east, and have 6 feet (2 m) or less normal-sense separation. Like faults in the pre-Cenozoic rocks, faults cutting the Miocene strata commonly are marked by gouge and breccia zones as wide as 10 feet (3 m). A breccia zone 1.6 feet (0.5 m) wide, which is filled with clays and red alteration products, forms the eastern boundary of one exposed basalt flow on the south side of Terrace Mountain.

Breccia is observed along contacts between silty strata and cherty carbonate rocks in both the Gerster and Murdock Mountain Formations. We consider the breccia to have originated by bedding-plane slip along mechanical discontinuities during folding.

Fractures are abundant in carbonate rocks of Permian strata. The most common fractures are oriented parallel to the northwest-striking faults. Less common fractures strike north to northeast and dip moderately to gently west.

ECONOMIC GEOLOGY

Mining of non-metallic materials has occurred on a small scale in the Hogup Mountains (figure 1) to the east (Stifel, 1964), and precious metals have been extracted from the Rosebud prospect, which lies between the Bovine and Grouse Creek Mountains to the west (Doelling, 1980), but Terrace Mountain itself has seen little mining activity. A single prospect pit was found in red, altered fault materials on the west side of Terrace Mountain (SW1/4 section 30, T. 8 N., R. 14 W.). Other orange- and red-stained altered zones in fault breccia have not been prospected.

Silicified Rocks

Parts of the Murdock Mountain and Gerster Formations show silicification and replacement of sand and fossils with chert. In general, silicification of sedimentary rocks may be related to hydrothermal activity and deposition of disseminated gold. We did not sample silicified Permian rocks for gold assay because the silicification is likely diagenetic.

Sand and Gravel

Lacustrine sand and gravel deposits of Lake Bonneville form thick platforms surrounding Terrace Mountain, some of which may be suitable for use in road construction and as fill for local construction. Clast composition varies, but generally is carbonate and cherty rocks. Eolian sand deposits generally contain mud pellets, gypsum, and ooids, making the sand unsuitable for many construction purposes.

Phosphate-Bearing Rocks

The Meade Peak Phosphatic Shale Tongue of the Phosphoria Formation contains phosphate in the region. The Meade Peak crops out in a few parts of the quadrangle and probably is shallowly buried by Cenozoic materials in others. It was not tested for P_2O_5, because the most favorable lithology, oolitic grainstone, was not observed. Also, samples taken from this unit in the Hogup Mountains (Stifel, 1964; Williams *in* Doelling, 1980, table 16) yielded concentrations of P_2O_5 too low for commercial use.

Brine

Concentrated elements in brines within the saturated mud flats adjacent to Terrace Mountain may be economically retrievable. Nolan (1927) described potash composition of brines in the Great Salt Lake Desert and Lines (1979) compared brines of Pilot Valley playa with those of the Bonneville Salt Flat.

GEOLOGIC HAZARDS

Northern Utah is part of a seismic belt characterized by numerous small-magnitude events and a potential for infrequent major events (Smith and Sbar, 1974; Christenson and others, 1987). There is no indication that active faults are present at Terrace Mountain, but Pleistocene and possible Holocene faults to the southwest in the Pilot Range (Miller and Schneyer, 1985; Miller and others, 1993) and historical earthquakes show that there is significant seismic potential in the region. Examples are the magnitude 6 and larger events in Hansel Valley during 1909 and 1934 and the magnitude 4 to 5 event near the Grouse Creek Mountains (Christenson and others, 1987). Frequent smaller magnitude earthquakes have also occurred east and southeast of Terrace Mountain (Christenson and others, 1987), including a magnitude 4.8 earthquake on November 4, 1992 (Arabasz and others, 1994). A thorough account of past seismic activity and potential for future damaging earthquakes in the region is given by Christenson and others (1987). Ground shaking due to earthquakes could dislodge material from the cliffs on Terrace Mountain or cause landslides in unconsolidated sedimentary deposits, whereas liquefaction is a possible hazard in some saturated sediments at low altitudes.

Flooding is a potential hazard at the lower altitudes of the quadrangle, where gullies contain debris-flow deposits and other signs of destructive floods, and in low areas where ponding can occur. At higher altitudes, coarse material is deposited on alluvial fans by seasonal high-energy flash floods and debris flows. In both areas, unconfined flow as sheet floods may take place.

Several other potential hazards are present in the quadrangle. Fine sediments throughout the quadrangle tend to hold water and become soft, making the roads impassable in wet conditions. Sand dunes are vegetated and stable, but disturbance could reactivate the dunes. Ground water is shallow beneath the mudflats and several old wells seep on the mudflats.

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