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

by

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U.S. Geological Survey

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ABSTRACT

The Terrace Mountain West quadrangle straddles the flat land between the west part of Terrace Mountain, an isolated small mountain on the north edge of the Great Salt Lake Desert, and the east part of the Bovine Mountains. Permian rocks underlie this part of Terrace Mountain, but their identity is uncertain in many places because the rocks are highly silicified and fractured. Faults cutting these rocks are typically altered, but are only prospected in one place at Terrace Mountain, a location east of the Terrace Mountain West quadrangle. Tertiary granitoid rocks and metamorphosed wall rocks are present in the northwestern corner of the quadrangle. Miocene strata overlying the older rocks of Terrace Mountain dip westward, apparently as a result of transport across a subhorizontal fault lying on the older rocks. Similar Miocene strata may be present under alluvial deposits between the Bovine Mountains and Terrace Mountain. Quaternary alluvial, lacustrine, and eolian sediments blanket much of the quadrangle. In particular, lacustrine deposits nicely display the many shorelines of late Pleistocene Lake Bonneville.

INTRODUCTION

The Terrace Mountain West quadrangle is located in northwestern Utah, mostly southeast of Utah State Highway 30 (figure 1) and about 25 miles (40 km) south of Park Valley. Rocks in the quadrangle include Permian and Miocene strata at Terrace Mountain and Tertiary granite and adjacent metamorphosed Upper Paleozoic sedimentary rocks at the Bovine Mountains. These rocks were eroded and then partially buried by deposits of late Pleistocene Lake Bonneville and younger alluvial sediments. Terrace Mountain, as well as the Southern Pacific Railroad siding at the townsite of Terrace (figure 1), apparently were named for the gravel terraces on the north side of the mountain. Terrace was an active town from the 1860s to the early 1900s, serving as a roundhouse, railroad yard, and watering stop for locomotives. A new railroad bypass was built in 1904 across the Great Salt Lake Desert, which brought about the decline of the town.

The high point of the quadrangle, at 4,855 feet (1,480 m), is in hills in the northwest corner. Flat and gently sloping terrain between this area and Terrace Mountain, or roughly 97 percent of the quadrangle, is composed of Quaternary lacustrine and reworked lacustrine deposits. The lowest elevation, 4,222 feet (1,288 m), is 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, and minor coarse conglomerate.

A small-scale county geologic map by Doelling (1980) was the first map to show the rock units at Terrace Mountain, eastern Bovine Mountains, and the surrounding region. The Terrace Mountain West quadrangle lies adjacent to the Terrace Mountain East quadrangle, geologically mapped by McCarthy and Miller (2002); east of the Bovine Mountains, mapped by Jordan (1983); and northeast of the Pigeon Mountain quadrangle, mapped by Glick and Miller (1987). Bedrock units mapped by Jordan (1983) and Compton and others (1977) are present in the northwest corner of the quadrangle and Paleozoic to Mesozoic rocks were mapped by Todd (1983) north of Terrace Mountain. The Hogup Mountains, where the stratigraphy is very similar to that at Terrace Mountain, lie about 19 miles (30 km) directly to the east. Stifel (1964) described the geology of the Hogup Mountains.

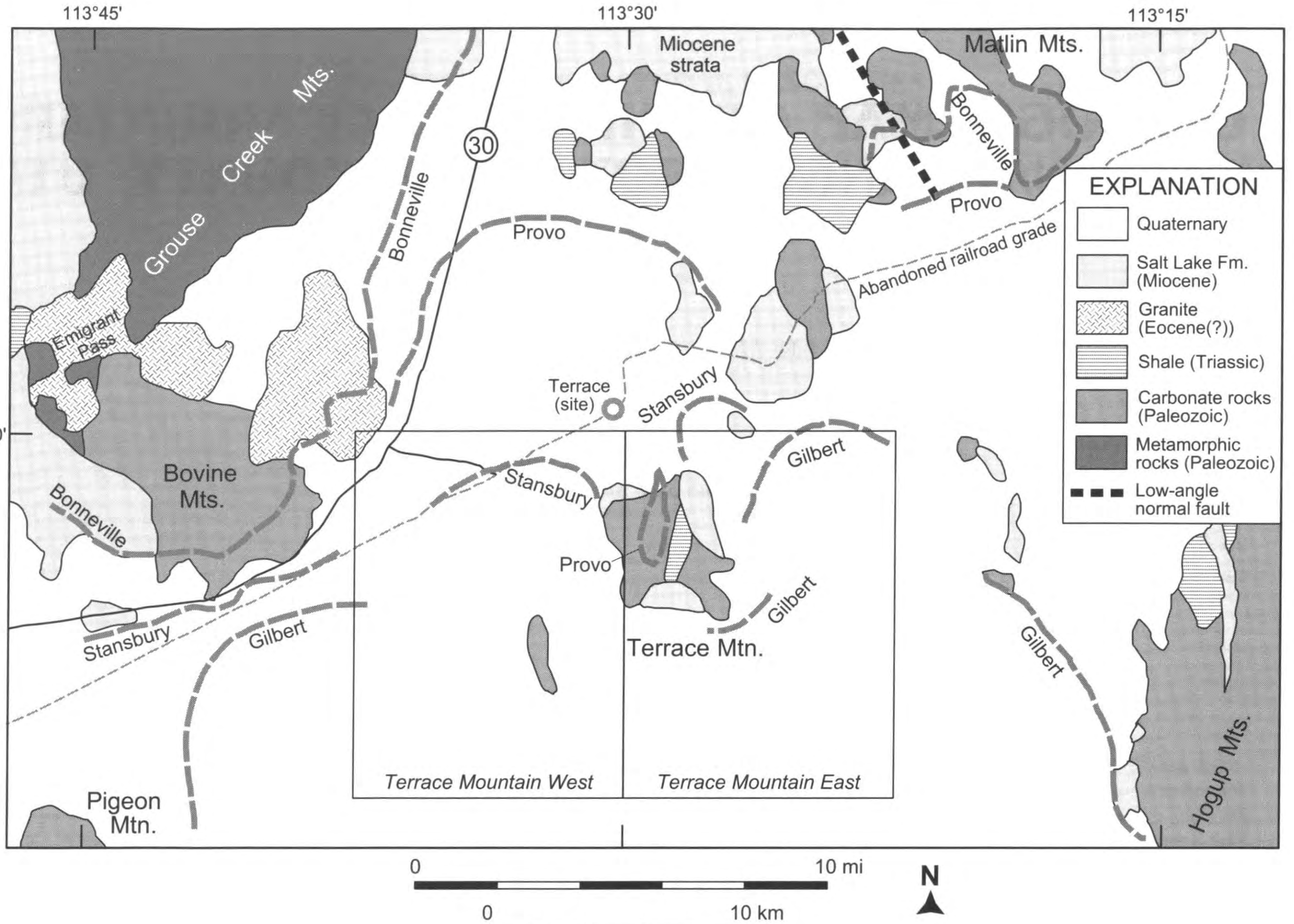

Figure 1. Location map showing general geologic features in vicinity of Terrace Mountain. Terrace Mountain West and Terrace Mountain East 7.5-minute quadrangles are outlined by boxes. Prominent Lake Bonneville shorelines are indicated by broad patterned lines. Thick dashed line in Matlin Mountains represents 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).

DESCRIPTION OF MAP UNITS

Upper Paleozoic Meta-sedimentary Rocks

Chainman(?) Shale and Diamond Peak(?) Formation, undivided (IPMcd?)

Rocks assigned to the undivided Chainman(?) Shale and Diamond Peak(?) Formation are metamorphosed and poorly exposed, so this assignment is tentative. Metamorphosed sedimentary rocks near the monzogranite of Emigrant Pass consist of thin-bedded, schistose to phyllitic, black and charcoal-gray, calcite marble; brown and white, thinly striped quartzite; and massive, green calcsilicate. Much of the rock is black because of a high content of graphite, leading us to assign it to the undivided Chainman(?) Shale and Diamond Peak(?) Formation. However, two rock types support a hypothesis that the unit may actually be the metamorphosed Oquirrh Formation: (1) the common limestone protolith (marble), and (2) some metamorphosed limestone beds containing quartz sand. If these rocks are indeed the undivided Chainman Shale and Diamond Peak Formation, they are of Mississippian and Pennsylvanian age; however, if they are the Oquirrh Formation, they are Pennsylvanian and Permian in age.

The rocks were probably contact metamorphosed when the adjacent Tertiary monzogranite of Emigrant Pass was emplaced. A similar metamorphic aureole in rocks of the Oquirrh Formation on the west margin of this pluton was described by Jordan (1983).

Permian Rocks

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). Southwest of Terrace Mountain it probably is exposed at the south margin of a small hill mainly underlain by the Murdock Mountain Formation. There, the Meade Peak consists of dark-brown, platy, silty limestone. The unit appears as chippy float in the wave-washed low hills near the aqueduct west of Terrace Mountain. Phosphatic nodules were not observed.

The Meade Peak Phosphatic Shale Tongue is too poorly exposed to determine its thickness. Nearby, in the Terrace Mountain East quadrangle, it is about 135 feet (40 m) thick (McCarthy and Miller, 2002). The Meade Peak Phosphatic Shale Tongue is late Leonardian (late Early Permian) in age in the region (Wardlaw and others, 1979b; Miller and others, 1984).

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. It underlies the southwestern part of Terrace Mountain and a few small hills to the southwest near the aqueduct that passes from the abandoned railroad bed to the south edge of the quadrangle. The unit consists of dark- to pale-brown and tan, thin- to very thick-bedded chert and dolomitic sandstone. Parts of the unit contain as much as 30 percent dolomite, present both in the form of large blocks surrounded by chert matrix and as distinct beds. Quartzite beds are present. The rocks are highly fractured and extensively silicified, making stratigraphic correlation with more complete sections to the east in the Terrace Mountain East quadrangle difficult.

The Murdock Mountain Formation, exposed in low hills just west of the aqueduct, contains medium-bedded dolomite, sandstone, chert, and medium-grained marble. These rocks are variably metamorphosed and highly fractured. A predominance of chert and its banded character suggest that these rocks belong to the Murdock Mountain Formation.

The thickness of the Murdock Mountain Formation is about 3,300 feet (1,000 m) in the Terrace Mountain East quadrangle, but less than a thousand feet (300 m) of the unit are exposed within the Terrace Mountain West quadrangle. 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 fossil ages reported for the formation in the Terrace Mountain East quadrangle (McCarthy and Miller, 2002).

Gerster(?) Formation (Pg?)

The Gerster(?) Formation crops out along the western part of Terrace Mountain. The Gerster typically is fossiliferous gray limestone and light-colored chert, but limestone beds are rare in the Terrace Mountain West quadrangle. Most of the Gerster(?) in the quadrangle 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.

The Gerster(?) Formation is about 1,600 feet (485 m) thick in the Terrace Mountain East quadrangle (McCarthy and Miller, 2002), but not all of the unit is exposed in the Terrace Mountain West quadrangle. Regionally, the Gerster is Early Permian in age (Wardlaw and others, 1979b).

Tertiary Rocks

Early Tertiary time in northwest Utah saw the development of non-marine strata and widespread volcanic deposits accompanying extensional tectonics (e.g., Miller, 1991; Dubiel and others, 1996). Intrusive rocks of Eocene and Oligocene age are exposed in some mountain ranges, including the pluton in the Terrace Mountain West quadrangle. 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).

Monzogranite of Emigrant Pass (Tep)

Exposed in the northwest corner of the quadrangle, this pluton was informally called the Immigrant Pass intrusion by Compton and others (1977), and is here informally named the monzogranite of Emigrant Pass. This brings the name-spelling into accordance with modern usage on U.S. Geological Survey topographic maps. Typical exposures are present at Emigrant Pass, where monzogranite grades to subordinate granodiorite in one of three lobes of the pluton in the southern Grouse Creek Mountains. In the eastern lobe in the Terrace Mountain West quadrangle, the rock is white to light gray, medium to coarse grained and subequigranular to porphyritic, with potassium feldspar phenocrysts. Biotite is the sole mafic mineral in the granite phase, although minor slightly more mafic phases contain hornblende. Thin dikes of pegmatite and aplite are common in all exposures.

Within the Terrace Mountain West quadrangle, potassium feldspar phenocrysts (0.1 to 1 inches [1-3 cm] wide) make up about 3 percent of the rock. Quartz, plagioclase and potassium feldspar, and biotite are coarse grained (2 to 3 inches [5-7 cm]), and also form a groundmass of medium-sized grains. Biotite (partly altered to chlorite) forms about 15 percent of the rock, and quartz 30 percent. This main phase of granite grades over a distance of 1 to 2.5 inches (2-6 cm) into a darker granodiorite to granite phase that is more biotite-rich (20% biotite with traces of hornblende). This more mafic phase is medium to fine grained and carries variably sized phenocrysts of all minerals in the main phase. Both phases of the granite possess a weak foliation defined by aligned biotite; the foliation is probably magmatic in origin. Quartz is weakly deformed, as indicated in thin section by undulose extinction, deformation lamellae, and sutured grain boundaries. Geochemically, both phases of the monzogranite of Emigrant Pass in the Terrace Mountain West quadrangle are rather typical granites: 69 to 71 percent SiO_2, Na_2O slightly greater than K_2O, and weakly peraluminous; but with slightly elevated Ba (>1000 ppm) and Zn (53 to 73 ppm). White quartz veins cut the pluton and are associated with highly fractured rocks and iron stain. No other evidence for mineralization, such as sulfide minerals, chlorite, sericite, or clay, are present.

The monzogranite of Emigrant Pass was dated by Rb-Sr methods on whole-rock powders from several dikes and one granite sample by Compton and others (1977). The results indicated an age of 38.2 ± 2.0 Ma, but, as noted by Compton and others (1977), that age is largely controlled by results from samples collected from dikes in the southwest lobe of the intrusion. A K-Ar date of 23.9 ± 0.5 Ma on biotite (Armstrong, 1970, sample number 140; revised with new constants of Steiger and Jäger, 1977) from the northwest lobe may: (1) represent a cooling age (Compton and others, 1977), (2) indicate that the Rb-Sr data are faulty, or (3) suggest that the lobes of the intrusion are of different ages. We consider the pluton to be Eocene(?) in age on the basis of the Rb-Sr data.

Salt Lake Formation (Ts)

The Salt Lake Formation crops out sparsely in the northeastern part of the Terrace Mountain West quadrangle. Most of its strata are sedimentary and were probably deposited in a lacustrine environment, and strata typically contain a conspicuous reworked volcanic ash component. The Salt Lake Formation is composed mainly of tuffaceous sandstone and siltstone, thick-bedded tuffaceous diamictite and mudstone, calcareous siltstone and mudstone, altered tuffaceous mudstone, siliceous siltstone, marl, and fine-grained sandstone. Also present are beds of white vitric tuff. Fine-grained sedimentary 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. Diamictite and mudstone are brown, unbedded, and generally consist of muddy ash, sometimes with gravel suspended in fine materials; these strata are interpreted as debris-flow deposits. Much of the unit is very fine grained and thin bedded or laminated, suggesting a lacustrine depositional environment. Tuffs are composed entirely of glass shards, with no crystals or lithics.

The Salt Lake Formation at Terrace Mountain is Miocene in age on the basis of lithic similarity with the unit in the Terrace Mountain East quadrangle (McCarthy and Miller, 2002) and 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 its poor exposures, but if not complicated by structures, it probably exceeds 6,500 feet (2,000 m).

Tertiary and Quaternary Units

Gravel deposits (QTg)

Coarse-grained alluvial gravel deposits underlie late Pleistocene lacustrine sand deposits (unit Qls) in the northwest corner of the quadrangle. The unit is greater than 26 feet (8 m) thick, and varies from coarse (cobble and pebble) gravel to sandy gravel to pebbly sand where it is exposed in the high bank of a wash. Maximum clast size is about 1 foot (30 cm). The upper part is strongly calcite-cemented and resistant, similar to alluvium elsewhere in the region assigned a Pliocene and early Pleistocene age (Machette, 1985).

Quaternary Units

Lacustrine and alluvial deposits are the most common Quaternary sediments in the Terrace Mountain West 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 (all Quaternary ages in this report are C^{14} ages) and left a prominent series of beach gravels at several lake levels, including several regionally recognized shorelines (figure 1). The earliest is the undated Pilot Valley shoreline. During an oscillation in lake level, multiple Stansbury shorelines formed about 25,000 years ago. The lake reached a maximum depth at about 15,000 years ago (Oviatt and others, 1992), forming the Bonneville shoreline. Shortly thereafter, the overflow threshold in southern Idaho catastrophically failed (Bonneville flood) and the lake declined to a stable threshold, forming the Provo shoreline until about 14,000 years ago. From about 14,000 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 Great Salt Lake formed the Gilbert shoreline between 10,900 and 10,300 years ago (figure 1). Subsequent erosion and alluvial and eolian deposition has modified the landscape only slightly, with the most notable feature being the alluvial fan along the west edge of the quadrangle extending from a wash in the Bovine Mountains.

Lacustrine gravel deposits (Qlg)

Coarse-grained lacustrine deposits consisting of cobble- and pebble-gravel and subordinate sand were deposited widely in shore zones of Lake Bonneville. In general, the coarsest and thickest deposits are beach gravel that lies either close to bedrock outcrops such as at Terrace Mountain, or to fluvial sources of coarse material, such as the ancestral Muddy and Rosebud Creeks. In addition to the regionally mapped shorelines, the coarse-grained deposits define several temporary shorelines of Lake Bonneville. Some of these local shorelines were formed during the transgression (rise) of the lake, overlain by deep-water deposits, and others formed during regression of the lake, overlie deep-water deposits; both are so labeled on plate 1. Lacustrine gravel was deposited at sites of Lake Bonneville having the proper combination of wave energy and sediment supply in the shifting shore-zone, such as barrier beaches and wave-battered bedrock prominences. Many long, narrow, gravel bars represent gravel reworked from alluvial sources; these are generally thinner than 40 feet (12 m). Broad areas covered by gravel, such as in the northwest corner of the quadrangle, may represent thin blankets of lacustrine gravel on bedrock. Broad low-relief hills in this area indicate bedrock control of physiography.

At its highstand, Lake Bonneville covered the entire quadrangle. The Provo shoreline is not well exposed in the quadrangle, but Provo beaches 1/3 mile (0.5 km) east of the quadrangle are at about 4,845 to 4,850 feet (1,477 to 1,478 m) altitude (McCarthy and Miller, 2002). Shorelines at lower altitudes, probably mostly transgressive, are preserved at 4,770, 4,630, 4,585, 4,570, 4,545, 4,535, 4,520 to 4,495, 4,480 to 4,475, 4,450 to 4,420, 4,403 to 4,382, 4,360 to 4,348, 4,300, 4,282, and 4,275 feet (1,454, 1,411, 1,398, 1,393, 1,385, 1,382, 1,378 to 1,370, 1,366 to 1,364, 1,356 to 1,347, 1,342 to 1,336, 1,329 to 1,325, 1,311, 1,305, and

1,303 m). Those at 4,300 and 4,282 feet (1,311 and 1,305 m) altitude are regressive shorelines. The shorelines between 4,520 and 4,495 feet (1,378 and 1,370 m) altitude represent the highstand and oscillation of the Stansbury shoreline (Oviatt and others, 1990), which probably produced shorelines as low as 4,475 feet (1,336 m) altitude. The shorelines labeled S on the map at about 4,400 and 4,435 feet (1,341 and 1,352 m) may or may not be Stansbury shorelines at the lower limit of the oscillation. The gravel in Stansbury-level beach deposits commonly is cemented by tufa (figure 2). The gravel beach at 4,275 feet (1,303 m) is tentatively correlated with the Pilot Valley shoreline, which is the lowest regional transgressive shoreline of Lake Bonneville (Miller, 1990, 1993). The Gilbert shoreline is not well developed, although gravel accumulations at about 4,250 feet (1,295 m) altitude west of the aqueduct may represent this shoreline.

Details of the altitudes and compositions of beaches provide information on the lake dynamics. Changes in altitude occur laterally along single beaches and beach complexes. This relation suggests progressive lateral building of a beach as the lake level changed. The deposits within the Stansbury stage of shorelines contain clasts of the Oquirrh Formation and the monzogranite of Emigrant Pass, indicating shore currents (wave energy) were from the west, and these currents probably reworked alluvium shed from the Bovine Mountains to form the beach deposits.

Lacustrine sand (Qls)

Lacustrine sand deposits consist of well-sorted and well-rounded, fine- to coarse-grained sand and minor fine gravel. Sand present in the Stansbury beach complex west of Terrace Mountain mostly represents elutriated fines deposited in low-energy areas adjacent to gravel deposits (Qlg), but wave energy was important in parts of the deposit because cross-lamination is locally well-developed (figure 3). Lacustrine sand deposits at higher altitudes are extensively reworked by wind to form dunes. Lacustrine sand 13 feet (4 m) thick overlies old alluvial gravel (QTg) in the northwest corner of the quadrangle. That sand is mainly composed of medium- to coarse-grained quartz, feldspars, and biotite, and minor lithic grains derived, respectively, from the underlying monzogranite of Emigrant Pass and metamorphic rocks.

Lacustrine fine-grained deposits (Qlf)

Fine-grained lacustrine deposits form thin sheets consisting mainly of poorly sorted marly fine sand, sandy marl, and mud deposited in quiet waters of Lake Bonneville between gravel beaches west of Terrace Mountain. The fine-grained lacustrine deposits contain reworked ostracodes. These deposits overlap gravel beach deposits (Qlg) in places, demonstrating that those beaches are transgressive.

Lacustrine marl (Qlm)

Lacustrine marl overlies coarser-grained lacustrine deposits such as sand (Qls) and gravel (Qlg) in the northern part of the Terrace Mountain West quadrangle. It forms sequences of laminated marl, deposited in shallow water, grading upward to dense gray marl, deposited in deep water, which in places is overlain by sandy and clayey marl. The laminated marl is conspicuous from a distance because it weathers white, in contrast to the gray marl above it. Bedding in the gray marl is indistinct. Matrix-supported pebbles, interpreted as dropstones, are relatively common in the unit. Ostracodes are abundant throughout the unit. The thickness of the unit ranges from less than 3 feet (1 m) to more than 20 feet (6 m). Marl deposited near fluvial sources such as Rosebud and Muddy Creeks contains more silt than elsewhere.

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) or gravel (Qlg) that mark the initial transgression of the lake. Following the highstand of the lake, regressive sandy marl was deposited as the lake level fell; the regressive marl makes up the upper part of the lacustrine marl unit in a few places.

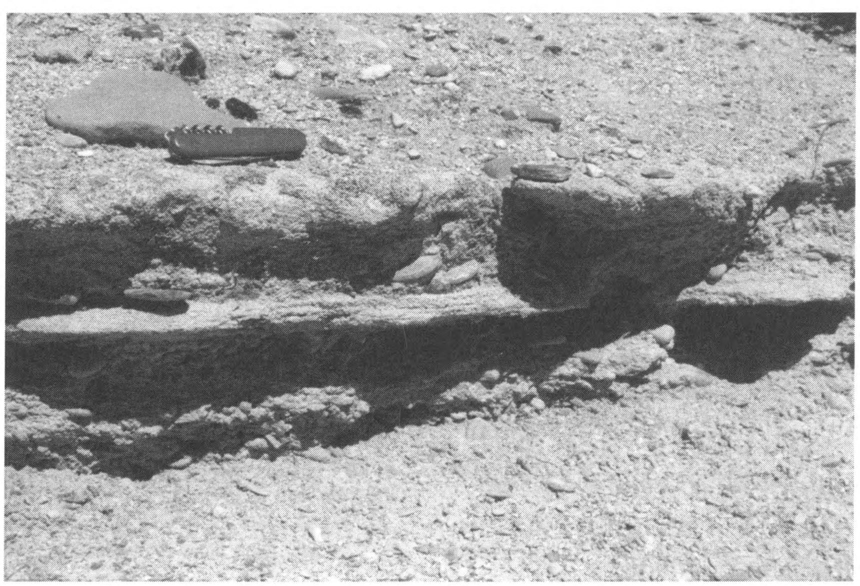

Figure 2. *Tufa-cemented sand and gravel in a Stansbury-level barrier beach deposit (unit Qlg). Note thin bed of laminated coarse sand between gravel beds containing imbricated pebbles. View is eastward; open lake was to the right.*

A

B

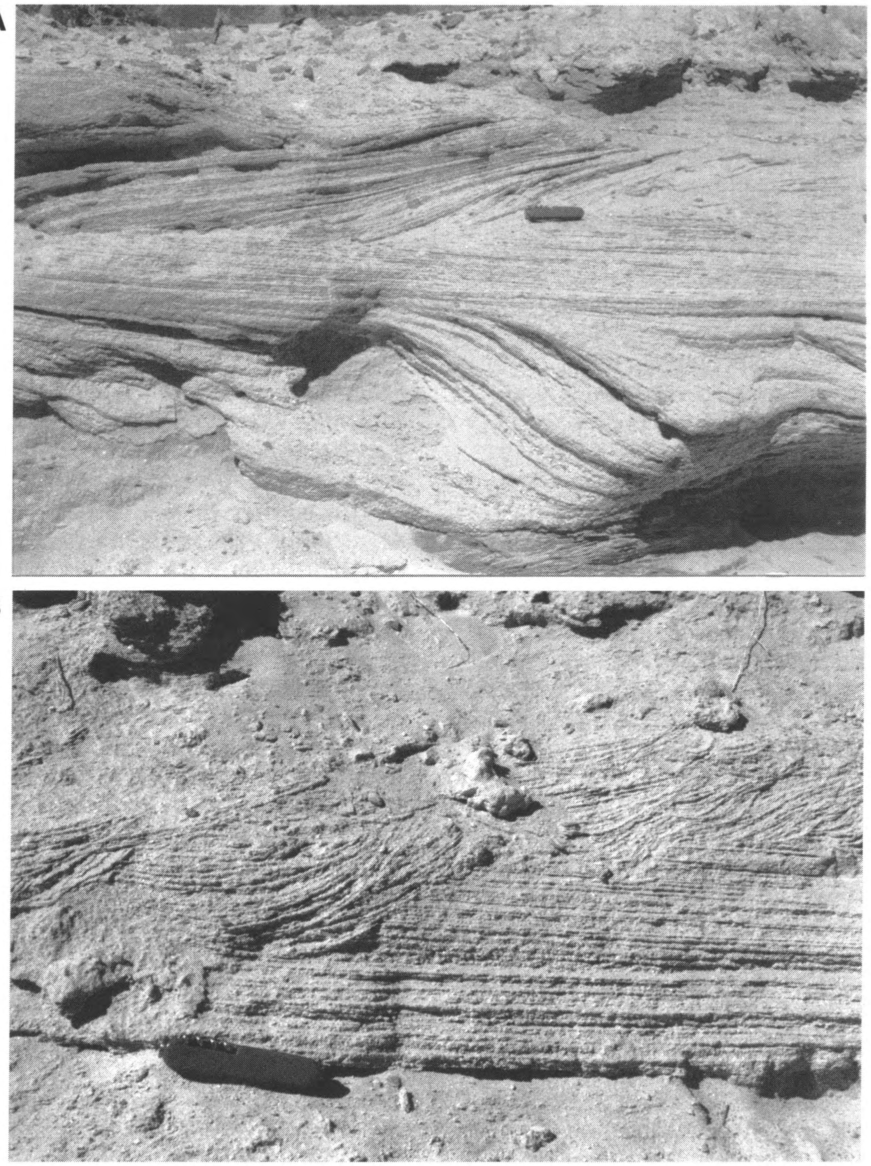

Figure 3. Photographs of lacustrine sand (unit Qls) south of and adjacent to Stansbury barrier beach. View is eastward; open lake was to the right. A. Parallel- and cross-laminated medium-grained sand. B. Planar laminated and trough cross-laminated sand resulting from scour and fill.

Alluvial sand and silt (Qas)

Alluvial sand and silt deposits crop out in an east-west band at the center of the quadrangle, along the margin of the gently-sloping piedmont and the mud flats. The deposits underlie a veneer of younger alluvial silt and rest on lacustrine marl. The alluvial sand and silt unit consists of medium-brown, thin-bedded, fine-grained sand, silt, and minor mud. The unit is more than 13 feet (4 m) thick in several exposures and coarsens upslope with an increase in sand and a decrease in mud. The mud deposits are 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 regression of Lake Bonneville and predate its rise to the Gilbert stage.

Lacustrine and alluvial deposits, undivided (Qla)

Thinly layered sand and gravel deposits of lacustrine and alluvial origin are mapped as an undivided unit along the piedmont slopes below the Bovine Mountains. In most places, this unit consists of thick, sandy, regressive lacustrine marl that is overlain by thin Holocene alluvial-fan deposits.

Eolian ooid sand (Qeo)

Eolian ooid sand forms a few large dunes and subdued vegetated ridges, all aligned roughly easterly. The deposits are at least 6 feet (2 m) thick, but no bases are observed. The elongate westernmost outcrop of the unit is level with the mud flats, most likely as a result of beveling by Gilbert or Holocene lake waters, whereas other dunes postdate the Gilbert lake. The sand is brown, fine-grained, and composed of ooids and minor mud pellets and quartz. Spherical ooids greatly exceed rod-shaped ooids in abundance. 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 sand (Qes)

Brown eolian sand is present as small dune fields and less common sand sheets, mostly less than 6 to 20 feet (<2-6 m) thick. Sand at the edge of the mud flats is composed of material derived from the underlying alluvial sand and silt unit (Qas), varies from dune to dune, and is progressively finer grained down slope, where it grades into the eolian silt (Qei) unit. Typical constituents at low altitude are ooids, gypsum, and quartz. Eolian sand above the Stansbury shoreline, at the north edge of the quadrangle, is composed of medium-sized grains derived from granite. Dune morphology of the unit indicates sediment transport to the east.

Eolian silt (Qei)

Eolian silt is present as small fields of dunes 3 to 13 feet (1-4 m) high and sheets adjacent to outcrops of the alluvial sand and silt (Qas) unit at the edge of the mud flats, where it overlies the alluvial mud (Qam). Eolian silt is largely composed of brown silt and fine sand reworked from the alluvial sand and silt unit. Up slope, where underlying materials are coarser, eolian silt grades to similar, somewhat coarser grained deposits designated as eolian sand (Qes). Dunes of eolian silt trend north and indicate sediment transport to the east.

Alluvial ripple deposits (Qar)

Alluvial ripple deposits are marked by ripple forms on the surface and consist of brown, well-sorted silt and fine sand. They lie on lacustrine marl (Qlm) and therefore postdate development of the Bonneville and younger shorelines. The deposits are about 3 feet (1 m) thick and nearly flat-lying. Internally, they are structureless and are therefore probably of alluvial sheetflow origin.

Alluvial mud (Qam)

Alluvial mud and minor sand and silt deposits underlie extensive low-gradient surfaces south and west of Terrace Mountain, labeled "mud flat" on the topographic map. The deposits consist of medium-brown to tan mud with a reflective clay surface coating, and are generally devoid of vegetation. The alluvial mud unit grades into the sparsely vegetated alluvial silt (Qai) unit 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, broad sheets of brown alluvial silt with subordinate fine sand and clay overlie lacustrine marl and sand (units Qlm and Qls, respectively) and the alluvial sand and silt (Qas) unit in plains near the edge of the mud flat. Blades of gypsum crystals as large as 2 inches (5 cm) long are common in alluvial silt. The alluvial sheets were probably deposited by streams and sheetflow floods and are transitional, with decrease in grain size, to alluvial mud (Qam) of the mudflats. Alluvial silt drapes shoreline scarps cut by Lake Bonneville (for example, section 12, T. 8 N., R. 15 W.). Alluvial silt also is present in depressions bounded by barrier beaches.

Alluvial-fan deposits (Qaf)

Alluvial-fan deposits of poorly sorted gravel, sand, and mud postdate the development of Lake Bonneville shorelines. These deposits form steep alluvial fans at mouths of canyons and drainages, mostly at Terrace Mountain, and a large alluvial fan at the mouth of Sand Wash, at the west margin of map area. The unit locally includes floodplain deposits bordering streams. Coarser deposits predominate at higher altitudes and on steeper slopes. Alluvial-fan deposits are probably as thick as 80 feet (25 m), but thickness varies considerably. The alluvial-fan deposits are mapped as undivided lacustrine and alluvial deposits (Qla) where they are thin and discontinuous.

Alluvium (Qa)

Extensive thin sheets of alluvium are present along active washes on the mud flats, with thicker alluvium in the washes of Muddy and Rosebud Creeks, and Sand Wash. This stream and fan alluvium consists of poorly sorted gravel, sand, and mud with grain size generally decreasing downstream. The deposits postdate the development of Lake Bonneville shorelines. These deposits represent broad alluvial fans, some with incised streams, and deposits in dry washes. Similar deposits are mapped as undivided lacustrine and alluvial deposits (Qla) where they are thinner and discontinuous.

Spring mud (Qsm)

Organic-rich mud deposits are present at spring discharge zones in the mud flats. These areas support fairly dense vegetation, probably as a result of the available low-salinity water. Most or all of the water issues from open drill holes.

STRUCTURE

Terrace Mountain 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). 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 mylonitization (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 4). The extensive Quaternary cover surrounding Terrace Mountain makes direct correlation with nearby structures difficult. The Terrace Mountain West quadrangle has few structures exposed, but rocks in the quadrangle are continuous with rocks in the Terrace Mountain East quadrangle and the Bovine Mountains. The following description

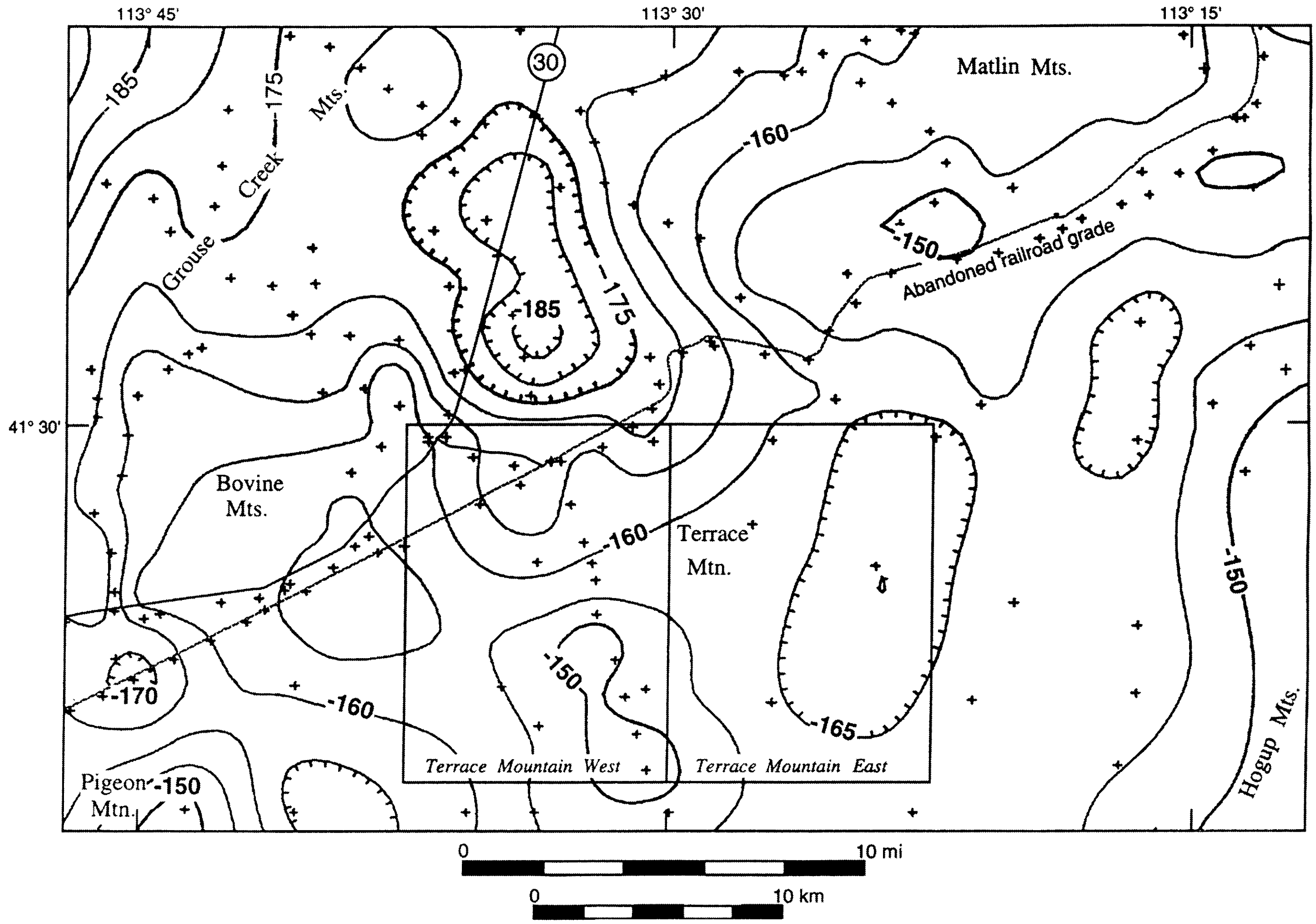

Figure 4. Map of Bouguer gravity in Terrace Mountain area, redrawn from Cook and others (1989). The area shown is the same as in figure 1. Crosses represent gravity stations; contour interval is 5 mgal. Higher (less negative) gravity values tend to coincide with mountain ranges underlain by Paleozoic rocks, including the rooted part of Matlin Mountains. Note relatively scant stations in Terrace Mountain East and West quadrangles.

of structure in the Terrace Mountain West quadrangle relies on these adjacent exposures.

The Matlin Mountains contain the nearest outcrops of Paleozoic rocks to those in the Terrace Mountain West quadrangle; some of these rocks have been displaced by Tertiary low-angle normal faults. 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 the 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, the contact relations between the Permian and Tertiary rocks suggest that a low-angle fault juxtaposes the two sections of rocks. Along the northwest side of Terrace Mountain (northeast side of the Terrace Mountain West quadrangle), a bedded outcrop of the tuffaceous Salt Lake Formation is brecciated and altered to an orange color. A few feet 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 represent the same fault. These exposures may indicate the presence of a low-angle fault that displaced Permian strata, but the 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 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 mostly 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. 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 consistently to the west at angles from 14 to 46 degrees. Assuming that there has been no structural duplication of the sequence, these strata represent a thick section of Tertiary sedimentary strata 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 4) 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 the Salt Lake Formation over the Permian rocks (cross section A-A', plate 2). This explanation also provides a mechanism for tilting the Miocene section across the region.

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 the tilt 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 West quadrangle (figure 4) show a gravity high with 5 to 10 mgal of relief passing across the southern part of the quadrangle from southeast to northwest. A saddle-shaped low is evident on the northwestern part of this gravity ridge. The data also show a pronounced low to the north of the Terrace Mountain West quadrangle that extends into the northern part of the quadrangle as a broad 5- to 10-mgal low. The gravity low within the quadrangle corresponds to a gravity deficiency appropriate for about 1,500 to 3,000 feet (460-915 m) of low-density sedimentary fill in a basin. The inferred basin possibly extends southwestward to the saddle in the gravity ridge crossing the southern part of the quadrangle. We interpret the gravity low as a Miocene basin about 2,000 feet (610 m) deep and show possible positions of faults bounding the basin on the geologic map and cross section A-A′. A similar thickness of Miocene strata probably underlies the southwest corner of the quadrangle. Buried traces of possible faults bounding the gravity ridge and southern basin are shown on the geologic map. The gravity values in the southeast part of the quadrangle are greater than the gravity values near bedrock at Terrace Mountain. Rocks exposed near this gravity high are fractured Permian strata, the northernmost exposures of which are metamorphosed to coarse-grained marbles. The gravity high may have its origin in a shallow mafic intrusive body that fractured and metamorphosed its roof rocks.

Foliation

A weak foliation that is defined mainly by aligned biotite is present in some outcrops of the monzogranite of Emigrant Pass. The foliation is variably oriented and weakly developed, and biotite grains are not strained, indicating that the foliation is probably magmatic in origin. However, quartz grains are weakly deformed, as indicated in thin section by undulose extinction, deformation lamellae, and sutured grain boundaries. Solid-state deformation of quartz was too weak to produce the alignment of biotite.

Foliation in metamorphic rocks is defined by aligned biotite, muscovite, and calcite. The few exposures of metamorphic rock had widely varying foliation orientations, making interpretation impossible. Foliation probably formed when rocks were heated during emplacement of the monzogranite of Emigrant Pass. However, inclusions of mylonitic quartzite in the monzogranite, located immediately west of the quadrangle, were deformed prior to intrusion, raising the possibility that some of the metamorphism and deformation in wall rocks also predated intrusion.

Folds

Permian strata exposed in Terrace Mountain lie in the west limb of a large syncline whose axis is exposed to the east (McCarthy and Miller, 2002). A single map-scale anticline on the west side of Terrace Mountain warped Permian rocks broadly. This fold, whose axis trends northeast, is offset by a north-striking high-angle fault. More impressive folds in these strata are mapped in the Terrace Mountain East quadrangle (McCarthy and Miller, 2002), where tight north-trending folds exist.

Rocks at Bovine Mountain were interpreted by Jordan (1983) as forming a large-scale recumbent fold. That fold is shown diagrammatically by form lines in Paleozoic rock on the west end of cross section A-A'. The fold was intruded by the monzogranite of Emigrant Pass, indicating that it formed before or during early phases of pluton injection.

Faults

As described above, a low-angle fault probably lies between the outcrops of Permian and Miocene strata. It is marked by altered breccia in several places, and its sinuous trace indicates a nearly flat orientation. The outcrop information is insufficient for determining which rocks lie in the hanging wall, but consideration of the structural styles and gravity data, as described above, strongly suggest that Miocene strata lie on Permian strata (cross section A-A′).

High-angle faults cut folded Permian rocks in the Terrace Mountain West quadrangle and others are inferred on the basis of gravity data to bound Miocene sedimentary basins. Faults exposed in the cherty Permian rocks generally consist of breccia zones 10 feet (3 m) wide that contain a calcite matrix.

Three steeply dipping faults are mapped in western Terrace Mountain. One strikes north and offsets an anticline in a right-lateral sense. A single measurable exposure of this fault indicates that it strikes N. 10° W. and is vertical. Altered rocks in the fault zone are bright red. A similarly oriented fault to the northeast shows down-to-the-east separation of strata on the adjacent Terrace Mountain East quadrangle (McCarthy and Miller, 2002). A covered fault mapped near the boundary between T. 8 and 9 N. continues northeastward into the adjacent Terrace Mountain East quadrangle, where it has several thousand feet of separation, based on offset strata (McCarthy and Miller, 2002). A short fault farther south at the east margin of the quadrangle strikes east and has uncertain separation. Faults in the low hills west of the aqueduct are marked by silicified breccia and strike both east-northeast and about west. The rocks they cut are highly fractured, with the main fracture set striking N. 80° W. and dipping steeply south.

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. Orange- and red-stained alteration is present in fault breccia but the breccia has not been prospected. White quartz veins that cut the Emigrant Pass pluton are associated with highly fractured rocks and iron stain, but sulfide minerals are not present, nor are alteration minerals such as chlorite, sericite, or clays. 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. Relatively coarse marble in the highly faulted Permian rocks near the aqueduct may indicate high temperatures caused by an underlying igneous body, which might be a source for mineralization.

Sand and Gravel

Lacustrine sand and gravel deposits of Lake Bonneville form thick platforms surrounding Terrace Mountain and contain clasts of carbonate and chert rock; some may be suitable for use in road construction and as fill for local construction. Two gravel pits are shown in the northwest corner of the topographic base map of the quadrangle near State Highway 30 (SW1/4NE1/4 section 24, T. 9 N., R. 16 W.; SE1/4SW1/4 section 18, T. 9 N., R. 15 W.). Test data for the excavated material and a nearby test hole (SW1/4SW1/4 section 18) was reported (numbers 02103 and 02105, respectively) by the Utah State Department of Highways (1971). Eolian sand deposits above the Stansbury shoreline contain silicate minerals and may also be suitable for construction purposes, but sand below the Stansbury shoreline generally contains mud pellets, gypsum, and ooids, making it 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 sediment 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 water 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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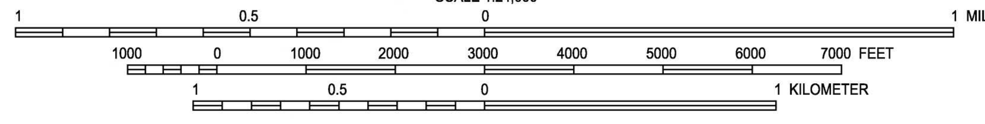
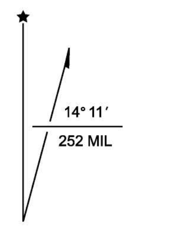
Plate 1
Utah Geological Survey Miscellaneous Publication 02-3
Geologic Map of the Terrace Mountain West Quadrangle

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

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

SCALE 1:24,000



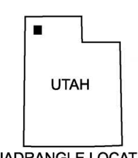


2002 MAGNETIC DECLINATION AT CENTER OF SHEET

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

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

2002



QUADRANGLE LOCATION