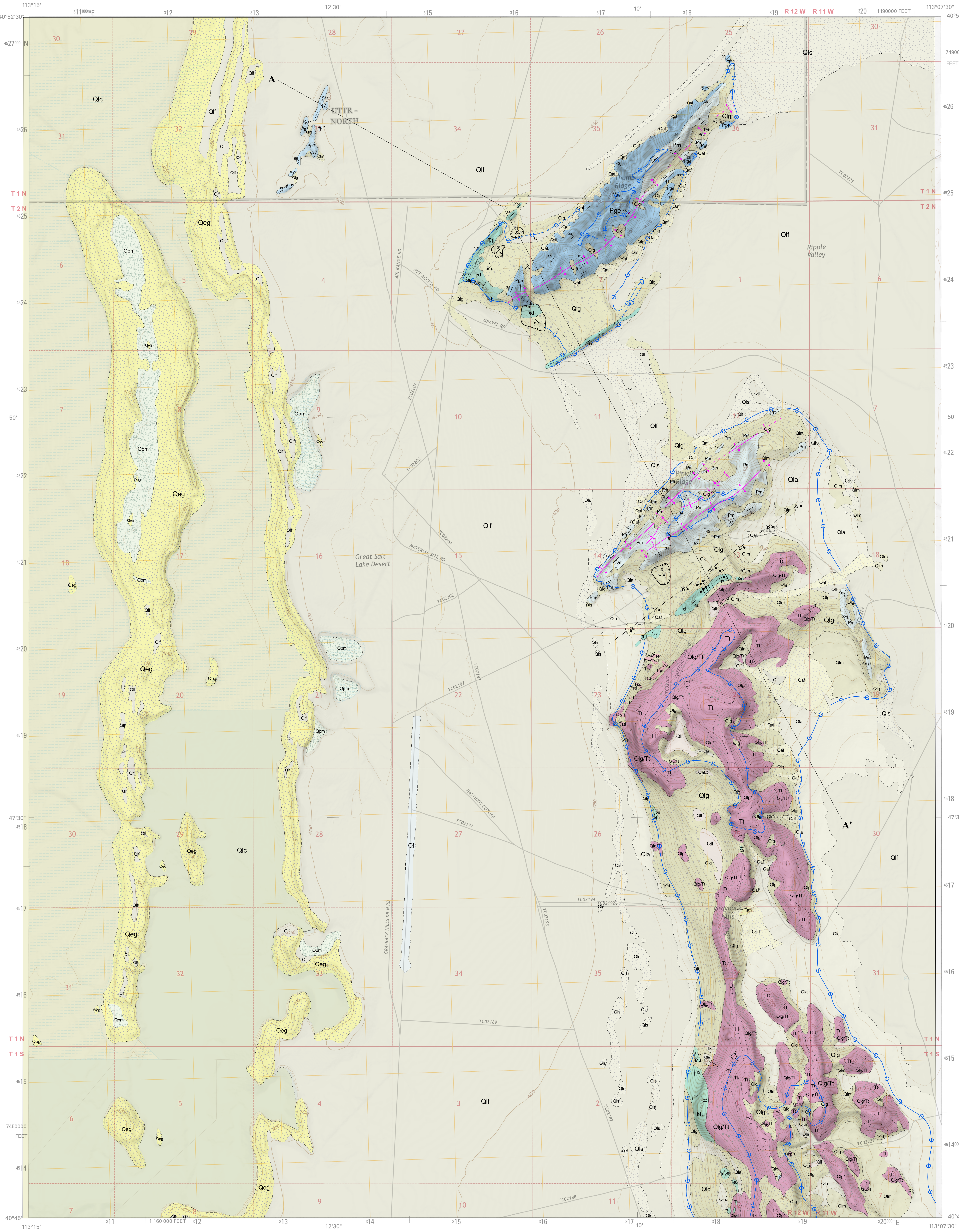

SCALE 1:24,000

1 0.5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0.5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET

Utah Geological Survey Open-File Report 679DM

Geologic Map of the Grayback Hills Quadrangle, Tooele County, Utah

(GIS reproduction of UGS Map 166 [1994])

by

Hellmut H. Doelling, Barry J. Solomon, and Stephen F. Davies

2018

UTAH GEOLOGICAL SURVEY
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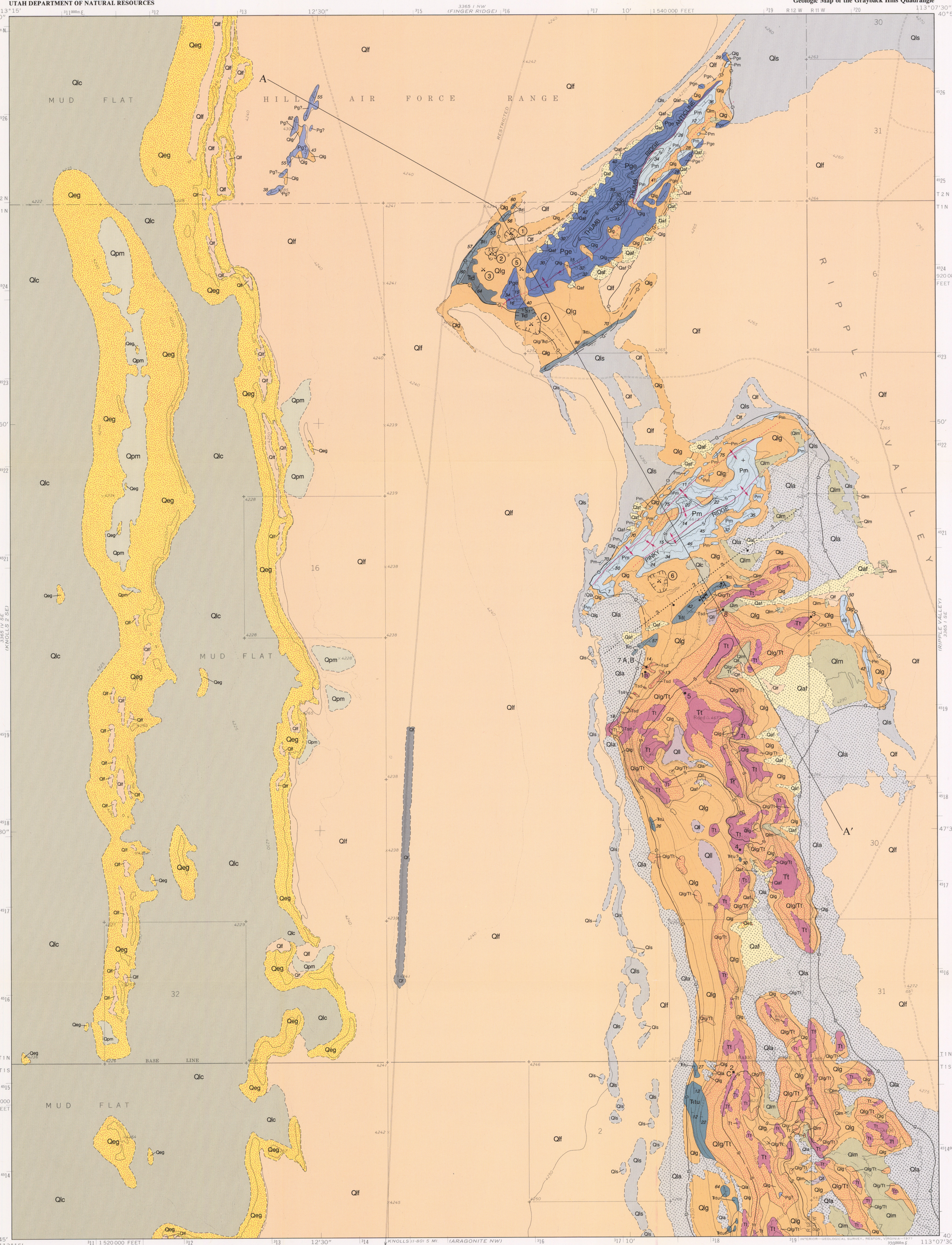
Plate 1
Utah Geological Survey Map 166
Geologic Map of the Grayback Hills Quadrangle



Base map from U.S. Geological Survey
Grayback Hills 7.5' Quadrangle, 1973

Field work by S.F. Davies 1977-1980,
B.J. Solomon 1989,
and H.H. Doelling 1990-1991
Lori J. Douglas, Cartographer

14°28'
257.2 mils

1994 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 10 FEET
DOTTED LINES REPRESENT 5-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

UTAH
QUADRANGLE LOCATION

GEOLOGIC MAP OF THE GRAYBACK HILLS QUADRANGLE, TOOELE CO., UTAH

by

Hellmut H. Doelling, Barry J. Solomon,
and Stephen F. Davies

1994

UTAH GEOLOGICAL SURVEY
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DESCRIPTION OF MAP UNITS

Qf Artificial-fill deposits - *Lake Bonneville gravels used as a thin base for a landing strip west of the Grayback Hills. Deposits are less than 1 foot (0.3 m) thick.*

Qes Silica-dune deposits - *Sand-sized quartz grains deposited as dunes on the east slope of the Grayback Hills. Probably locally reworked from lacustrine and alluvial sediments. The dunes are as high as 10 feet (3m).*

Qeg Gypsum-dune deposits - *Primarily sand-sized gypsum grains deposited as dunes in the east margin of extensive mud flats. The gypsum probably was derived both from the erosion of efflorescent mud flat salts and in-place reworking of lacustrine beach deposits at the 4,230-foot (1,289 m) level of the Gilbert shoreline. Dunes form north-south linear ridges up to 30 feet (9 m) high.*

Qal Alluvial-channel and -floodplain deposits - *Fine-grained alluvium with thin gravel layers and lenses, deposited in a channel and floodplain near the northeast end of the Grayback Hills after the regression of Lake Bonneville from the Provo shoreline. Includes some alluvially reworked colluvium deposited on piedmont slopes. Deposits are generally less than 10 feet (3 m) thick.*

Qaf Alluvial-fan deposits - *Coarse- to fine-grained alluvium, mixed with debris-flow sediments, deposited on piedmont slopes after regression of Lake Bonneville from the Provo shoreline. Generally finer grained in the distal portion of the fans, where locally mixed with lacustrine sediments. Deposits are generally less than 10 feet (3 m) thick.*

Qpm Playa-mud deposits - *Poorly sorted clay and silt and small amounts of sand, deposited within and adjacent to gypsum dunes west of the Grayback Hills. Deposits are generally less than 10 feet (3 m) thick.*

Qls Lacustrine sand - *Fine- to medium-grained, silty sand deposited in bars, spits, tombolos, and beaches near the Gilbert shoreline. Locally contains pebbly layers and lenses and thin clayey and marly interbeds. The unit may be as much as 30 feet (9 m) thick.*

Qlm Lacustrine marl - *Very fine-grained white to gray marl and alluvially reworked sandy marl and marly sand. Outcrops occur near the crest and along the eastern margin of the Grayback Hills. Locally contains ostracodes and gastropods. Deposits are generally less than 6 feet (2 m) thick.*

Qll Lacustrine lagoon deposits - *Silt, clay, marl, and minor sand that fill lagoons behind shoreline gravel bars along the flanks of the Grayback Hills. Deposits are generally less than 10 feet (3 m) thick.*

Qlg Lacustrine gravel - *Sandy gravel deposited in beaches and spits on the margins of the Grayback Hills, as a tombolo connecting Pinky Ridge to the main portion of the hills, and as barrier bars adjacent to lagoons near the crest of the hills. Bars and spits are associated with the Gilbert and Stansbury shorelines, but gravel is common between these levels and above the Stansbury shoreline. Thin, unmappable beds of lacustrine tufa, draped on bedrock units, are included. Gravels are typically well rounded and locally intertongue with volcanic talus at unmappable scales. The unit may be up to 30 feet (9 m) thick.*

Qlg/Tt Lacustrine gravel overlying trachyandesite lava - *Thin deposits of gravel, mostly composed of reworked volcanic talus, resting on trachyandesite lava flows beneath the flanks of the Grayback Hills.*

Qlg/TRd Lacustrine gravel overlying Dinwoody Formation - *Thin deposits of gravel, mostly composed of small angular fragments of the Dinwoody Formation, lying on the Dinwoody Formation beneath a gravel bar connecting the central part of Thumb Ridge with its south margin.*

Qlf Lacustrine fine-grained deposits - *Silt, clay, and lesser amounts of fine sand and marl deposited on the basin floor east of the mud flats. Typically contains low-relief, crescentic features known as desert ripples. These deposits are generally less than 30 feet (9 m) thick.*

Qlc Lacustrine clay - *Typically consists of thin-bedded to laminated clay deposited in mud flats west of the Grayback Hills. Includes small amounts of interbedded fine sand, silt, and marl. Commonly overlain by a thin crust of efflorescing salts or a thin layer of sand- and silt-sized gypsum particles, particularly in areas adjacent to gypsum dunes. The unit generally less than 10 feet (3 m) thick.*

Qla Undifferentiated lacustrine and alluvial deposits - *Fine- to coarse-grained sediments in the piedmont. Coarser in middle and upper piedmont areas. Locally contains colluvium which intertongues with the lacustrine and alluvial material at unmappable scales. The unit is generally less than 10 feet (3 m) thick.*

Tt Trachyandesite lava flows - *Grayish-black, olive-black, olive-gray, dark-gray, medium-dark-gray and grayish-brown fresh; grayish-black, grayish-brown, moderate-yellowish-brown, and brownish-gray- weathering trachyandesite that is porphyritic with an average of 15 percent phenocrysts typically of calcic plagioclase and pyroxene. Matrix, commonly trachytic, contains phenocryst minerals plus as much as 20 percent glass. (Parallel to conchoidal fracturing or jointing.) Some vesicular textures, generally blocky weathering. Dated at 39.1 ± 1.0 and 38.5 ± 0.6 Ma by K-Ar methods. Individual flows are 35 feet (15 m) thick or less.*

Tsd Volcaniclastic rocks - *Interbedded light-gray tuffaceous conglomeratic sandstone and dacite tuff. Tuffaceous conglomeratic sandstone (80 percent of unit) composed of fine sand- to cobble-sized clasts; coarser clasts consist of silty or sandy limestone, siltstone, sandstone, and chert; finer grained constituents are of broken volcanic glass shards, grains of mica, mafic minerals, quartz, feldspar, and bits of siltstone, sandstone, and chert. Dacite tuff (20 percent) contains phenocrysts of mica, quartz, and feldspar in a devitrified matrix. Dated at 38.6 ± 1.0 Ma by K-Ar method and 35.52 ± 0.38 Ma by weighted age. Incomplete exposures are more than 300 feet (90 m) thick.*

TRtu Upper Thaynes Formation - *Gray limestone, weathers brown where silty and sandy, thin- to thick-bedded, locally fosiliferous containing cephalopods (Prohungarites, Keyserlingites, Stachites), pelecypods (Bakevillia, Eumorphotis, Claraia, Monotis, Nuculana, Unionites, Neoschizodus?), brachiopods (Lingula), conodonts (Neospathodus), and other fossil debris (crinoid columnals, fish teeth, shark denticles, scaphopods?). Incomplete exposures are more than 220 feet (67 m) thick.*

TRtl Lower Thaynes Formation - *Gray, ledge-forming limestone, thin- to thick-bedded porous; and locally fossiliferous, containing conodonts (Ellisonia, Platyvillosus, Neospathodus), microgastropods (Cylindrobullina, Naticopsis), crinoid columnals, shark denticles, fish teeth, and echinoid fragments. Incomplete exposures are more than 240 feet (73 m) thick*

TRd Dinwoody Formation - *Interbedded shale, sandstone, and silty and sandy limestone; shale is yellowish-gray, grayish-yellow, and light-olive-gray; limestone is grayish-red, light-olive-gray, and medium-gray; shaly to medium bedded; slope former, lower half very poorly exposed; contains sporadic poorly preserved fossils. The complete unit is 1,280 feet (390 m) thick.*

Pge Gerster Formation - *Limestone and chert; limestone gray and light-gray-weathering; fine- to coarse-grained crystalline; medium-bedded to massive; resistant and ledge forming; hackly weathering; light-blue-gray chert present and nodules, blebs, stringers, and beds that weather to produce a brown rind; fossiliferous containing productid and spiriferid brachiopods, shell fragments, and crinoid columnals. The complete unit is 310 feet (95 m) thick on Thumb Ridge.*

Pm Murdock Mountain Formation - *Interbedded light-gray, blue-gray, and gray-tan, brown-weathering, mostly medium-bedded and nodular chert and light-gray cherty dolomite and limestone; forms subdued and rubbly ledges; locally contains poorly preserved fossil debris. More than 500 feet (150 m) of the unit is exposed, total thickness estimated at 1,650 feet (503 m).*

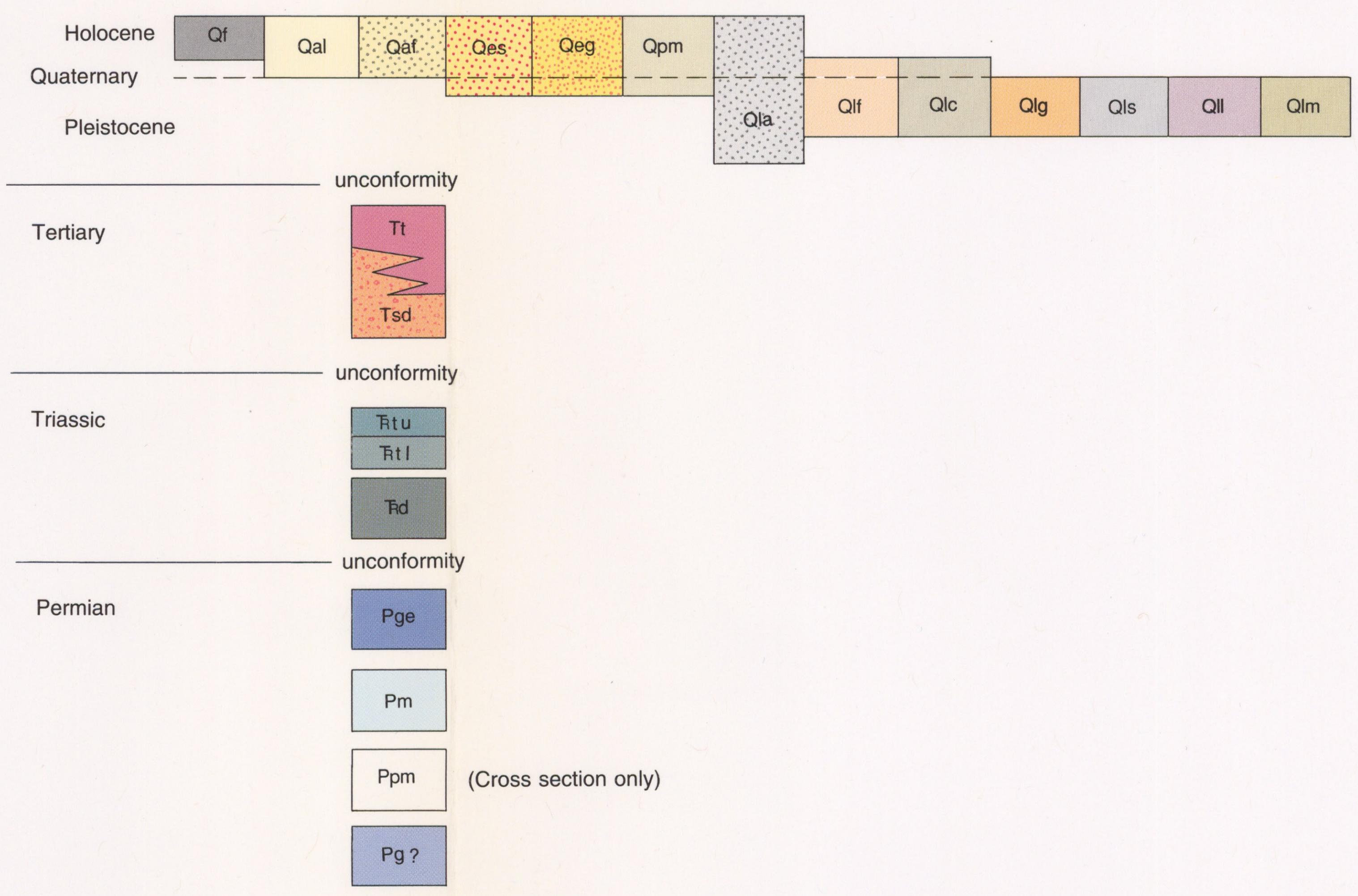
Ppm Meade Peak Member of the Phosphoria Formation - *in cross section only*

Pg? Grandeur? Formation - *Interbedded light-gray-weathering sandy limestone, dolomitic limestone, and dolomite; chert common as nodules and blebs, as well as in sporadic thin beds. Generally resistant, ledge-forming, and hackly weathering. More than 500 feet of the unit (150 m) is exposed.*

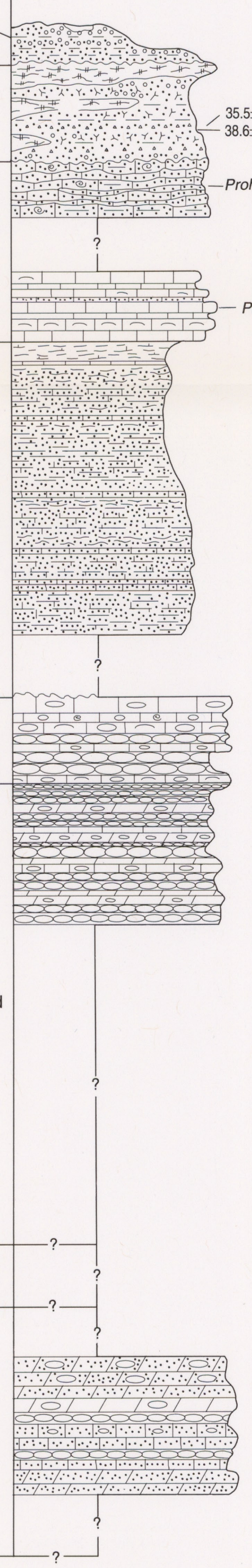
MAP SYMBOLS

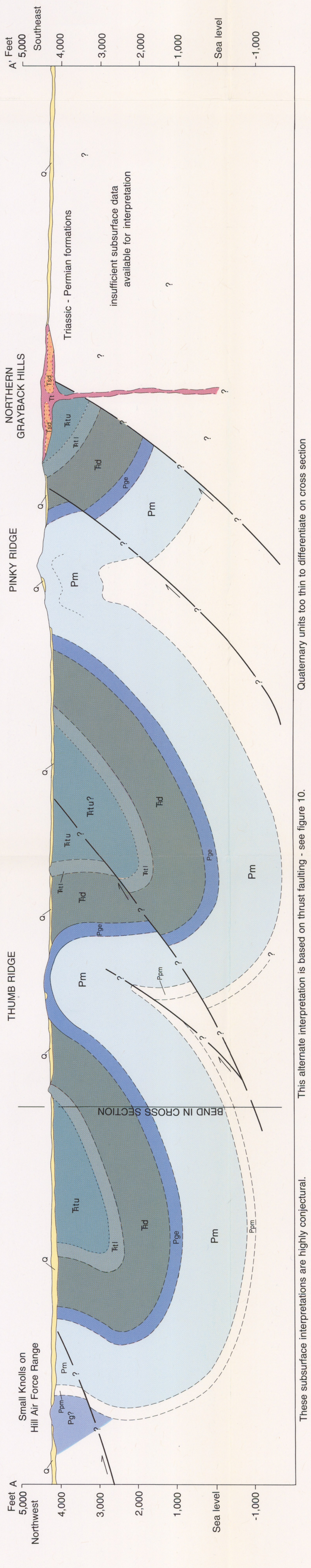
- Contact, dashed where approximate
- High-angle fault, dashed where approximately located, dotted where concealed, queried where conjectural.
- Anticline - showing trace of axial plane and plunge of axis. Dotted where projected beneath surficial deposits.
- Syncline - showing trace of axial plane. Dotted where projected beneath surficial deposits.
- 21 Strike and dip of bedding
- Horizontal bedding
- Strike of vertical bedding
- 85 Strike and dip of overturned bedding
- —G —— G— Gilbert shoreline of the Great Salt Lake
- —S —— S— Stansbury shoreline of Lake Bonneville
- (1) Gravel pits, circled numbers designate pits described in table 3.
- •3 Sample locations of materials collected for geochemical analyses reported in table 1.
- •B Sample locations of materials collected for radiometric dating reported in table 2.

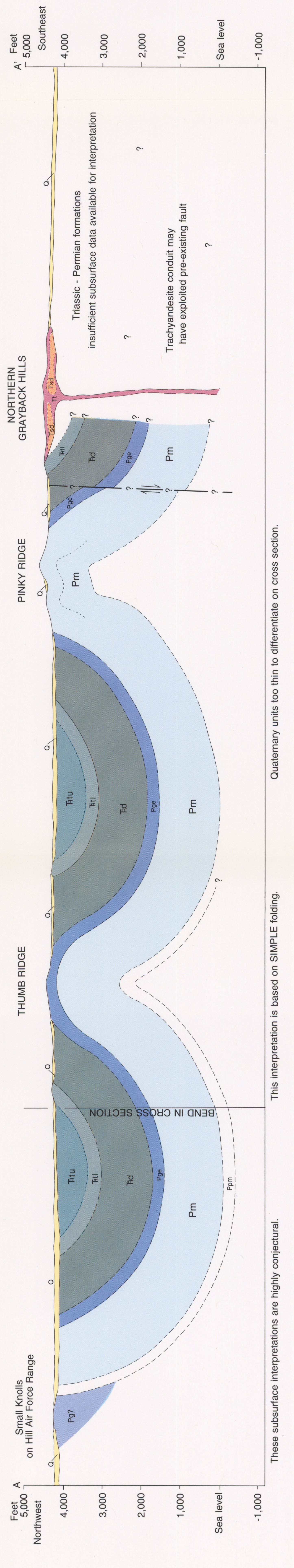
CORRELATION OF MAP UNITS



PERIOD	EPOCH	FORMATION OR MEMBER		SYMBOLS	THICKNESS FEET (M)	LITHOLOGY
QUATERNARY	Holocene	Surficial deposits		Qf, Qal, Qaf, Qes, Qeg, Qpm, Qla	0 - 50 (0-15)	
QUATERNARY	Pleistocene	Mostly Lake Bonneville deposits		Qla, Qlf, Qlc, Qlg, Qls, Qll, Qlm	0 - 50+ (0-15+)	
TERTIARY	Eocene or Oligocene	Trachyandesite lava flows		Tt	35+ (11+)	
TERTIARY	Eocene or Oligocene	Volcaniclastic rocks		Tsd	307+ (94+)	35.5±0.4 Ma (Ar-Ar) 38.6± 1.0 Ma (K-Ar)
TRIASSIC	Lower	Thaynes Formation		TRtu	220+ (67+)	Prohungarites
TRIASSIC	Lower	Thaynes Formation		TRtl	240+ (73+)	Platyvillosus asperatus
TRIASSIC	Lower	Dinwoody Formation		TRd	1280 (390)	
PERMIAN	Guadalupian	Gerster Formation		Pge	310 (95)	
PERMIAN	Guadalupian	Murdock Mountain Formation		Pm	500+ (150+) total estimated 1650 (503)	
PERMIAN	? Leonardian	Phosphoria Formation	Meade Peak Member	Ppm	230? (70?)	
PERMIAN	Leonardian	Grandeur? Formation		Pg ?	500+ (150+)	







Doelling, Solomon, Davies

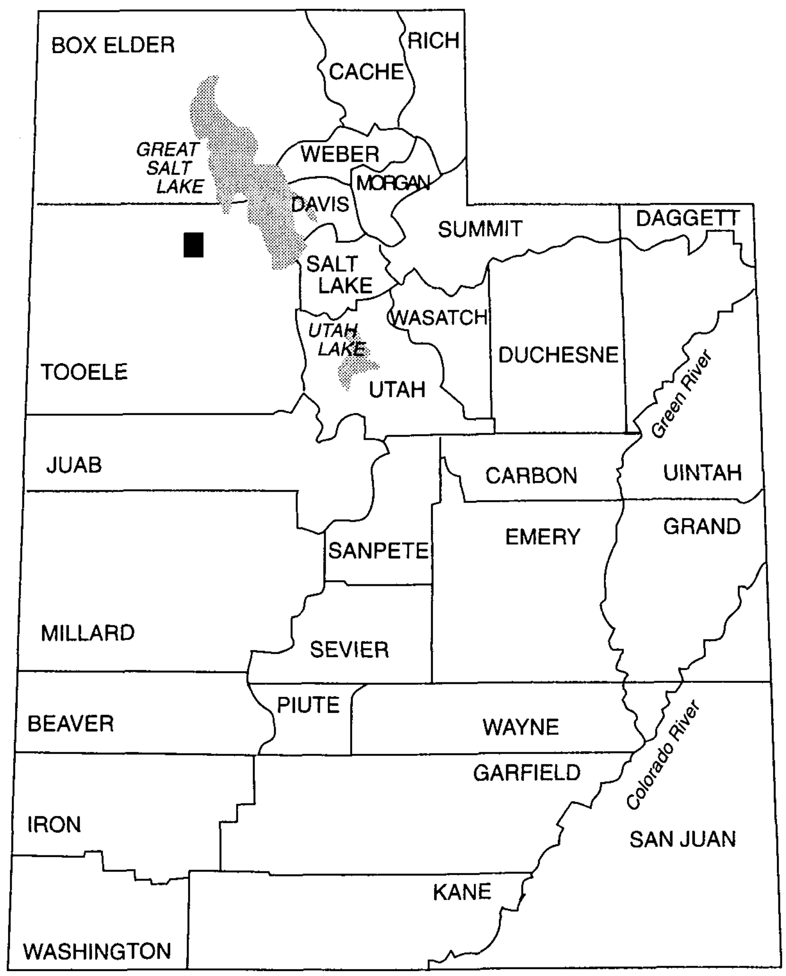
GEOLOGIC MAP OF THE GRAYBACK HILLS QUADRANGLE, TOOELE COUNTY, UTAH

UGS MAP 166

GEOLOGIC MAP OF THE GRAYBACK HILLS QUADRANGLE, TOOELE COUNTY, UTAH

by

H.H. Doelling, B.J. Solomon, and S.F. Davies



Map 166 **1994**

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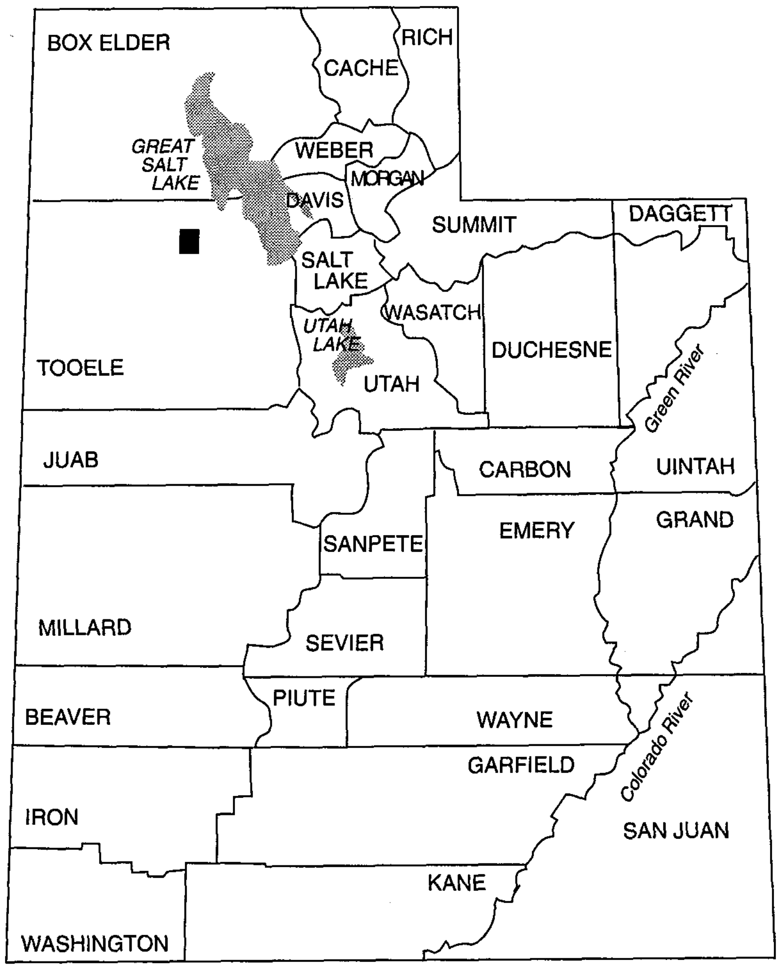
UTAH CENTENNIAL 1896-1996

GEOLOGIC MAP OF THE GRAYBACK HILLS QUADRANGLE, TOOELE COUNTY, UTAH

by

H.H. Doelling, B.J. Solomon, and S.F. Davies



Map 166 **1994**

UTAH GEOLOGICAL SURVEY

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UTAH GEOLOGICAL SURVEY
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GEOLOGIC MAP OF THE GRAYBACK HILLS QUADRANGLE, TOOELE COUNTY, UTAH

by

H. H. Doelling, B. J. Solomon*, and S. F. Davies*

ABSTRACT

The Grayback Hills quadrangle lies along the eastern margin of the Great Salt Lake Desert in northwestern Utah about 80 miles (129 km) west of Salt Lake City. Exposed rocks are Permian and Triassic strata, Tertiary lava and volcaniclastic rocks, and Quaternary deposits of late Pleistocene and Holocene age. Permian rocks are assigned to the Grandeur? Formation, Murdock Mountain Formation, and Gerster Formation. Exposed Triassic rocks are assigned to the Dinwoody? Formation and Thaynes Formation. Upper Early Triassic (Smithian and Spathian) conodonts and ammonites have been identified in the Thaynes Formation. Tertiary rocks consist of a unit of tuffaceous sandstone, conglomerate, dacite, and a trachyandesite unit. The trachyandesite lava is above the volcaniclastic rocks, but may also be interlayered with them.

All bedrock units were inundated by Pleistocene Lake Bonneville, and veneers of lake sediment generally mask bedrock exposures. Lake Bonneville units include clay, silt, sand, gravel, and marl arranged in a variety of geomorphic forms. The Stansbury shoreline of Lake Bonneville and Gilbert shoreline of the Great Salt Lake are etched on low ridges of the Grayback Hills. Post-Bonneville Holocene surficial units include alluvial-fan and -channel deposits, gypsum dunes, playa muds, and engineered fill.

Permian and Triassic strata are mostly steeply inclined. Structures exposed in Thumb and Pinky Ridges are moderately folded, northeast-trending anticlines with wavelengths of about 2 miles (3.2 km) and amplitudes of about 0.7 mile (1 km) that probably formed during the Late Cretaceous Sevier orogeny. No major faults are exposed in the quadrangle though late Cenozoic normal faults, buried by Quaternary deposits, may be present along the flanks of the Grayback Hills.

Geologic economic resources include sand, gravel, and gypsite that have been used as foundation materials for local roads and waste-disposal facilities located in the quadrangle. Potential geologic hazards include earthquakes, surface flooding, adverse soil conditions, debris flows, and rock falls. Land use, other than for geologic resources, includes sheep grazing, hazardous-waste disposal, and military-training activities. The quadrangle includes parts of the West Desert Hazardous Industry Area and Hill Air Force Range.

INTRODUCTION

The Grayback Hills 7½ minute quadrangle lies on the eastern side of the Great Salt Lake Desert about 45 miles (72 km) east of Wendover and 80 miles (129 km) west of Salt Lake City (figure 1). The southern boundary of the quadrangle is located 2 miles (3.2 km) north of Interstate Highway 80 (I-80) between the Union Pacific Railroad sidings of Clive and Knolls. The area lies within the eastern Basin and Range Province and the ancestral Lake Bonneville basin. During the highest stage of Lake Bonneville, the quadrangle was covered by nearly 1,000 feet (300 m) of water, and nearby Cedar and Grassy Mountains were small islands (figure 2).

The Grayback Hills quadrangle includes the north-central part of the West Desert Hazardous Industry Area, an administrative unit established in 1988 by the Tooele County Commissioners Board to coordinate the development of hazardous-waste treatment, storage, and disposal facilities. The Grassy Mountain hazardous-waste landfill, operated by U.S. Pollution Control, Inc., is located in section 16, T. 1 N., R. 12 W., Salt Lake Base and Meridian. The U.S. Air Force conducts airborne gunnery and missile practice on the Hill Air Force Range, which extends into the northern part of the quadrangle. A large part of the quadrangle was used for military purposes during World War II.

* *Utah Geological Survey*

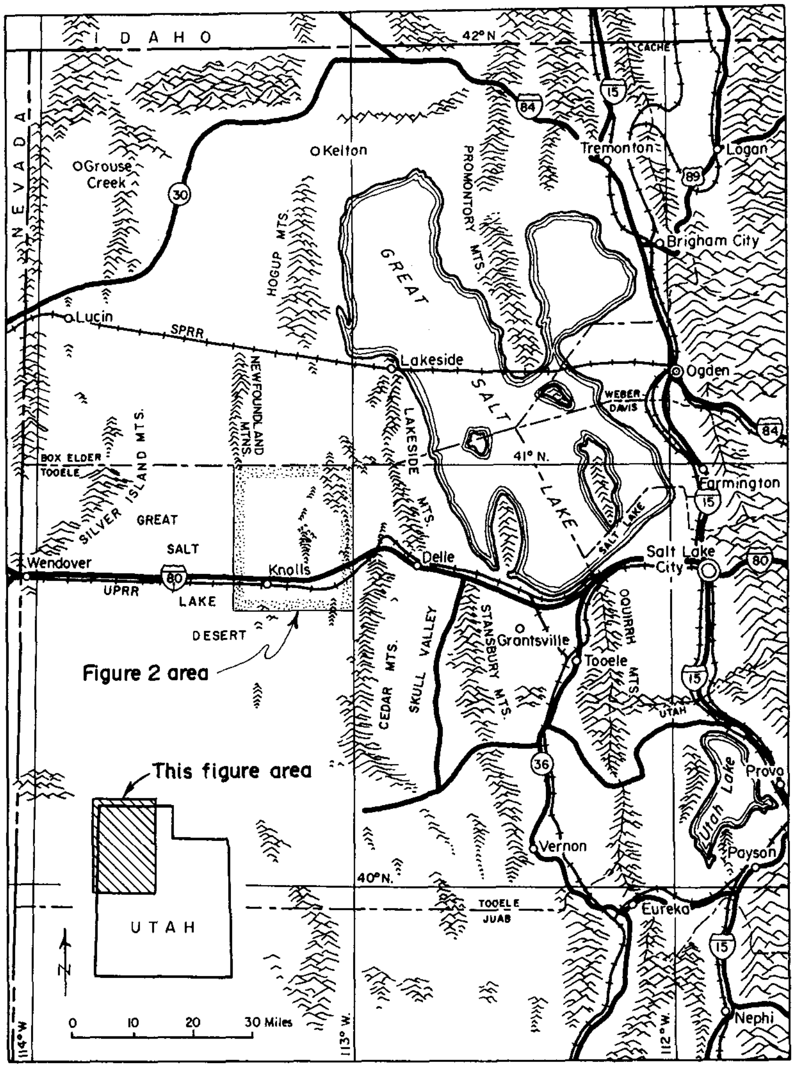

Figure 1. *Index map showing the location of the Grayback Hills area. Rectangle marked "figure 2" denotes an area of nine quadrangles with the Grayback Hills quadrangle in the center.*

The remains of a landing strip are in the south-central part of the quadrangle, and a few bombing targets can still be identified. In addition, the Grayback Hills are intermittently used for winter grazing of sheep and several gravel deposits in the Grayback Hills foothills have been exploited for road metal, road fill, and other nearby construction.

The Grayback Hills, and associated Thumb and Pinky Ridges, lie mostly in the east half of the quadrangle. They are aligned north-south and are as much as 1.5 miles (2.4 km) wide. They extend one mile south into the adjoining Aragonite NW quadrangle, so the length of the entire ridge group is about 9.5 miles (15.3 km). The altitude of the Grayback Hills varies from about 4,260 feet (1,298 m) to 4,715 feet (1,437 m). Ripple Valley, located east of the Grayback Hills, is 4,260 to 4,280 feet (1,298-1,305 m) in altitude.

The west half of the quadrangle is mostly flat, former lake bottom over which two very narrow, linear, north-trending dune ridges were deposited. The altitude of the former lake bottom varies from about 4,220 feet (1,285 m) in the northeastern corner of the quadrangle to about 4,260 feet (1,298 m) at the foot of the Grayback Hills. The two north-trending dune ridges have a maximum relief of 35 feet (10 m).

The principal access to the quadrangle is from an I-80 frontage road, and thence along a north-south-oriented gravel road (figure 2). Several dirt roads extend easterly to the base of the Grayback Hills. Some end at deserted sheep camps or wells, others at gravel pits. Another dirt road extends north from the I-80 frontage road east of the Grayback Hills in Ripple Valley; it provides access to the east side of the ridge.

Numerous sources of geologic information are available for the quadrangle. Early investigators (Stansbury, 1852; Gilbert, 1890) provided regional observations of the Great Salt Lake Desert. Gilbert (1890) said of the desert that "the area formerly covered by the main body of Lake Bonneville is now a plain, conspicuous for its flatness." He described the "lost mountains of Great Salt Lake Desert" as "circled by rocky and inhospitable coasts" during the Lake Bonneville highstand.

Doelling (1964) mapped the east two-thirds of the Grayback Hills quadrangle, and Davies (1980) later mapped the Grayback Hills. Hogg (1972) discussed volcanic rocks exposed there. Jones (1953), Eardley (1962), and Dean (1978) described eolian deposits of the region. Halverson (1961), Stepp (1961), Tanis (1963), Cook and others (1964, 1975, 1989), and Baer and Benson (1987) conducted regional gravity surveys. Gravity data (Baer and Benson, 1987) suggest that basin floors of the region are complex collections of troughs and ridges rather than single downfaulted grabens. Limited data on seismicity and the engineering properties of soils were generated for highway construction (Utah State University Engineering Experiment Station, 1962; Utah State Department of Highways, 1967) and for a proposed superconducting supercollider site (Dames & Moore and others, 1987a, 1987b). The U.S. Department of Agriculture Soil Conservation Service mapped soils in the area and determined erosion hazard, permeability, and land-use suitability (unpublished data, 1989). Solomon and Black (1990) reported on Quaternary geology and geologic hazards of the West Desert Hazardous Industry Area. Carpenter (1913), Stephens (1974), and Gates and Kruer (1981) summarized the regional hydrology.

B.J. Solomon mapped and described the Quaternary deposits and discussed Quaternary geologic history and geologic hazards. H.H. Doelling and S.J. Davies worked out the Permo-Triassic and Tertiary stratigraphy and structure for this project.

STRATIGRAPHY

The rocks of the Grayback Hills and associated knolls are Permian, Triassic, and Tertiary in age. Unconsolidated surficial deposits in the quadrangle are Quaternary in age. The rocks consist of partial sections totaling nearly 3,400 feet (1,036 m) in thickness. Perhaps an additional 2,000 feet (610 m) of these rocks are shallowly buried by the sediments of Pleistocene Lake

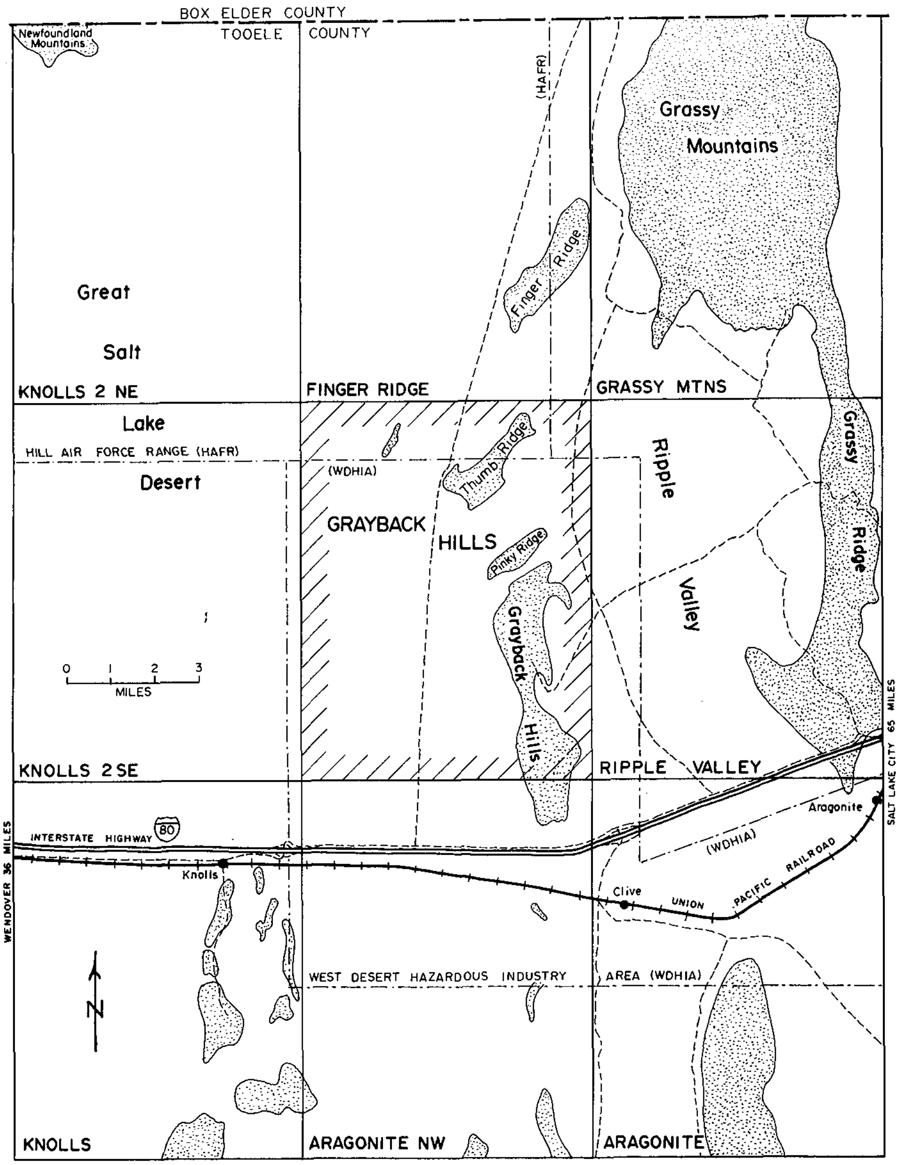

Figure 2. Nine-quadrangle area showing physiographic and cultural features and the names and positions of the Grayback Hills and the surrounding quadrangles. Short dashed lines represent the principal secondary roads. Boundaries for the Hill Air Force Range (HAFR) and West Desert Hazardous Industry Area (WDHIA) are also shown.

Bonneville. Baer and Benson (1987) assumed that no more than 3,000 feet (914 m) of basin fill, including Tertiary and Quaternary units, cover bedrock in the western part of the quadrangle.

Permian Rocks

We place Permian strata exposed in the Grayback Hills quadrangle in the marine Grandeur?, Murdock Mountain, and Gerster Formations (plates 1 and 2). Wardlaw and others (1979) gave a summary of Permian rocks in the region. These formations are present in northeast-trending elongate ridges north of the Grayback Hills, and in a small exposure in the south Grayback Hills. Of these formations, only the Gerster is completely exposed. Permian rocks exposed in the quadrangle are just over 1,300 feet (396 m) thick.

Grandeur? Formation (Pg?)

Strata assigned to the Grandeur? Formation are present in the northwest part of the quadrangle, in unsurveyed section 33, T. 2 N., R. 12 W., in the Hill Air Force Range. The strata form jagged and cliffy outcrops that match Grandeur Formation exposures elsewhere in northwest Utah. No definitive fossils were found to constrain the age. We attach a query (?) to the name because other Permian units in the quadrangle are partly similar in lithology and appearance. Principles of stratigraphic position, thickness, structure, or geographic position cannot be applied because other Permian rock outcrops are more than a mile away. Additionally, we assigned a very small exposure in the SE¼ section 1, T. 1 S., R. 12 W. to the Grandeur? Formation because it matches the rocks in the northwest part of the quadrangle more closely than those of the nearby Triassic Thaynes Formation. Other isolated outcrops of Grandeur? Formation with near-vertical attitudes are 3 miles (5 km) to the east in the Ripple Valley quadrangle (Doelling, 1964, map 4).

The Grandeur? Formation consists of light-gray-weathering sandy limestone, dolomitic limestone, and dolomite. Light-gray chert is common as nodules and blebs, as well as in sporadic thin beds. The exposed interval in the northwest part of the quadrangle is approximately 500 feet (150 m) thick. The Grandeur Formation in the Grassy Mountains was estimated to be over 1,000 feet (300 m) thick (Doelling, 1964, p. 230). A measured section in the Hogup Mountains shows the Grandeur Formation as 1,838 feet (560 m) thick (Stifel, 1964, p. 56-59).

The Meade Peak Member of the Phosphoria Formation is commonly present between the Murdock Mountain and Grandeur Formations in this part of the Great Basin. The unit is economically important because of its phosphate content, and is assumed to be present in the subsurface (Ppm, section A-A′, plate 2). We found no exposures of Meade Peak lithologies in the scattered outcrops in the Grayback Hills quadrangle. Doelling (1964, p. 256) measured an incomplete section of 233 feet (71 m) of the Meade Peak Member on Finger Ridge about 3 miles (5 km) north of the Grayback Hills quadrangle. Maurer (1970, p. 98) measured 141 feet (43 m) of the Meade Peak Member in the Cedar Mountains about 16 miles (25 km) to the southeast. Stifel (1964, p. 69) measured 404 feet (123 m) of the Meade Peak Member in the Hogup Mountains 38 miles (61 km) north of the Grayback Hills quadrangle.

Murdock Mountain Formation (Pm)

Wardlaw and others (1979) described the various Permian rocks in northwest Utah; in the Grayback Hills area they depict dolomite, chert, mudstone, and sparse limestone of the Plympton Formation grading into the chert, cherty dolomite, limestone, and sandstone of the Murdock Mountain Formation, which in turn grades northward into the Rex Chert Member of the Phosphoria Formation. In the Grayback Hills the rocks found in this interval match the description of the Murdock Mountain Formation, although they were previously assigned to the Rex Chert (Doelling, 1964; Stifel, 1964).

The Murdock Mountain Formation crops out on Thumb and Pinky Ridges, and in a small ridge trending N. 10° E. at the north end of the Grayback Hills. The upper contact of the formation is found in the northeast part of the core of the Thumb Ridge anticline. No contacts are present in either of the other two exposures.

In the Grayback Hills quadrangle, the Murdock Mountain Formation is mostly light-gray, blue-gray, gray-tan, and brown-weathering, bedded and nodular chert, and light-gray cherty dolomite and limestone. Most units are medium bedded and rarely exceed 1.5 feet (0.5 m) in thickness. Lake Bonneville has modified the outcrops considerably and has covered many rock outcrop areas with a veneer of lacustrine sediments so the rocks now appear as subdued rubbly ledges. In a few localities the formation contains poorly preserved fossils (brachiopods). At least 500 feet (150 m) of the unit are exposed. Doelling (1964, p. 230) measured about 1,650 feet (503 m) of the Rex Chert (Murdock Mountain Formation) on Finger Ridge, and Stifel (1964, p. 71) measured nearly 1,160 feet (354 m) in the Hogup Mountains. We applied Doelling's estimated thickness to section A-A′ and the lithologic column (plate 2).

The contact with the overlying Gerster Formation is poorly exposed and was mapped at the base of a thick-bedded to massive light-gray limestone ledge assigned to the Gerster Formation. Brown-weathering chert rubble is commonly found below the contact.

Gerster Formation (Pge)

Outcrops of the Gerster Formation are limited to Thumb Ridge. There, the unit weathers gray and light-gray, and consists of fine- to coarse-grained and crystalline cherty limestone in medium to massive beds. Chert is present as beds, nodules, blebs, and stringers and is tan, light gray, and light blue gray. Weathering produces brown rinds around the chert. The unit is fossiliferous, containing layers with productid and spiriferid brachiopods, crinoid columnals, and shell fragments. Wardlaw and others (1979) described the Gerster of northern Utah as cherty bioclastic limestone containing minor beds of chert, dolomite, and siltstone that interfinger with and overlie the Murdock Mountain Formation.

On Thumb Ridge the formation is about 310 feet (95 m) thick. Doelling (1964, p. 259) measured an incomplete 263 foot (80 m) section on Finger Ridge and Stifel (1964, p. 83) recognized 900 feet (274 m) in the Hogup Mountains. The upper contact of the Gerster Formation with the overlying Dinwoody Formation may be present at the north end of a gravel pit in unsurveyed section 3, T. 1 N., R. 1 N., where soft, brownish, shaly limestone in the Dinwoody is adjacent to resistant and fossiliferous limestone of the Gerster Formation (unit 9 in measured section below). Regional relationships indicate the contact is an unconformity (Hintze, 1988, p. 37).

Measured section of the GERSTER FORMATION exposed on the north flank of Thumb Ridge, N ½ section 2, T. 1 N., R. 12 W., Tooele County, Utah (measured by H.H. Doelling, April 1992).

TRIASSIC

Covered Dinwoody Formation. Measurement begins where the first resistant limestone ledge of the Gerster rises above the level of a prominent Lake Bonneville gravel bar. The Dinwoody overlying the Gerster Formation is covered for 238 feet (73 m).

PERMIAN

Gerster Formation

Unit	***Feet***
9. Limestone, light-gray, crystalline, massive; weathers hackly; ledge-former; contains large, spheroidal, gray chert nodules, and crinoidal and brachiopodal debris	*15+*
8. Limestone; light- to medium-gray, crystalline and bioclastic, thick-bedded to massive; contains many small brown-weathering blebs and nodules of chert, resistant and hackly weathering; contains crinoidal and brachiopodal debris and sparse productid brachiopods	*20*
7. Limestone; like unit 8, but less resistant, poorly exposed, contains brachiopods	*28*
6. Limestone; light-gray, like unit 8, 85 percent limestone and 15 percent chert, weathers into hackly and sugary surfaces, commonly very fossiliferous (crinoids and brachiopods)	*33*
5. Interbedded chert and limestone; chert brown and brown-gray, medium- to thin-bedded, rubbly weathering; limestone light-tan, sandy, medium-bedded, very fossiliferous (productid and spiriferid brachiopods); upper and lower parts dominated by chert, middle more fossiliferous and dominated by limestone; unit is partially brecciated	*72*
4. Interbedded limestone and chert; limestone tan-gray, medium-bedded, hard and ledgy; tops of ledges weather pitted with granular surfaces; chert gray, light-blue-gray, bedded and in nodules, nodule rinds weather medium brown; upper 12 feet (3.6 m) is 30 percent chert and 70 percent limestone, middle 17 feet (5 m) nearly chert free, lower 16 feet (4.9 m) is 60 percent chert and 40 percent limestone	*45*
3. Covered slope littered with limestone fragments (70 percent) and brown-weathering chert (30 percent)	*50*
2. Chert; gray, medium-bedded, forms resistant brownish-gray ledges with thin irregular interbeds of light-gray limestone (upper and lower parts contain as much as 30 percent limestone)	*30*
1. Limestone; light-gray, crystalline, thick-bedded to massive; contains large, medium-gray nodules with brown rinds; contains scattered small brachiopods and traces of shellfish debris	*18*
Total Gerster Formation	*311+ feet*

Murdock Mountain Formation: *Covered slope littered with blocky, brown-gray-weathering gray chert. Brown, rubbly ledges of chert crop out at base of slope.*

Triassic Rocks

Triassic rocks of the Grayback Hills quadrangle include the Dinwoody and Thaynes Formations, the exposures of which display over 1,700 feet (518 m) of strata. A summary of Triassic rocks of the region is available in Carr and Paull (1983).

Dinwoody Formation (₮d, Olg/₮d)

The Dinwoody Formation is poorly exposed at the west end of Thumb Ridge. The best exposures are on the northwest flank of the Thumb Ridge anticline. Float from the Dinwoody and/or Thaynes Formations is present in a gravel bar connecting the central part of Thumb Ridge with its south margin. We mapped this area as Lake Bonneville gravel overlying the Dinwoody (Qlg/₮d). The Dinwoody Formation also probably underlies the gravel bar connecting Pinky Ridge with the Grayback Hills. The Dinwoody consists of interbedded shale, sandstone, and silty and sandy limestone (figure 3). The unit is fossiliferous and locally contains ripple marks. The lower half of the Dinwoody is very poorly exposed in the quadrangle.

The thickness of the Dinwoody Formation is about 1,280 feet (390 m) on the north side of Thumb Ridge. Large intervals covered by surficial deposits preclude a more precise thickness calculation. Stifel (1964) measured 1,670 feet (509 m) and Paull (1982) measured 1,342 feet (409 m) of Dinwoody strata in complete sections in the Hogup Mountains to the north. The contact with the overlying, more resistant, gray-weathering limestone of the Thaynes Formation is sharp and conformable.

Measured section of the DINWOODY FORMATION as exposed at the edge of a Lake Bonneville bar at the southwest end of Thumb Ridge, E ½ of unsurveyed section 3, T. 1 N., R. 12 W., Tooele County, Utah (Measured by H.H. Doelling, March, 1992).

TRIASSIC

Thaynes Formation: Pale-brown (5YR 5/2) limestone that weathers light gray (N7) to medium light gray (N6), with patchy or blotchy grayish-yellow (5Y 8/4) to moderate-yellow (5Y 7/6) silty limestone, very fine grained and partially recrystallized, containing some very fine sand grains; indistinct bedding, weathering somewhat platy, forms a crude slope, and contains fossil fragments; about 20 feet (6 m) thick; grades upward into a coquina of fragmented and tightly packed pelecypods and microgastropods, thin- to medium-bedded, pocked with irregular openings. Contact is reasonably sharp, with very silty, thin-bedded limestone in the basal foot.

Dinwoody Formation

Unit ***Feet***

7. *Interbedded shale, very thin-bedded siltstone, and thin beds of very silty limestone, yellowish-gray (5Y 7/2) to grayish-yellow (5Y 8/4) fresh and weathered; minor fine-grained sandstone; shales are slightly calcareous; limestone beds 1-2 inches (5 cm) thick, shale laminae 0.04 - 0.4 inches (1mm-1cm) thick; weathers to steep shaly slope covered with irregular platelets with diameters to 3 inches (7.6 cm); thin limestones contain poorly preserved fossil debris, mostly fragments of small shellfish; limestone beds decrease in number rapidly below upper contact, and are widely spaced 122*
6. *Silty and sandy shale; yellowish-gray to light-olive-gray, paper-thin to nearly one-inch (2 cm) thick laminae; weathers to rounded slopes littered with fine shaly debris 68*
5. *Alternating sandstone and limestone; sandstone pale red to dusky brown, fine grained, calcareous, and platy weathering; limestone grayish red, light-olive gray, and medium gray, sandy, rough weathering, contains rare fossil debris; 80 percent sandstone and 20 percent limestone 350*
4. *Alternating sandstone and limestone like unit 5, but limestones generally fossiliferous, with **Claraia?** or similar pelecypod 490*
3. *Covered interval 5*

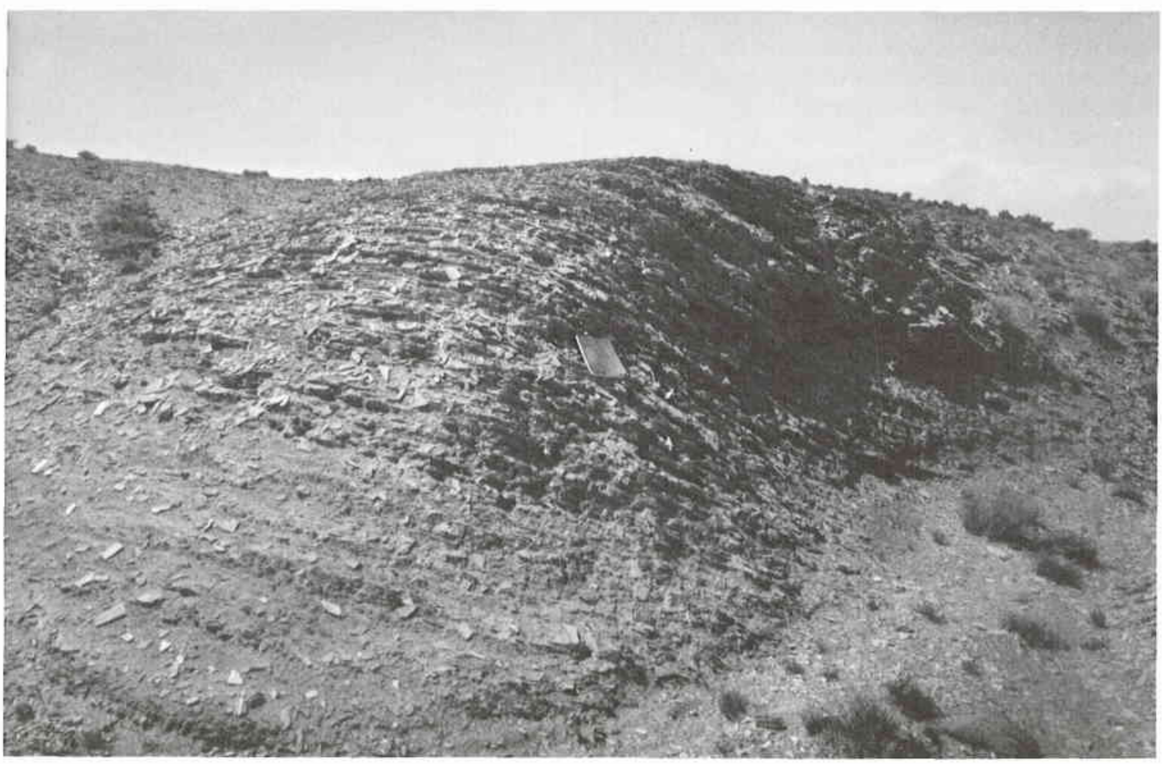

Figure 3. *Outcrop of upper Dinwoody Formation (₮d) on Thumb Ridge. Upper Dinwoody strata are shaly and contain thin (2 inches [5 cm] or less) beds of limestone.*

2. Siltstone; dark-reddish-brown, shaly, like Moenkopi Formation of the Colorado Plateau 16

1. Covered interval 230

Total Dinwoody Formation 1,281

— disconformity —

PERMIAN

Uppermost Gerster Formation: Light-gray, thick-bedded to massive, resistant, contains large light-gray to very-light-gray chert concretions as much as 1 foot (0.3 m) in diameter, rinds of chert concretions weather to dusky brown, contains fossil debris, mostly crinoid columnals and a few productid brachiopod outlines.

Thaynes Formation (₸tl, ₸tu)

The Thaynes Formation crops out in three areas in the Grayback Hills quadrangle but no continuous section could be found. The lower part of the Thaynes Formation (Trtl) is exposed in thin ridges of steeply dipping beds on both sides of Thumb Ridge. A thicker section is exposed in a northeast-trending ridge at the north end of the Grayback Hills. Heavy Thaynes-derived float in surficial deposits indicates that the formation is near the surface along much of the west side of the Grayback Hills.

The lower Thaynes consists of gray ledges of thick- to very thin-bedded, resistant limestone (figures 4 and 5). These limestones are dominantly micrite. Fossils found in the lower Thaynes include crinoids, echinoids, microgastropods, pelecypods, conodonts, and fragments from fish and sharks. The conodont guide fossil *Platyvillosus asperatus* indicates a lower Spathian substage (Carr and Paull, 1983, p. 41) and provides biostratigraphic control for the lower Thaynes in the Grayback Hills quadrangle. This fossil was found 50 feet (15 m) above a starting point in a section with no exposed base. We assume that the lower contact with the Dinwoody Formation at Thumb Ridge marks the base of the *Meekoceras gracilitatis* zone, but we could not verify this. The original sediments of the lower Thaynes probably consisted of carbonate mud deposited in a sheltered environment (Davies, 1980, p. 46). At least 240 feet (73 m) of lower Thaynes strata are exposed in the Grayback Hills quadrangle.

Measured section of a part of the lower THAYNES FORMATION taken across a ridge at the northern end of the Grayback Hills in N½ SW¼ SW¼ unsurveyed section 13, T. 1 N., R. 12 W., Tooele County, Utah (measured by S.F. Davies, 1980, p. 160-162).

TRIASSIC

Upper contact covered.

Thaynes Formation - lower part:

Unit ***Feet***

17. Limestone, light-gray (N7) to light-olive-gray (5Y 5/2); weathers medium-gray (N5.5) to grayish-orange (10YR 7/4); thinly bedded, wavy laminations scattered throughout, stylolites present; moderately resistant; abundant crinoid columnals, common pelecypods, rare ***Pentacrinus*** *columnals and microgastropods 3.3*

16. Covered slope 3.6

15. Limestone; light-gray (N7) to light-olive-gray (5Y 2/2), weathers medium-gray (N5.5) to grayish-orange (10YR 7/4); outcrop description same as unit 17; pelecypods, abundant crinoid columnals and echinoid fragments; common ***Cylindrobullina*** *sp. and unidentified microgastropods; uncommon scaphopods? and* ***Pentacrinus****; rare* ***Naticopsis****? sp. 2.5*

14. Covered slope 6.8

13. Limestone (60 percent) and sandstone (40 percent); limestone light-gray (N7) to light-brown (5YR 5/4), weathering to dusky brown (5YR 5/4), poorly developed wavy laminations present; sandstone medium-brown (5YR 5/4), weathers same color to dusky brown (5YR 2/2); laminated and thinly laminated, weakly developed cross-laminations; very thin beds and laminations of sandstone and limestone are intercalated; moderately resistant, surfaces weather smooth to hackly; commonly contains unidentified pelecypods and microgastropods, ***Naticopsis****? sp.,* ***Cylindrobullina*** *sp.,* ***Pentacrinus*** *columnals, shark denticles and fish teeth; uncommon scapho-pods?, echinoid fragments, rare* ***Ellisonia*** *sp. 3.7*

12. Covered slope 35.9

11. Limestone and sandstone; same as unit 13; contains common unidentified conodonts, ***Cylindrobullina*** *sp., shark denticles and fish teeth,* ***Platyvillosus asperatus****,* ***Naticopsis****? sp., scaphopods?, uncommon crinoid columnals and echinoid fragments,* ***Neospathodus? triangularis****, and rare* ***Pentacrinus*** *columnals . . 8.3*

10. Covered slope 38.6

9. Limestone; medium-gray (N5.5), weathers same color; moderately resistant, surface weathers hackly; contains abundant echinoid fragments and unidentified pelecypods, common ***Naticopsis****? sp.,* ***Cylindrobullina*** *sp., and unidentified microgastropods, uncommon scaphopods?,* ***Pentacrinus*** *columnals, shark denticles and fish teeth, rare unidentified conodont fragments 5.5*

8. Covered slope 31.6

7. Limestone, light-gray (N7) to light-olive-gray (5Y 5/2), weathers medium-gray (N6); bedding is thin to very thin in lower one-fourth, middle part slightly thicker bedded; upper part is massive, blocky, and weathers hackly; very resistant unit; abundant unidentified pelecypods, uncommon crinoid columnals, echinoid fragments, shark denticles and fish teeth, rare ***Cylindrobullina*** *sp. 14.2*

6. Covered slope 23.2

5. Limestone; light-gray (N7), weathers same color to medium gray (N6); lower half of unit displays thin to very thin bedding and upper half is massive; all surfaces display hackly weathering; abundant pelecypods; common unidentified microgastropods, ***Cylindrobullina*** *sp., shark denticles, and fish teeth; uncommon* ***Naticopsis****? sp., crinoid columnals, echinoid fragments, and unidentified conodont fragments; rare* ***Ellisonia*** *sp. 9.1*

4. Covered slope 10.5

3. Limestone; medium-gray (N5), weathers light gray (N6); massive, broken at irregular intervals by well-developed bedding planes; highly resistant, surfaces weather hackly; abundant unidentified pelecypods, common shark denticles and fish teeth, uncommon ***Naticopsis****? sp., and echinoid fragments, rare* ***Pentacrinus*** *columnals 15.8*

2. Covered slope 28.7

1. Limestone; like unit 3, but pale brown (5YR 6/2) to light gray (N7), weathers medium gray (N5); abundant unidentified pelecypods, common microgastropods, crinoid columnals, shark denticles, and fish teeth, uncommon ***Naticopsis****? sp., and echinoid fragments, and rare* ***Pentacrinus*** *columnals 14.2*

Total lower Thaynes Formation (incomplete) 255.5

Lower contact covered.

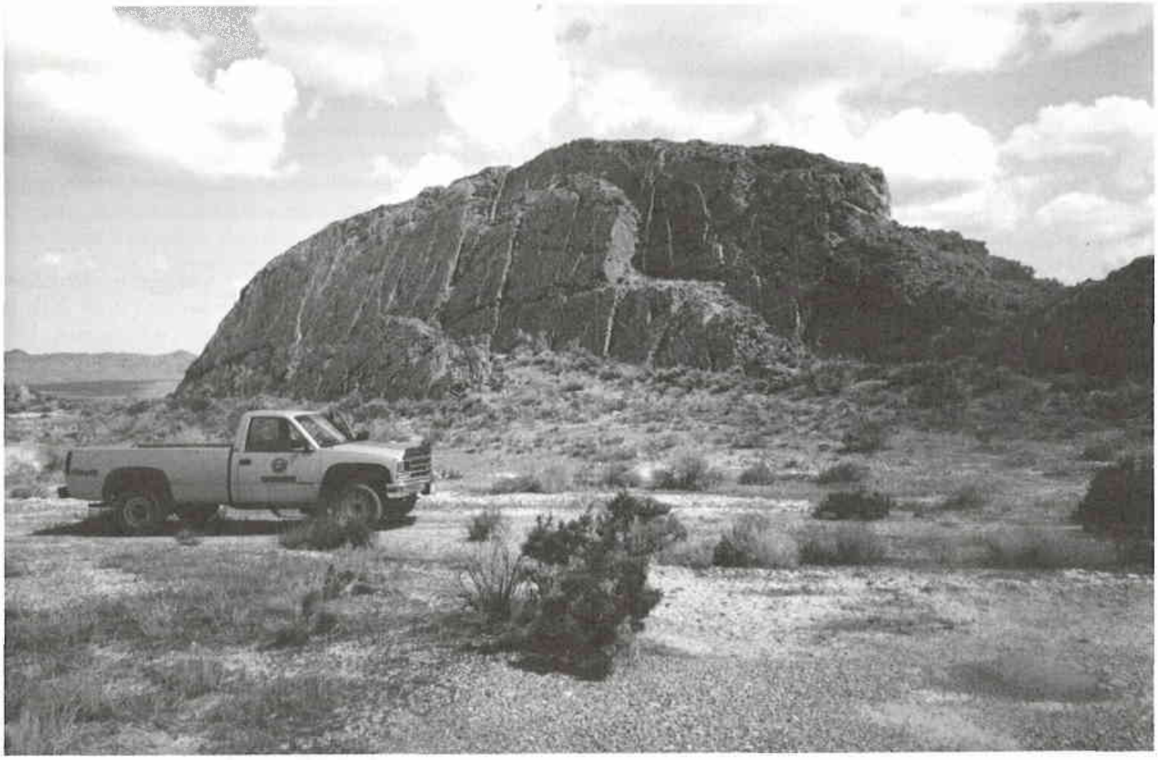

Figure 4. *Resistant outcrop of the lower Thaynes Formation (Ŧtl) on the northwest flank of Thumb Ridge.*

Figure 5. *Porous beds of limestone consisting of fossil shells near the base of the Thaynes Formation (Ŧtl) along the northwest flank of Thumb Ridge.*

The upper Thaynes Formation (Ŧtu) is exposed on the west side of the Grayback Hills, and is composed mainly of yellowish-brown, gray, or tan weathering, silty, very thin-bedded to laminated limestone. The finely recrystallized limestone displays characteristic, irregular-spaced, rough-surfaced wavy laminations and forms discontinuous low-relief outcrops. About 200 feet (60 m) of upper Thaynes rocks were measured in the Grayback Hills quadrangle, and additional strata are probably present in isolated, poorly exposed outcrops. The upper Thaynes Formation is locally fossiliferous and biostratigraphic control is provided by the ammonite guide fossil *Prohungarites* sp. which indicates an upper Spathian substage (Kummel, 1954, p. 176).

Measured section of a part of the upper THAYNES FORMATION (Ŧtu) taken across a series of low- to moderate-relief limestone beds that crop out along the southwest flank of the Grayback Hills in the W½ SE¼ unsurveyed section 12, T. 1 S., R. 12 W., Tooele County, Utah. The line of measurement was offset in many places to obtain the best information (measured by S.F. Davies, 1980, p. 149-152).

TRIASSIC

Upper contact covered.

Thaynes Formation--upper part:

Unit ***Feet***

*31. Limestone (50 percent) and silty limestone (50 percent); light-gray (N7), weathers pale-yellow-brown (10YR 5/2) to dusky brown (5YR 2/2); limestone forms upper half of unit, finely crystalline, massive, weathers hackly; silty limestone with wavy-laminated coarse silt, weathers into rounded to blocky low outcrops; fossiliferous with abundant microgastropods and pelecypod fragments, common scaphopods?, echinoid fragments, shark denticles and fish teeth, and uncommon **Pentacrinus**?, and crinoid columnals. 1.8*

30. Covered slope 13.3

29. Silty limestone; light gray (N7), weathers same color to moderate yellowish brown (10YR 6/4); coarse silt; massive to wavy laminated; weathers hackly and into rounded and blocky low-relief outcrops; fossiliferous with abundant echinoid and pelecypod fragments, uncommon microgastropods, and rare scaphopods? 2.2

28. Covered slope 1.9

*27. Silty limestone; light gray (N7) to moderate yellowish brown (10YR 5/4), weathers to same colors; coarse silt; wavy laminated; rounded to blocky moderate-relief outcrops that weather into rough surfaces; fossiliferous with common microgastropods and hematite-replaced echinoid spines, and rare **Bakevillia?** sp. 3.2*

26. Covered slope 1.6

*25. Limestone; light gray (N7) to yellowish gray (5Y 7/2), weathers to same colors to moderate yellowish-brown (10YR 6/4); contains minor coarse silt; massive to wavy laminated, forms blocky to rounded moderate-relief outcrops; fossiliferous with abundant pelecypod fragments, common echinoid fragments, uncommon fragments of **Lingula borealis**?, and rare **Prohungarites** sp., **Bakevillia**? sp., and **Neoschizodus** sp.. . . . . 7.7*

24 Covered slope 22.3

*23. Silty limestone; light gray (N7) and dusky yellow (5Y 6/3), weathers light olive brown (5Y 5/4) and dark yellowish brown (10YR 6/2); coarse silt; weathers to rounded to blocky low-relief outcrops; fossiliferous with common microgastropods and **Lingula borealis?** fragments, uncommon echinoid fragments and scaphopods?, and rare pelecypod fragments 1.3*

22. Covered slope 22.2

21. Silty limestone; light gray (N7), weathers moderate yellowish brown (10YR 6/4) to dark yellowish brown (10YR 4/2); medium silt; massive and wavy laminated; weathers smooth and hackly into low- to moderate-relief outcrops; contains abundant microgastropods, common echinoid fragments, and uncommon scaphopods? and pelecypod fragments 5.7

20. Covered slope 15.2

*19. Limestone; olive gray (5Y 5/2), weathers moderate yellowish brown (10YR 6/4) to dusky yellowish brown (10YR 2/2); contains minor quantities of medium silt; common wavy laminations; weathers to rough, slightly hackly surfaces and forms outcrops with low relief; contains abundant microgastropods and echinoid fragments, and rare **Lingula borealis** 1.4*

18. overed slope 13.7

17. Silty limestone; light gray (N7), weathers to same color and moderate yellowish brown (10YR 5/4); medium silt common in wavy laminations; weathers to rounded to blocky low-relief outcrops; fossiliferous with abundant microgastropods 2.6

16. Covered slope 8.5

*15. Limestone; light gray (N7), weathers to same color and moderate yellowish brown (10YR 5/4); minor amount of medium silt present as wavy laminations; forms rounded to blocky low-relief outcrops; fossiliferous with common microgastropods, and echinoid and pelecypod fragments, uncommon scaphopods?, and rare **Prohungarites?** sp. and **Keyserlingites bearlakensis?** 1.8*

14. Covered slope 8.0

13. Silty limestone; like unit 17, but not fossiliferous 4.6

12. Covered slope 13.0

*11 .Silty limestone; light gray (N7), weathers same color to pale yellowish brown (10YR 6/2); medium silt, wavy laminations common; weathers smooth to hackly; fossiliferous with abundant microgastropods, common echinoid fragments, uncommon pelecypod fragments, and rare **Prohungarites?** sp. and **Keyserlingites bearlakensis** 1.8*

10. Covered slope 11.4

*9. Silty limestone; like unit 17, fossiliferous with abundant microgastropods, echinoid fragments, and **Prohungarites** sp., common **Lingula borealis** and pelecypod fragments, uncommon **Eumorphotis multiformis,** and rare **Keyserlingites bearriverensis?** and **Bakevillia?** sp. 2.3*

8. Covered slope 17.7

*7. Silty limestone; yellowish gray (5Y 7/2), weathers same color and pale-yellowish-brown (10YR 7/2); contains coarse silt with wavy laminations; weathered to discontinuous, low- to moderate-relief outcrops; fossiliferous with abundant **Prohungarites** sp., and rare **Lingula borealis** and **Neoschizodus** sp. 3.8*

6. Covered slope 3.7

*5. Silty limestone; pale olive (5Y 7/2), weathers grayish orange (10YR 7/4) to moderate brown (5YR 3/4); commonly contains medium silt grains; massive to wavy laminated; weathers to rough and pitted surfaces; resistant; fossiliferous with abundant **Prohungarites** sp. and **Keyserlingites bearlakensis**, common microgastropods and echinoid fragments, uncommon **Lingula borealis** fragments, **Bakevillia?** sp, and scaphopods?, and rare **Eumorphotis multiformis, Stachites** sp., and **Keyserlingites bearriverensis?** 12.0*

4. Covered slope 6.0

3. Silty limestone; pale olive (5Y 7/2), weathers pale orange (10YR 7/3) to dusky-brown (5YR 2/2); contains medium silt, wavy laminations are common; surfaces weather smooth to rough, forming outcrops with low relief 7

2. Covered slope 3.0

1. Silty limestone; pale olive (5Y 7/2), weathers pale orange (10YR 7/3) to dusky brown (5YR 2/2); common coarse silt and wavy laminations; surfaces weather smooth to hackly, outcrops display moderate relief; fossiliferous with abundant microgastropods, echinoid fragments and pelecypod fragments, common ***Prohungarites*** *sp., uncommon scaphopods? and* ***Keyserlingites bearlakensis****, and rare* ***Keyserlingites bearriverensis?****,* ***Bakevillia?*** *sp., shark denticles, and fish teeth 3.9*

Total upper Thaynes Formation (incomplete) 219.3

Lower contact covered.

Tertiary Rocks

Volcaniclastic Rocks (Tsd)

Outcrops of a tuffaceous conglomeratic sandstone and dacite tuff are exposed in gullies at the northwest end of the Grayback Hills (unsurveyed sections 13 and 23, T. 1 N., R. 12 W.) and are assigned to the volcaniclastic rocks unit. The scattered exposures are present in the piedmont well below the Stansbury shoreline (about 4,525 feet or 1,379 m) of Lake Bonneville, but above the Gilbert shoreline (about 4,290 feet or 1,308 m). Similar rocks may be present along the west side of the Grayback Hills, but have been so reworked by Lake Bonneville that they can no longer be positively identified as bedrock outcrops.

The tuffaceous conglomeratic sandstone contains clasts ranging in size from very fine sand grains to cobbles. The percentage of grit-sized and larger clasts in the rocks is highly variable. The sand-sized and smaller particles of the rock are loosely cemented, and are somewhat laminated and cross-stratified (figure 6). Lenticular channels 0.2 to 1 foot (6-30 cm) deep and 1.5 to 10 feet (0.5-3 m) wide are common and are filled by poorly sorted lag concentrations of cobbles, pebbles, and granules that are embedded in a tuffaceous sandy matrix. The coarser constituents of the tuffaceous conglomeratic sandstone consist mostly of silty or sandy limestone, siltstone, sandstone, and chert, whereas the finer clasts are glass shards, grains of mica, mafic minerals, quartz, feldspar, and bits of siltstone, sandstone, chert, gypsum, and calcite. The gypsum and calcite may be secondary. The coarse clasts are generally subangular; cobbles show the greatest degree of rounding.

Interlayered with the tuffaceous conglomeratic sandstone are grayish-pink or yellowish-gray dacite airfall tuffs (Le Bas and others, 1986) (figure 7). In thin section the tuff is composed of minute clayey, mostly devitrified glass shards, quartz, light-brown mica, and subordinate feldspar and mafic minerals. The minerals are mostly finely crystalline, but in some layers are as large as one millimeter in diameter. Tuff layers make up 20 percent of the following measured section.

Measured section of the VOLCANICLASTIC ROCKS unit (Tsd) at the north end of the Grayback Hills in E½ NE¼ unsurveyed section 23, T. 1 N., R. 12 W., Tooele County, Utah (measured by H.H. Doelling, 1991).

TERTIARY

Trachyandesite flow, black, dark-gray, porphyritic, poorly exposed, reworked by Lake Bonneville below Stansbury level into rounded boulders, at least 25 to 35 feet thick.

Volcaniclastic rocks unit

Unit ***Feet***

9. Tuffaceous conglomeratic sandstone; light gray, a little lighter color where weathered; mostly very fine- to coarse-grained with laminae of grit, pebbles, and local cobbles; sand-sized grains are black, transparent, and light yellowish orange; cobbles generally consist of calcareous, fine-grained sandstone or silty and sandy limestone derived from the Triassic Thaynes Formation; finer constituents dominate and are composed of broken glass shards, grains of biotite, and clinopyroxene with subordinate sanidine(?), quartz, and calcite; cross-bedded at angles as high as 25 degrees; generally resistant but friable and breaks easily with hammer, poorly exposed under mantle of Lake Bonneville sediments 103

8. Covered interval, concave slope 52

7. Dacite tuff; yellowish gray fresh, very pale orange weathered, very fine grained; scattered tiny phenocrysts of dull-white mineral and black flecks of mica; structureless, massive; forms subdued rounded outcrops 35

6. Dacite tuff; grayish orange pink fresh, grayish pink weathered; very friable and clayey; altered and poorly exposed (tuff dated at 38.6 ± 1.0 Ma) 2

5. Dacite tuff; like unit 7, interlayered with very thin bands of reworked tuff, like unit 6. .... 6.5

4. Tuffaceous conglomeratic sandstone; like unit 9 57

3. Dacite tuff; like unit 7 16

2. Dacite tuff; like unit 6 .... 1.5

1. Mostly covered interval with patches of very poorly exposed tuffaceous conglomeratic sandstone .... 34+

Total volcaniclastic rocks unit (incomplete) .... 307+

Base of section covered by Lake Bonneville deposits.

Volcaniclastic rocks in the N¼ unsurveyed section 23, T. 1 N., R. 12 W., are apparently coeval with the trachyandesite lava flows in the Grayback Hills. The tuffaceous conglomeratic sandstone strikes N. 50-55° E. and dips 12-15° SE., apparently beneath the trachyandesite flows of the Grayback Hills. In the NW¼ SE¼ of the same section, the strike is N. 8° W. and the dip is 18° SW. In the SW¼ section 13, T. 1 N., R. 12 W., tuffaceous conglomeratic sandstone appears to underlie Quaternary Lake Bonneville white marl (Qlm) and overlie a lava flow. However, the white marl may have been deposited where previous erosion removed an overlying lava flow.

Sanidine from a sample of dacite tuff (unit 6 in the measured section) had a K-Ar age of 38.6 ± 1.0 Ma. The trachyandesite lava flows age (about 39 million years) we obtained is similar and indicates a late Eocene age for both units. An Ar-Ar total fusion age estimate was determined by the U.S. Geological Survey on five plagioclase crystals taken from the same dacite tuff layer used in the K-Ar determination (table 2). The resulting weighted age estimate of 35.52 ± 0.38 Ma indicates an early Oligocene age for the rock.

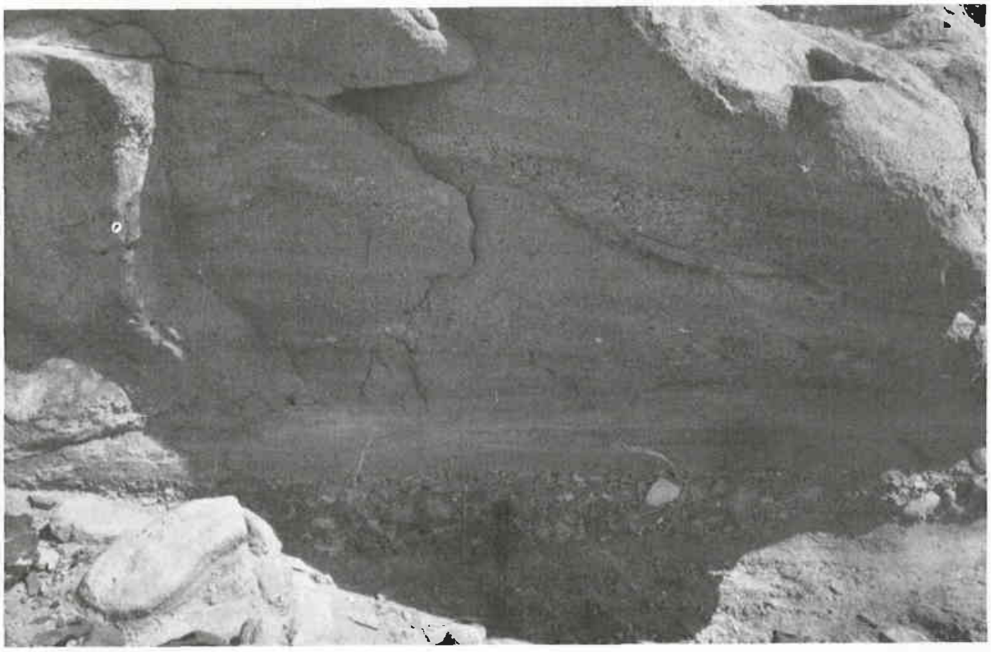

Figure 6. *Outcrop of tuffaceous conglomeratic sandstone of the volcaniclastic rocks (Tsd) at the north end of the Grayback Hills.*

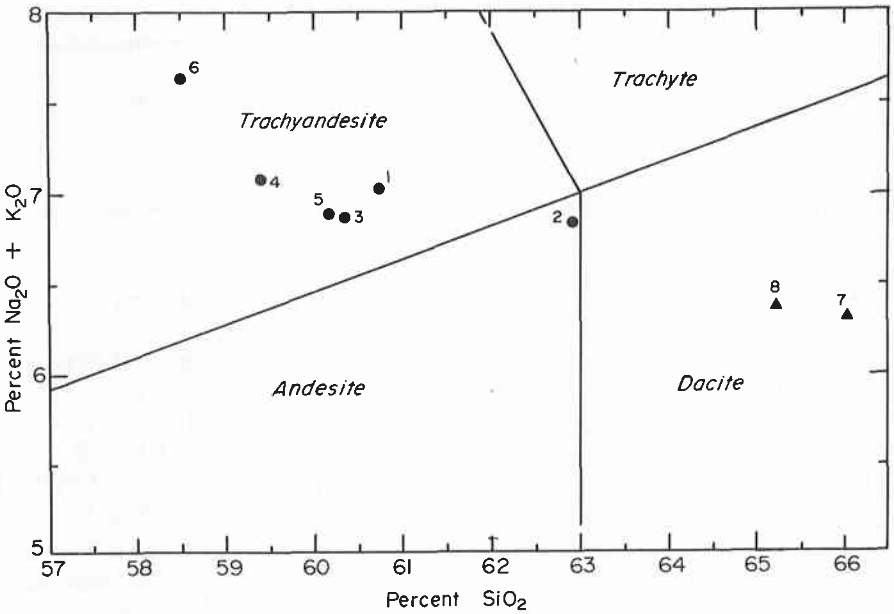

Figure 7. *Geochemical plot for the Grayback Hills volcanic rocks (field from Le Bas and others, 1986). Dots represent lava samples and triangles represent dacite-tuff samples. See table 1 for more complete geochemistry.*

Trachyandesite Lava Flows (Tt, Qlg/Tt)

A large part of the Grayback Hills is capped with trachyandesite lava flows. Lake Bonneville inundated and modified these outcrops (figure 8). Most exposures are labeled Qlg/Tt; less-affected exposures are shown as Tt.

The lava flows were probably erupted from fissures which mostly paralleled the trend of the Grayback Hills. Doelling (1964, p. 272) assumed the vents trended roughly N. 15° W., because they are visible as resistant linear features on aerial photos. He discovered linear igneous dikes with similar trends in the nearby Grassy Mountains, and thought the Grayback Hills activity was related. The compositions of the Grassy Mountains dikes are unknown.

Davies (1980, p. 125 and 126) indicated the presence of two parallel north- by northwest-trending fissures in the Grayback Hills, one passing through Reed Peak, NE¼ SW¼ unsurveyed section 24, T. 1 N., R. 12 W. (Reed Triangulation Point 4673), the other through Triangulation Point 4623 in the SW¼ NE¼ unsurveyed section 1, T. 1 S., R. 12 W. We presume lava emerged from these linear fissures (figure 9). We could not determine if eruptions occurred as a single event or in multiple episodes. Most lavas (Tt) appear to overlie the volcaniclastic rock unit (Tsd), but in a few places are found at the same level or below the volcaniclastic rock outcrops. Lava may have cut through the volcaniclastics in fissures or may be interlayered with the Tsd. The thickness of the capping lava flows is difficult to determine but appears to be less than 35 feet (11 m) in most places.

The lava is grayish black, olive black, olive gray, dark gray, medium dark gray, and grayish brown on fresh surfaces. Less commonly the fresh rock is grayish red. Some rocks, especially those with olive coloration, have regular, narrowly spaced (less than 0.2 inches [0.5 mm]), very thin (less than 0.02 inches [0.5 mm]), subparallel, somewhat lighter mottlings, probably due to deuteric alteration. Weathered rock is grayish black, grayish brown, moderate yellowish brown, and brownish gray in color.

Much of the rock is porphyritic, with an average phenocryst content of about 15 percent, with phenocrysts as large as 0.2 inches (5 mm) in diameter. The phenocrysts are randomly scattered in an aphanitic to cryptocrystalline to trachytic groundmass. In order of abundance phenocrysts include calcic plagioclase, ortho- and clino-pyroxene, olivine, iddingsite, and iron

Table 1. *Major-element geochemical analyses of selected Grayback Hills lava and tuff samples.*

	LAVA SAMPLES							TUFF SAMPLES	
	1	2	3	4	5	6		7	8
SiO_2	58.83	60.97	58.50	58.30	58.32	57.93		63.96	63.30
TiO_2	0.07	0.98	0.71	0.75	0.69	0.87		0.60	0.36
Al_2O_3	16.25	16.03	16.57	16.62	16.50	16.65		15.12	17.82
Fe_2O_3	6.53	5.70	6.53	6.97	6.52	7.22		4.75	3.28
MnO	0.08	0.08	0.10	0.11	0.10	0.09		0.06	0.04
MgO	2.37	1.45	2.40	2.52	2.44	2.44		1.90	5.02
CaO	5.04	4.78	5.25	5.60	5.63	5.93		4.15	0.88
Na_2O	3.09	3.43	3.08	3.26	3.09	3.13		3.02	3.79
K_2O	3.71	3.21	3.60	3.69	3.60	4.46		—	—
P_2O_5	0.29	0.28	0.25	0.36	0.27	0.35		0.20	0.16
LOI	2.02	2.04	2.06	1.98	2.04	*		1.95	1.75
Total	98.91	98.95	99.05	100.16	99.02	99.07		98.80	98.78

Notes and Sample Locations

** Loss on ignition (LOI) not given*

1. NW¼ SE¼ NW¼ section 23, T. 1 N., R. 12 W. (volcanic neck - north Grayback Hills)

2. NE¼ NE¼ NW¼ section 1, T. 1 S., R. 12 W. (banded lava)

3. SW¼ SW¼ section 18, T. 1 N., R. 11 W. (northeast Grayback Hills)

4. C section 25, T. 1 N., R. 12 W. (middle Grayback Hills)

5. SW¼ SW¼ NW¼ section 24, T. 1 N., R. 12 W. (vesicular lava)

6. From Hogg (1972, table B-4, p. 180)

7. SE¼ NE¼ NE¼ section 23, T. 1 N., R. 12 W. (unit 7, measured section of volcaniclastic rocks

8. NW¼ SE¼ SW¼ section 13, T. 1 N., R. 12 W. (tuff under white marl)

Table 2. *Age estimates of Grayback Hills Tertiary volcanic rocks.*

Total $^{40}Ar/^{39}Ar$ fusion ages (determined by laser fusion of small numbers of grains). Sample A (unsurveyed section 23, T. 1 N., R. 12 W., plate 1) collected by D.M. Miller, U.S. Geological Survey, and analyzed by Malcolm Pringle, U.S. Geological Survey.

K/Ca	% 40*Ar	Age (Ma)	Weighted age
.07	72.1	28.25 ± 2.79	
.09	63.2	35.02 ± 0.57	
.18	85.5	36.02 ± 0.55	35.52 ± 0.38
.08	63.9	34.94 ± 1.04	
.08	74.7	35.61 ± 1.12	

Potassium-argon age estimates of a sanidine concentrate from a dacite tuff, sample B (unsurveyed section 23, T. 1 S., R. 12 W.) and the groundmass (whole rock) from a sample of banded trachyandesite lava, sample C (unsurveyed section 1, T. 1 S., R. 12 W.) collected by H.H. Doelling.

Sample	40*Ar/40K	Age (Ma)
B	.002268	38.6 ± 1.0
C	.002296	39.1 ± 1.0

*Note: 40*Ar refers to radiogenic argon.*

Figure 8. *Boulder beach along the Stansbury shoreline of Lake Bonneville (Qlg/Tt). Much of the Grayback Hills has been modified by Lake Bonneville. Boulders are trachyandesite (Tt).*

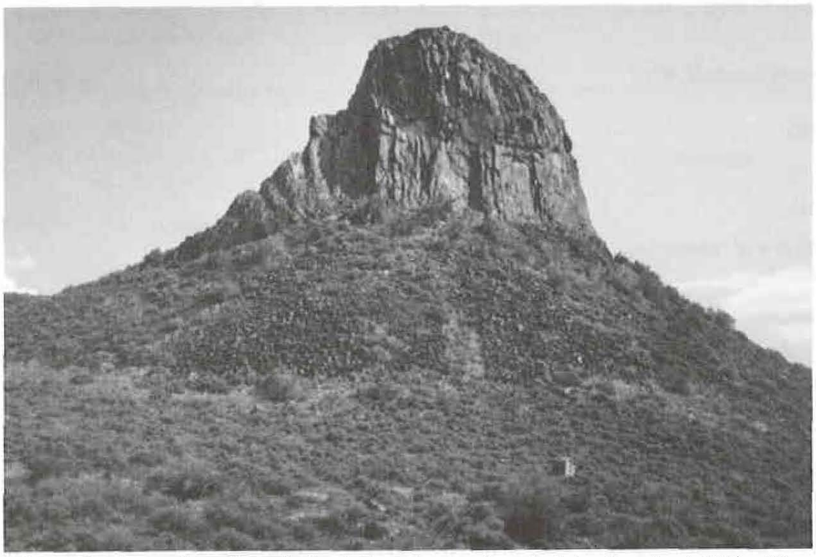

Figure 9. *Butte of trachyandesite (Tt) at the north end of the Grayback Hills. The outcrop rises from just above the Gilbert shoreline (4,290 feet or 1,308 m) nearly to the Stansbury shoreline (about 4,525 feet or 1,379 m) of Lake Bonneville and may be a remnant feeder dike.*

oxides. The groundmass includes the phenocryst minerals as well as alkali feldspar and glass. The rock is variably vesicular (0 to 30 percent) and some of the rock is dense and uniform and breaks with a conchoidal fracture.

Other lava displays distinct flow banding, either by a change in color or vesicule density. Flow-banded rock is commonly grayish black and grayish red. In places the vesicles are filled with a secondary, concentrically deposited mineraloid, tentatively identified as chlorophaeite (Davies, 1980, p. 85). Vesicle filling colors vary and include moderate olive brown, light olive gray, and brownish gray.

The lava is strongly jointed with joint orientations subparallel or perpendicular to the direction of flow. Talus derived from the lava is shaped as blocks or thick plates. The larger blocks have diameters exceeding 3 feet (1 m). Large, rounded boulders rest along the ancient shorelines where Lake Bonneville wave action was strong (figure 8).

Our major-element chemical data indicate that the lava flows are trachyandesites (table 1). This classification is based on a total alkali-silica diagram with the classification fields of Le Bas and others (1986). These trachyandesites can also be called latites because they are intermediate in composition between andesites and trachytes. The term trachyandesite is used in this report due to the trachytic texture in the groundmass. These rocks were previously classified as basalt porphyry (Doelling, 1964, map 4), andesitic basalt based on modal analyses (Davies, 1980, p. 77-90), and banakite (a variety of potassic andesite) based on major element chemistry (Hogg, 1972, p. 148-149).

A sample of flow-banded trachyandesite lava collected from the southern part of the Grayback Hills (NW¼ NE¼NW¼ unsurveyed section 1, T. 1 S., R. 12 W.) was dated by the K-Ar method. The age estimate of the groundmass of this sample is 39.1 ± 1.0 Ma. This age estimate corresponds well to that from a whole-rock sample of a slightly vesicular lava from the Grayback Hills tested by Dr. Myron Best of Brigham Young University (38.5 ± 0.6 Ma, reported in Davies, 1980, p. 90). These age estimates are nearly the same as that for a dacite tuff in the volcaniclastic rocks unit (Tsd) we analyzed for this study (38.6 ± 1.0 Ma).

Quaternary Deposits

Quaternary units in the Grayback Hills quadrangle consist of alluvial, eolian, artificial-fill, lacustrine, and playa deposits. Latest Pleistocene, fine-grained lacustrine deposits are predominant on the valley floor and are overlain in places by younger, Holocene deposits. Latest Pleistocene transgressive shoreline gravels are the predominant Quaternary deposits in the Grayback Hills, and are commonly associated with nearshore lacustrine deposits of sand, silt, and reworked marl.

Lacustrine Deposits

Undifferentiated lacustrine and alluvial deposits (Qla): We map much of the surficial material within the piedmont of the

Grayback Hills as Qla (plate 1). This unit consists mainly of fine- to coarse-grained alluvial-fan deposits that were moderately reworked by Lake Bonneville. As a result, the alluvial-fan deposits are overlain by a thin cover of lacustrine sediments, generally less than 10 feet (3 m) thick. The lacustrine sediments are coarser grained in the upper and middle piedmont because the pre-lake fan material was finer near the distal ends of the fans. Erosional remnants of older alluvial-fan deposits, reworked at the surface, form prominent knobs on the piedmont below drainages in bedrock in the SW¼ unsurveyed section 1, T 1. S., R. 12 W. Small areas of Qla occur where Lake Bonneville lacustrine deposits were slightly reworked by post-lake alluvial-fan processes, or where lacustrine and alluvial gravels intertongue at unmappable scales. This unit is latest Pleistocene through latest Holocene in age.

Lacustrine clay deposits (Qlc): This unit consists primarily of water-saturated, thinly bedded to laminated, lake-deposited clay, but also includes small amounts of marl and non-lacustrine sand and silt. The unit is generally less than 10 feet (3 m) thick, and is commonly overlain by a thin crust of efflorescing salts or a thin layer of sand- and silt-sized gypsum particles, particularly where it occurs adjacent to coarser grained deposits. Lacustrine clay occurs on the west margin of the quadrangle and extends westward into the Great Salt Lake Desert. The lacustrine clay deposits are latest Pleistocene to early Holocene in age but may include surficial layers of younger, alluvial-mud or playa-lake deposits that are not differentiated.

Lacustrine fine-grained deposits (Qlf): Lacustrine fine-grained deposits occur in Ripple Valley, in the flats north of the Grayback Hills, and between the Grayback Hills and mudflats to the west. These deposits are generally less than 30 feet (9 m) thick, and consist of varying combinations of lake-deposited sediment in which silt and clay predominate, and fine sand and marl are subordinate. In some places this unit is reworked into shrub-coppice dunes; elsewhere eolian deflation has removed fines, exposing the underlying water-saturated mud and leaving small, isolated remnant buttes. The unit is characterized by crescentic, 1- to 2-feet (0.3-0.6 m) wide, unvegetated features first named "desert ripples" by Ives (1946), who attributed their formation to a combination of precipitation, evaporation, and wind transport of sediment. Lacustrine fine-grained deposits are latest Pleistocene to early Holocene in age.

Lacustrine gravel (Qlg): This unit consists of well-rounded coastal gravel and typically contains significant intervals of interbedded sand. It is generally thin, but may be up to 30 feet (9 m) thick in some barrier beaches. Most Lake Bonneville coastal gravel was deposited during the lake's transgressive phase. Tertiary volcanic rocks in the Grayback Hills and Permo-Triassic rocks in Thumb and Pinky Ridges constituted the major source material for the lacustrine gravel, although alluvial fans provided a significant component. Large quantities of reworked volcanic talus ("residual boulder-pebbles" of Davies, 1980) in the Grayback Hills, transported short distances by waves and deposited near outcrops of trachyandesite lava flows (Tt), are shown as Qlg/Tt. Tufa masses on the west slope of the Grayback Hills near the Stansbury shoreline (about 4,525 feet or 1,379 m) are too small to be mapped separately and are included with the lacustrine gravel unit. Geomorphically, the gravel deposits formed as beaches, spits, tombolos, bayhead barriers, and cuspate barriers (V-bars). Lacustrine gravel deposits are latest Pleistocene in age.

Lacustrine lagoon deposits (Qll): Lacustrine lagoon deposits consist of silt, clay, marl, and small amounts of fine sand that were primarily deposited in lagoons behind Lake Bonneville gravel bars along the Stansbury and other prominent shorelines. This unit occurs at several locations along the flanks of the Grayback Hills. The unit is generally less than 10 feet (3 m) thick, and latest Pleistocene in age, although a minor amount of post-Lake Bonneville, Holocene slopewash and ponding sediment may have accumulated in the lagoonal basins.

Lacustrine marl (Qlm): This unit includes finely bedded to indistinctly laminated, very fine-grained, white to gray lacustrine marl (Gilbert's [1890] pelagic Lake Bonneville white marl), and younger, alluvially reworked sandy marl and marly sand. In the Grayback Hills quadrangle, marl is generally less than 6 feet (2 m) thick and occurs below the Stansbury shoreline as isolated erosional remnants which locally contain ostracodes and rare gastropods. The lacustrine marl is latest Pleistocene to middle Holocene in age.

Lacustrine sand (Qls): The lacustrine sand unit typically contains silty, and locally clayey quartzitic and feldspathic sand that is fine to medium grained. The unit also contains pebbly layers and lenses in the tombolo which connect Thumb and Pinky Ridges. The unit locally contains thin clayey and marly interbeds. The lacustrine-sand unit may be as much as 30 feet (9 m) thick. The unit occurs in bars, spits, tombolos, and beaches, usually at or below, but locally higher than the Gilbert shoreline. A probable source for the sand is pre-Lake Bonneville alluvial fans which underlie the various lacustrine deposits of the piedmont and were originally derived from Permian rocks. The lacustrine sand is of latest Pleistocene age.

Playa-Mud Deposits (Qpm)

Playa-mud deposits consist of poorly sorted, muddy mixtures of clay and silt, and small amounts of sand. Local accumulations of gypsum, halite, and other salts form on the playa surface. The unit is generally less than 10 feet (3 m) thick. Small mud-filled playas have formed within and adjacent to gypsum dunes on the eastern margin of the Great Salt Lake Desert, west of the Grayback Hills. Playa-mud deposits are Holocene in age.

Alluvial Deposits

Alluvial-fan deposits (Qaf): Alluvial-fan deposits include coarse- to fine-grained alluvium and debris-flow sediments deposited on piedmont slopes after regression of Lake Bonneville from the Provo level. The distal portions of the fans generally contain finer grained alluvial material which is locally mixed with lacustrine sediments. The fan deposits are thickest near fan apices and thin to a feather edge into the basin but are generally less than 10 feet (3 m) thick. Alluvial-fan deposits have been accumulating from latest Pleistocene time to the present.

Alluvial-channel and floodplain deposits (Qal): Alluvial-channel and floodplain deposits consist of fine-grained sediment with thin gravel layers and lenses. These deposits respectively occur in a channel and associated floodplain on the northeast end of the Grayback Hills, and include small amounts of alluvially reworked colluvium on adjacent piedmont slopes. Deposits are generally less than 10 feet (3 m) thick. They are of post-Provo shoreline age, and vary in age from latest Pleistocene to latest Holocene.

Eolian Deposits

Gypsum dune deposits (Qeg): Morphologically well-developed dunes composed mainly of sand-sized gypsum particles are located on the west edge of the quadrangle. The dunes form a pair of north-south linear ridges, up to 30 feet (9 m) high, east of the extensive mudflats of the Great Salt Lake Desert. The dunes are mostly active, but in places are stabilized by vegetation and capped by shrub-coppice dunes. The gypsiferous material may be derived, in part, from the erosion of efflorescent mudflat salts (Eardley, 1962), and may also represent almost in-place eolian reworking of lacustrine beach deposits associated with the final static level of the Gilbert beach cycle of Murchison (1989). This level, established at an elevation of about 4,230 feet (1,289 m) between 9,400 and 9,700 years ago, is at approximately the same elevation as the base of the gypsum-dune deposits, indicating the dunes were preferentially deposited at and near the former Gilbert shoreline. The phenomenon of eolian sand preferentially depositing along former shorelines has been noted elsewhere in the Bonneville basin (Dennis, 1944; Ross, 1973; Currey, 1980; Sack, 1990). The results of parametric tests by Dean (1978) also indicate that the gypsum dunes of this region were derived from local lacustrine sediments. The dunes are mostly Holocene in age, but some may have started accumulating in latest Pleistocene time.

Silica-dune deposits (Qes): A small deposit of siliceous, fine-grained sand on the east-central flank of the Grayback Hills consists of longitudinal and parabolic dunes. The dunes are up to 10 feet (3 m) high and are partly active. The sand was probably derived from nearshore, sandy lakebeds and pre-Lake Bonneville alluvial fans. The silica-dune deposits are mostly Holocene in age, but may have started accumulating in latest Pleistocene time.

Artificial-Fill Deposits (Qf)

A thin layer of Lake Bonneville gravel has been used as a base for a landing strip west of the Grayback Hills. This artificial-fill deposit is less than 1 foot (0.3 m) thick.

STRUCTURAL GEOLOGY

The Grayback Hills and associated ridges trend subparallel to the principal mountain ranges of the eastern Basin and Range Province. Most of these larger ranges are bounded by one or more major basin-and-range faults, but no direct evidence of such faults was found in the Grayback Hills quadrangle. However, Baer and Benson (1987) show two such faults on the east side of the Grayback Hills based on gravity data. The elevation of the valley floor at the base of the piedmont is 20 to 30 feet (6-9 m) higher on the east side of the Grayback Hills. Although difficult to prove, this may indicate displacement along a down-dropped to the west basin-and-range fault.

Structures in Permo-Triassic Rocks

The Permo-Triassic rocks are folded into anticlines that trend northeast and plunge gently southwest in the northern part of the quadrangle (plates 1 and 2). Corresponding synclines are thought to be buried between the ridges. To the south, Permo-Triassic rocks strike north and dip gently along the margins of the Grayback Hills. We found no major faults between the two areas, but assume a northeast-trending fault (not shown), buried by the Tertiary volcaniclastic rocks and lava flows, may be present to account for the change in strike and dip between the northern and southern parts of the Grayback Hills.

One or more faults may be present between Pinky Ridge and the northern Grayback Hills to account for the assumed thicknesses of rocks that should be present between the ridges. Paralleling faults may cut rocks between the northern ridges and under the Grayback Hills although the lack of major faulting in the exposed strata in this area suggests otherwise.

Structure in Knolls of Unsurveyed Section 33, T. 2 N., R. 12 W.

The Permian Grandeur? Formation beds that form knolls in the Hill Air Force Range mostly strike N. 20-25° E., but veer easterly to N. 45° E. at the south end of the knolls. The inclination of beds is steep, ranging from 38 degrees to vertical. It is not clear whether the east or west side is up because strata are overturned along much of the outcrop length. The inclinations are as steep or steeper than those in the other ridges in the quadrangle and may represent the steepest part of an anticlinal or synclinal limb.

Thumb Ridge Anticline

The rocks in Thumb Ridge are folded into an anticline which plunges 2.5 to 3 degrees to the southwest. The plunge steepens to at least 16 degrees at the southwest end of the ridge. The axial trace of the anticline does not strictly follow the ridge top, but occurs halfway down the southeast-facing ridge slope. The axial trace curves such that it trends N. 65° E. in the southwest part of the ridge and N. 45° E. in the northeast part of the ridge. The dips on each side of the axial trace steepen from 30 to 40 degrees in the Permian Gerster Formation to 50 to 90 degrees in the Triassic Thaynes Formation.

Pinky Ridge Anticline

The rocks of Pinky Ridge are folded into a broad box-type anticline with two subparallel anticlines separated by a shallow southwest-plunging syncline. The axial traces of the two anticlines trend N. 45-65° W., and are 600 to 1,400 feet (185-425 m) apart. The medial syncline is barely noticeable at the northeast end of Pinky Ridge, where the rocks are locally flat-lying. The strata dip to a maximum of about 30 degrees between the two anticlinal axes. Rocks on the northwest flank of Pinky Ridge dip 50 to 70 degrees and rocks on the southeast flank dip 25 to 45 degrees. Abrupt changes in dip across flexures are common along the ridge flanks.

Grayback Hills Structure

A ridge of Triassic Thaynes Formation trends N. 40° E. at the north end of the Grayback Hills in unsurveyed section 13, T. 1 N., R. 12 W., and may be a more resistant part of the southeast limb of the Pinky Ridge anticline. The rocks in this ridge mostly dip 40 to 60 degrees to the southeast.

The Thaynes Formation is also exposed in scattered locations on the west margin of the Grayback Hills. These rocks strike north and dip 10 to 20 degrees east under Tertiary lava. The Permian Murdock Mountain Formation crops out as a resistant ridge on the northeast side of the Grayback Hills in sections 18 and 19, T. 1 N., R. 11 W. These strata strike approximately north and dip 40 to 60 degrees to the west which suggests that a synclinal structure underlies the Grayback Hills. No connecting exposures show how these north-striking rocks on both sides of the Grayback Hills are structurally interrelated and how they may be related to the northeast-striking rocks of Pinky and Thumb Ridges. Two tiny exposures of Permo-Triassic rocks mapped along the Grayback Hills crest probably strike east-west. If the small outcrop is Permian Grandeur? Formation as mapped, then a feature more complex than a syncline underlies the Grayback Hills.

The Tertiary volcaniclastic rocks in N¼ unsurveyed section 23, T. 1 N., R. 12 W., strike N. 20-30° E. and dip 10-15 degrees to the southeast. Another small area of volcaniclastic rocks in the SE¼ unsurveyed section 23, T. 1 N., R. 12 W., strike about N. 10° W., and dip 15-20 degrees to the southwest. Strikes and dips were averaged from partially cross-bedded rocks. We assume these rocks were deposited on a terrain of moderate relief, and may not have been deposited in a strictly horizontal fashion. The lavas flowed over a terrain exposing both Permo-Triassic and volcaniclastic rocks. We assume the lava issued from mostly north-northwest-trending fissures and flowed over nearly flat surfaces or down gentle slopes.

GEOLOGIC HISTORY

The Permian rocks exposed in the ridges and knolls of the Grayback Hills quadrangle were deposited in a large miogeoclinal basin that covered western Utah. Some units (Grandeur and Gerster) were deposited in shallow seas, others (Meade Peak and Murdock Mountain) were deposited in deeper waters (Hintze, 1988, p. 38). The unconformity that divides Permian from Triassic rocks is of world-wide proportion (Hintze, 1988, p. 37) and represents an erosional interval of more than 5 million years.

The Triassic rocks generally represent the shallow-water deposits of the last marine transgression into western Utah from the west. Most were removed when western Utah was uplifted during the Cretaceous Sevier orogeny. The Sevier orogeny is characterized by piggy-back thrust faulting, folding, and faulting (Hintze, 1988, p. 7). Rocks in the eastern Great Basin, including those of the Grayback Hills quadrangle, were generally displaced many miles eastward (Levy and Christie-Blick, 1989), to accommodate crustal shortening caused by crustal compression. The thrust plates near the Wasatch Front have been defined and named, but those in the Sevier hinterland belt of northwest Utah are poorly defined and understood (Allmendinger and others, 1984). Postulated and known thrust faults in northwest Utah are shown in figure 10. Cashman (1992, p. 172) described anticline-syncline pairs in the Stansbury Mountains, which are somewhat comparable to those in Thumb and Pinky Ridges, as fault-propagation folds, representing the deformation directly ahead of the propagating fault surface. If propagation folding formed the Grayback Hills ridges, they would indicate southeast-vergent thrusting.

The trachyandesite flows and volcaniclastic rocks of the Grayback Hills have been dated as latest Eocene to earliest Oligocene (38-35 million years). An early surge of magmatism occurred in northwestern Utah during this time. Intermediate volcanic and volcaniclastic rocks of this age have been described in the Thomas and Drum Mountains, Wasatch Range near Ogden (Norwood Tuff), Traverse Mountains, and elsewhere (Hintze, 1988, p. 65). Simultaneously several stocks of intermediate composition intruded an area between Park City and the Oquirrh Mountains.

Basin-and-range faulting commenced in middle Miocene time (15 million years), elevating northwest Utah and forming the characteristic north-south-trending, fault-block mountain ranges separated by wide graben-like basins. These extensional structures displaced and, in some cases, masked the earlier Sevier orogenic compressional structures. The Grayback Hills may be a small, tilted, fault-block range, but more likely they are an erosional remnant of resistant lava and Permo-Triassic rocks.

Pleistocene Lake Bonneville materials dominate the surficial geology of the quadrangle. Marginal, shore-zone, and deep-water sediments deposited during the various oscillations of the lake are present. The lake's basin has been an area of closed drainage for much of the past 15 million years, and several lakes existed in the basin during this time. Pre-Lake Bonneville lacustrine sediments of Quaternary age are believed to be buried in the valleys adjacent to the Grayback Hills (Heylmun, 1963, p. 293; Patton and Lent, 1980, p. 118). Younger Holocene sediments overlie the Lake Bonneville deposits in places.

The Bonneville lacustrine cycle was essentially coincident with the last global ice age, and lasted from about 28,000 to 12,000 years ago (Oviatt and others, 1992). Lake Bonneville began to rise from levels close to those of the modern Great Salt Lake and transgression was well underway about 26,000 years ago (Currey and Oviatt, 1985). The lake experienced a major oscillation between 22,000 and 20,000 years ago that resulted in the formation of the Stansbury shoreline (Oviatt and others, 1990).

Lake Bonneville occupied its highest shoreline, which Gil-

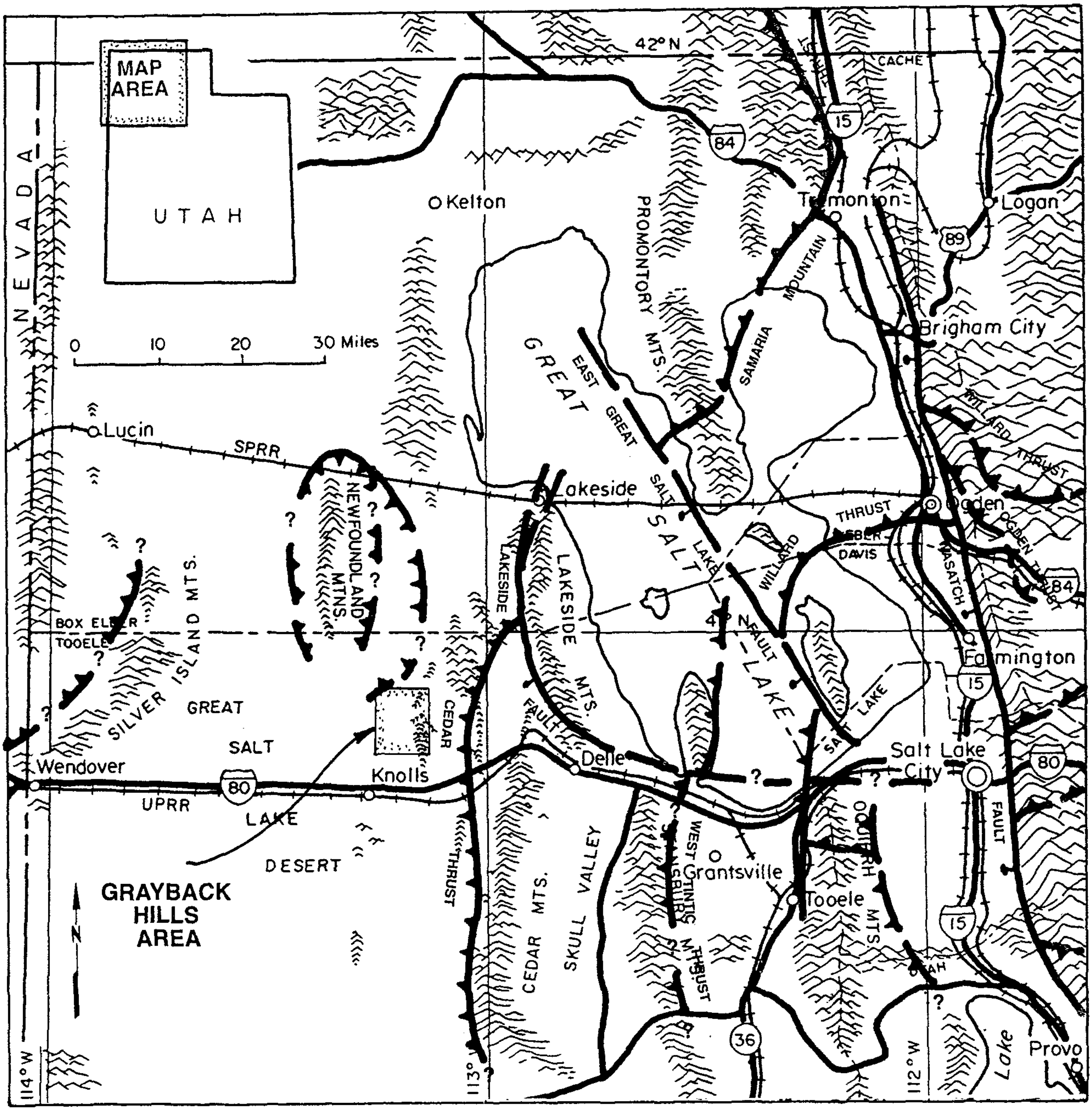

Figure 10. Thrust faults and postulated thrust faults of the Sevier orogeny and important basin-and-range faults in northwestern Utah (modified from Allmendinger and others 1984; Smith and Brauhn, 1984; and Cashman, 1992).

bert (1875) named the Bonneville beach, after 16,400 years ago and perhaps as late as 15,000 years ago (Currey and Oviatt, 1985). After the catastrophic incision of the Zenda threshold in southern Idaho and the rapid drawdown of Lake Bonneville, the lake stabilized at a lower threshold and formed the prominent Provo shoreline (Gilbert, 1875, 1890). About 14,000 years ago climatic factors induced regression from the Provo level (Currey and Oviatt, 1985). During all this time the Grayback Hills were submerged. In less than 2,000 years the lake level declined to below the altitude of the present Great Salt Lake. Subsequent transgression of the earliest post-Lake Bonneville oscillation, known as the Gilbert, began about 12,000 years ago (Murchison, 1989), and culminated between 10,900 and 10,300 years ago (Currey, 1990). The lake regressed from the Gilbert stage between 9,400 and 9,700 years ago.

Only two of the regional lacustrine shorelines, the Stansbury and the Gilbert, occur in the Grayback Hills quadrangle. The Bonneville and Provo shorelines are at elevations higher than

Table 3.

Gravel-pit descriptions for the Grayback Hills quadrangle. Dimensions and highwall data are in feet.

No.	Dimensions	Pit Shape	Highwall	Cu. yards removed	Material
1.	220 x 205	rectangular	14	10,000	limestone
2.	370 x 285	rounded	10	15,000	limestone
3.	360 x 315	triangular	11	6,000	limestone
4.	860 x 370	rectangular	25	140,000	limestone
5.	125 x 110	rectangular	8	6,000	limestone
6.	815 x 685	irregular	25	200,000	volc. & limestone

No.	Location	Remarks
1.	SE¼NE¼NE¼ section 3, T. 1 N., R. 12 W.	Two feet of overburden removed, exhausted.
2.	NW¼SE¼NE¼ section 3, T. 1 N., R. 12 W.	May have scraped off 5,000 cubic yards additional northeast of main pit.
3.	SE¼SW¼NE¼ section 3, T. 1 N., R. 12 W.	Much gravel remains, unusable due to munitions burial.
4.	NW¼SW¼ section 2 and SE¼SE¼ section 3 T. 1 N., R. 12 W.	Exhausted.
5.	SE¼SE¼NE¼ section 3, T. 1 N., R. 12 W.	As much gravel as removed remains.
6.	NW¼SW¼ section 13, and NE¼SE¼ section 14, T. 1 N., R. 12 W.	Additional resources, but interbedded with marl and sand.

Table 4.

Test data from the Utah Department of Transportation (about 1967). Sample 1 is from a pit at the south end of the Grayback Hills, in section 18, T. 1 S., R. 11 W., in the Aragonite NW quadrangle just north of Interstate Highway 80. Sample 2 is from pit 6 (see table 3). Notes: B.G. = base gravel; S.G. = surface gravel; N.P. = not plastic.

	MATERIAL					TEST DATA - REPRESENTATIVE SAMPLE																			
									SIEVE ANALYSIS																
									BEFORE CRUSHING		PERCENT PASSING AFTER CRUSHING TO 1" MAX. SIZE										IMMERSION COMPRESSION AVG. P.S.L.			SODIUM SULFATE LOSS	
																					LIME				
	USE OF MATERIAL	TYPE OF DEPOSIT	PRESENT ESTIMATED QUANTITY (CU. YDS.)	THICKNESS OF MATERIAL	DEPTH OF OVERBURDEN	DATE SAMPLED *	TYPE OF SAMPLE	DEPTH OF SAMPLE	> 3"	> 1"	1"	1/2"	No. 4	No. 8	No. 50	No. 200	LIQUID LIMIT	PLASTICITY INDEX	SWELL	A. A. S. H. O. CLASSIFICATION	WO/	W/	ABRASION 500 REV.	+ 4	- 4
Sample 1	B. G. S. G.	Lake Terrace	1,000,000	10	1	1964	Cut bank	8-12	3	36	100	64	38	33	27	10.6	20.7	NP	.003		226	295	17.2	6.3	4.8
Sample 2	B. G. S. G.	Bar	500,000	9	1	1964	Cut bank	3-6	2	28	100	53	31	22	9	3.4	22.0	NP	.140				21.0	2.73	8.53

those present in the quadrangle. Both the Stansbury and Gilbert shorelines are complex groups or sets of shorelines that record lake fluctuations. The highest static level of each shoreline complex is mapped. The highest level of the Stansbury shoreline occurs at altitudes between 4,520 and 4,530 ± 10 feet (1,378 and 1,381 ± 3 m). This is higher than the elevation noted by Davies (1980), who recorded the most prominent, rather than the highest, level of the Stansbury shoreline complex. The highest level of the Gilbert shoreline complex occurs at an elevation of about 4,290 ± 10 feet (1,308 ± 3 m). This agrees with the elevations of the Gilbert shoreline noted by Currey (1982, table 1C, locations 16 and 17) in the Grayback Hills, and is at about the same elevation as the highest Gilbert shoreline identified by Murchison (1989) in the central Bonneville basin. The Gilbert shoreline of Davies (1980) is the most prominent Gilbert level, and likely corresponds to the final static level of the Gilbert beach cycle of Murchison (1989). The Pilot Valley shoreline is present elsewhere in northwestern Utah (Miller and others, 1990) at about the same elevation as the highest Gilbert level in the Grayback Hills. We found no evidence to indicate that the shoreline herein identified as the highest Gilbert level is actually the Pilot Valley shoreline.

ECONOMIC GEOLOGY

Gypsite

Longitudinal and transverse dunes (Qeg) consisting of 60 percent gypsum, 35 percent calcareous material, and 5 percent quartz and other impurities lie in the west half of the Grayback Hills quadrangle. Dune material mixed with sand has been used as fill and as pavement material in the construction of the roads servicing the hazardous-waste landfill in the northwest part of the quadrangle. The roads constructed using gypsite are excellent in the dry climate and produce little dust. These roads are durable and are used by heavy trucks. Other uses for the gypsite may be to condition soils deficient in sulfur, modify soil alkalinity, and granulate heavy-clay soils. If the average thickness of the dunes is 15 feet (5 m) (dunes are as much as 30 feet [9 m] high), then the volume of this resource in the Grayback Hills quadrangle is about 65 million cubic yards (50 million cubic meters) or 53 million tons (47 million tonnes).

Sand and Gravel

Several gravel pits have been opened in the Lake Bonneville gravels (Qlg) along the margins of Thumb and Pinky Ridges (table 3, plate 1). The material has been used in local road construction as base and surfacing gravel, and for construction in support of the hazardous-waste landfill in the northwest part of the quadrangle. Test data by the Utah Department of Transportation (about 1967) (table 4), indicate good-quality gravel with low abrasion and a low percentage of fines. Gravel sizes mostly range from pebbles to 3-inch (7.5-cm) cobbles, but cobbles to 1 foot (30 cm) in diameter are common as are grit and sand. The cobbles are mostly subrounded. Areas where more gravel may be exploited are limited; the thickest sources are the lacustrine bars (Qlg) adjacent to Thumb and Pinky Ridges.

Gravel resources from pits 1, 2, and 4 (plate 1) are exhausted. Additional resources may be developed in adjacent areas. About one-half of the available resource remains in pit 3, but a warning sign indicates that the area has been used as a munitions-residue burial site and that no material should be removed or added without proper authority. Irregular masses of a silvery-colored slag remain in the bottom of pit 3. Additional gravel resources are exposed along parts of the highwall of pit 6, but 50 percent of the material forms thin sandy or marly tongues. Thin soil horizons exist at the top of some of the sandy or marly tongues, and at least one exhibited spaghetti-like masses of root casts. The bottoms of most pits contain fine-grained Lake Bonneville deposits, but pit 4 is mainly floored in the Dinwoody Formation.

WATER RESOURCES

Studies of the hydrogeology of the Bonneville mud flats to the west of the quadrangle (Nolan, 1928; Turk, 1969) suggested to Stephens (1974) a model of a ground-water system for the Great Salt Lake Desert divided into three distinct segments: (1) a surficial brine-yielding aquifer composed of lakebeds and crystalline salt, (2) an alluvial-fan aquifer on piedmont slopes that yields moderately saline water, and (3) a valley-fill aquifer that underlies lake-bed sediments and also yields brine. This model applies to the study area: the surficial brine-yielding aquifer is in the mud flats west of the Grayback Hills, the alluvial-fan aquifer extends from the east in the piedmont zone of the Grassy and Cedar Mountains to the mudflats, and the valley-fill aquifer underlies the entire area.

GEOLOGIC HAZARDS

Geologic hazards in the Grayback Hills quadrangle have been summarized by Solomon and Black (1990) for the West Desert Hazardous Industry Area, and include earthquakes and related hazards, the possible contamination of ground water in basin-fill aquifers, surface flooding, debris flows in the piedmont, and rock falls on steep slopes. Unsafe foundation conditions may result from numerous other factors such as earthquake-induced liquefaction, hydrocompaction of silty and sandy sediments, shrinking or swelling of clayey sediments and mud flats, and subsidence due to dissolution of gypsiferous dunes and salt flats.

Earthquake Hazards

The Grayback Hills quadrangle lies beyond the western edge of the Intermountain seismic belt, a zone of pronounced earthquake activity extending from Montana to southwestern Utah and including the Wasatch Front (Smith and Sbar, 1974). Seismic risks are lower in the quadrangle than along the Wasatch Front. The University of Utah seismograph stations earthquake catalog shows that no earthquake with a magnitude greater than 3.0 has been recorded since 1850 within 35 miles (60 km) of the Grayback Hills (Arabasz and others, 1989). An earthquake in the Wasatch Front area might be of sufficient magnitude to affect the quadrangle. Within a 50-year exposure time, there is a 10 percent probability that the area will experience horizontal ground accelerations between 0.10 and 0.20 g (Algermissen and others, 1983). The Grayback Hills lie in the boundary area between seismic zones 2B and 3 of the Uniform Building Code (International Conference of Building Officials, 1991).

No faults displacing Quaternary deposits were identified within the quadrangle; the closest suspected Quaternary-age fault is the Puddle Valley fault, about 15 miles (25 km) northeast of the Grayback Hills on the east flank of the Grassy Mountains. Scarps in this zone may be related to two different surface-faulting events; one predates the Lake Bonneville highstand (more than 15,000 years ago) and the other postdates it (less than 15,000 years ago) (Barnhard and Dodge, 1988). Faceted spurs mark the west range front of the Cedar Mountains, about 10 miles (15 km) southeast of the Grayback Hills, but there are no scarps in the adjacent lake beds. The range-front fault has not experienced movement in Holocene time.

Earthquake hazards to be expected in the quadrangle include ground shaking and the resulting effects, such as soil liquefaction and slope failure. Conditions necessary to induce liquefaction include earthquakes of magnitude 5.0 or greater (Kuribayashi and Tatsuoka, 1975, 1977; Youd, 1977) and the presence of ground water within about 30 feet (9 m) of the ground surface (Youd and others, 1978). Soils with more than about 15 percent clay typically have sufficient cohesive strength to prevent liquefaction (Anderson and others, 1986). Deposits of loose, fine to medium sand with uniform grain-size distributions are generally considered to be the most susceptible to liquefaction. Saturated, sandy sediments less than 30 feet (9 m) deep within the quadrangle include eolian material (Qeg) west of the Grayback Hills and alluvial-fan deposits (Qaf) adjacent to the hills. Since essentially all the lacustrine deposits have sandy subsurface intervals, potentially liquefiable areas exist west and north of the Grayback Hills, where ground water in lacustrine sediments is less than 30 feet (9 m) deep. Although soils susceptible to liquefaction are present in the quadrangle, Mabey and Youd (1989) indicate that the probability of occurrence of ground shaking sufficient to cause liquefaction is relatively low; they estimate a 10 percent probability that moderate to severe damage may occur in 250 years.

Shallow Ground Water and Recharge Areas

Areas with shallow ground water are susceptible to infiltration of contaminants into aquifers. Ground water is less than 50 feet (15 m) deep beneath all valleys within the quadrangle. The abundance of sandy, permeable interbeds in lacustrine deposits, and the possibility of fractured lacustrine clays underlying valley bottoms, contribute to the potential for ground-water contamination.

Recharge to aquifers provides a direct pathway for contaminants to enter the ground-water system. Recharge to the three regional aquifers (see WATER RESOURCES section) originates from precipitation, particulary on the mountains and upper parts of alluvial fans on the piedmont. Lateral subsurface inflow from alluvial fans into the surficial brine-yielding aquifer is probably negligible (Gates and Kruer, 1981).

Construction of facilities which might contaminate aquifers in either shallow-ground-water or recharge areas, should be avoided. If avoidance is not practical, aquifers should be protected from contamination with the use of appropriate liners, pumps, and channels.

Surface Flooding

Flooding potentially may occur in the quadrangle from a rise in the level of the Great Salt Lake or a lake in the Great Salt Lake Desert, which are separated by a 4,217-foot (1,285-m) topographic threshold (Currey and others, 1984). Recent work by Murchison (1989) has identified the highest lake level attained during the last 10,000 years to be 4,230 feet (1,290 m), reached between 9,700 and 9,400 years ago. A late Holocene high of 4,221 feet (1,286 m) was reached between 3,440 and 1,400 years ago, and the historic peak elevation of 4,212 feet (1,284 m) was reached in 1873, 1986, and again in 1987 (Harty and Christenson, 1988; Arnow and Stephens, 1990). A rise in the Great Salt Lake to 4,230 feet (1,290 m) is unlikely, but should it occur, the lake would exceed the 4,217-foot (1,285-m) topographic threshold. Low-lying mud flats on the west edge of the quadrangle, which are at elevations as low as 4,226 feet (1,288 m), would be inundated.

Alluvial fans (Qaf) on the slopes of the Grayback Hills are areas undergoing active alluvial deposition. Channels carry runoff and sediment from the hills and deposits them on the fan surface as the stream channel emerges from its fanhead trench. In channels and on active fan surfaces, flooding may be severe during major storms. Overflowing channels add to sheet-flood problems lower on the fan. Most precipitation that falls on the valley floor is not naturally channelized and generally becomes lost to evapotranspiration and infiltration. However, sheet flooding and ponding may occur here during periods of intense, cloudburst rainfall or rapid snowmelt. Runoff and precipitation on the mud flats on the west margin of the quadrangle usually evaporate quickly, but sustained ponding often occurs during the winter and early spring.

Debris Flows and Debris Floods

Although annual rainfall is generally low, periods of intense, cloudburst storms may trigger debris flows and debris floods in the quadrangle. Rapid spring snowmelt can also contribute to this hazard. Large rocks carried by debris flows or debris floods can cause considerable damage to structures in their path. Debris flows can be initiated or be deposited on hill slopes of the Grayback Hills where post-Bonneville alluvial fans (Qaf) are exposed. Slope aspect and angle, vegetation cover, precipitation, and weathering characteristics of rock all affect the potential for debris flows.

Adverse Soil Conditions

A critical factor in the integrity of engineered structures is the nature of the soils on which they are constructed. Soil suitability is mainly determined by its susceptibility to compaction, expansion, and dissolution. These factors, in turn, can be influenced by the position of the water table and are related to the geologic environment in which they were deposited.

Certain low-density soils are subject to settling hydrocompaction when saturated for the first time since deposition (Curtin, 1973). Upon deposition, the sediment dries, hardens, and forms a loose framework susceptible to collapse upon rewetting. Silty sands deposited in alluvial fans in hot, dry areas are particularly susceptible to collapse. Such deposits (Qaf) are present on the flanks of the Grayback Hills, where a relatively deep water table has allowed the fan material to remain dry since deposition. Although no incidences of settlement due to hydrocompaction have been documented, the presence of collapsible soils should be considered in soil-foundation studies prior to construction.

Expansive clays that shrink and swell with changes in moisture content may present problems on mudflats (Qlc) on the west edge of the quadrangle, and on fine-grained lacustrine soils (Qlf) east and west of the Grayback Hills. Subsidence caused by dissolution of gypsum and calcium carbonate in mud flats (Qlc) and adjacent dunes (Qeg) is a potential problem, although we identified no subsidence features in the quadrangle. The alkaline ground water of the region may not be capable of dissolving gypsum or calcium carbonate, but addition of precipitation and runoff could promote dissolution.

Rock Fall

Rock falls originate when erosional processes and gravity dislodge rocks from slopes. The most susceptible slopes are those with outcrops broken into loose rock fragments by bedding surfaces, joints, or other discontinuities. Boulders on paleoshoreline benches can also dislodge and fall if located on or above steep slopes. A primary agent responsible for triggering rock falls is water which, when frozen, enlarges bedrock discontinuities and, when liquid, "lubricates" them. Many rock falls occur during spring snowmelt and periods of heavy rainfall.

Rock-fall hazard is present in large portions of the Grayback Hills and adjacent foothills. Talus and highly jointed outcrops of Tertiary volcanic rocks, and shoreline boulders on steep benches at the Gilbert and Stansbury levels, can produce rock falls.

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REFERENCES

Algermissen, S.T., Askew, B.L., Thenhaus, P.C., Perkins, D.M., Hanson, S.L., and Bender, B.L., 1983, Seismic energy release and hazard estimation in the Basin and Range Province: U.S. Geological Survey Open-File Report, 83-358, 13 p.

Allmendinger, R.W., Miller, D.M., and Jordan, T.E., 1984, Known and inferred Mesozoic deformation in the hinterland of the Sevier belt, northwest Utah, *in* Kerns, G.J., and Kerns, R.L., Jr., editors, Geology of northwest Utah, southern Idaho, and northeast Nevada: Utah Geological Association Publication 13, p. 21-34.

Anderson, L.R., Keaton, J.R., Spitzley, J.E., and Allen, A.C., 1986, Liquefaction potential map for Salt Lake County, Utah: Logan, Utah State University, and Salt Lake City, Dames and Moore Consulting Engineers, 48 p.

Arabasz, W.J., Pechmann, J.C., and Brown, E.D., 1989, Evaluation of seismicity relevant to the proposed siting of a superconducting supercollider (SSC) in Tooele County, Utah: Utah Geological and Mineral Survey Miscellaneous Publication 89-1, 107 p.

Arnow, Ted, and Stephens, Doyle, 1990, Hydrologic characteristics of the Great Salt Lake, Utah -- 1847-1986: U.S. Geological Survey Water-Supply Paper 2332, 32 p.

Baer, J.L., and Benson, A.K., 1987, Results of gravity survey, Skull Valley--Ripple Valley, Tooele County, Utah, *in* Dames & Moore, The Ralph M. Parsons Company, and Roger Foott Associates, Inc., Site proposal for the superconducting supercollider--proposal appendix A--geotechnical report, Ripple Valley site: Utah Department of Business and Economic Development, v. 2, appendix E, 8 p.

Barnhard, T.P., and Dodge, R.L., 1988, Map of fault scarps formed on unconsolidated sediments, Tooele 1° x 2° quadrangle, northwestern Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1990, scale 1:250,000.

Burr, T.N., and Currey, D.R., 1988, The Stockton Bar, *in* Machette, M.N., editor, In the footsteps of G.K. Gilbert--Lake Bonneville and neotectonics of the eastern Basin and Range Province: Utah Geological and Mineral Survey Miscellaneous Publication 88-1, p. 66-73.

Carpenter, Everett, 1913, Ground water in Box Elder and Tooele Counties, Utah: U.S. Geological Survey Water-Supply Paper 333, 90 p.

Carr, T.R., and Paull, R.K., 1983, Early Triassic stratigraphy and paleogeography of the Cordilleran miogeocline, *in* Reynolds, M.W., and Dolly, E.D., editors, Mesozoic paleogeography of the west-central United States: Denver, Colorado, Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, p. 39-55.

Cashman, P.H., 1992, Structural geology of the northeastern Stansbury Mountains [Tooele County, Utah], *in* Wilson, J.R., editor, Field guide to geologic excursions in Utah and adjacent areas of Nevada, Idaho, and Wyoming: Prepared for the Geological Society of America, Rocky Mountain Section Meeting in Ogden, Utah, May 13-15, 1992, Utah Geological Survey Miscellaneous Publication 92-3, p. 171-178.

Cook, K.L., Bankey, Viki, Mabey, D.R., and DePangher, Michael, 1989, Complete Bouguer gravity anomaly map of Utah: Utah Geological and Mineral Survey Map 122, scale 1:500,000.

Cook, K.L., Halverson, M.O., Stepp, J.C., and Berg, J.W., Jr., 1964, Regional gravity of the northern Great Salt Lake Desert and adjacent areas in Utah, Nevada, and Idaho: Geological Society of America Bulletin, v. 75, p. 715-740, scale 1:250,000.

Cook, K.L., Montgomery, J.R., Smith, J.T., and Gray, E.F., 1975, Simple Bouguer gravity anomaly map of Utah: Utah Geological and Mineral Survey Map 37, scale 1:1,000,000.

Currey, D.R., 1980, Coastal geomorphology of Great Salt Lake and vicinity, *in* Gwynn, J.W., editor, Great Salt Lake, a scientific, historical and economic overview: Utah Geological and Mineral Survey Bulletin 116, p. 69-82.

— 1982, Lake Bonneville--selected features of relevance to neotectonic analysis: U.S. Geological Survey Open-File Report 82-1070, 30 p.

— 1990, Quaternary palaeolakes in the evolution of semidesert basins, with special emphasis on Lake Bonneville and the Great Basin, U.S.A.: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 76, p. 189-214.

Currey, D.R., Atwood, Genevieve, and Mabey, D.R., 1984, Major levels of Great Salt Lake and Lake Bonneville: Utah Geological and Mineral Survey Map 73, scale 1:500,000.

Currey, D.R., and Oviatt, C.G., 1985, Duration, average rates, and probable causes of Lake Bonneville expansions, stillstands, and contractions during the last deep-lake cycle, 32,000 to 10,000 years ago, *in* Kay, P.A., and Diaz, H.F., editors, Problems of and prospects for predicting Great Salt Lake levels: Salt Lake City, Center for Public Affairs and Administration, University of Utah, p. 9-24.

Curtin, George, 1973, Collapsing soil and subsidence, *in* Moran, D.E., Slosson, J.E., Stone, R.O., and Yelverton, C.A., editors, Geology, seismicity, and environmental impact: Association of Engineering Geologists Special Publication, October, 1973, p. 89-100.

Dames & Moore, The Ralph M. Parsons, Co., and Roger Foott Associates, Inc., 1987a, Site proposal for the superconducting supercollider--proposal appendix A--geotechnical report, Cedar Mountain site: Utah Department of Business and Economic Development, 2 volumes.

— 1987b, Site proposal for the superconducting supercollider--proposal appendix A--geotechnical report, Ripple Valley site: Utah Department of Business and Economic Development, 2 volumes.

Davies, S.F., 1980, Geology of the Grayback Hills, north-central Tooele County, Utah: Salt Lake City, University of Utah, M.S. thesis, 204 p., 2 geologic maps, scale 1:7,000.

Dean, L.E., 1978, Eolian sand dunes of the Great Salt Lake Basin: Utah Geology, v. 5, no. 2, p. 103-111.

Dennis, P.E., 1944, Shorelines of the Escalante Bay of Lake Bonneville: Utah Academy of Science Proceedings, v. 19-20, p. 121-124.

Doelling, H.H., 1964, Geology of the northern Lakeside Mountains and the Grassy Mountains and vicinity, Tooele and Box Elder Counties, Utah: Salt Lake City, University of Utah, Ph.D. dissertation, 354 p., 5 geologic maps, scale 1:31,680.

Eardley, A.J., 1962, Gypsum dunes and evaporite history of the Great Salt Lake Desert: Utah Geological and Mineralogical Survey Special Study 2, 27 p.

Gates, J.S., and Kruer, S.A., 1981, Hydrologic reconnaissance of the southern Great Salt Lake Desert and summary of the hydrology of west-central Utah: Utah Department of Natural Resources Technical Publication no. 71, 55 p.

Gilbert, G.K., 1875, Report upon the geology of portions of Nevada, Utah, California, and Arizona, examined in the years 1871 and 1872, *in* Wheeler, G.M., editor, Report upon geographical and geological explorations and surveys west of the one hundredth meridian, v. III, Geology: Washington D.C., Government Printing Office, p. 17-187.

— 1890, Lake Bonneville: U.S. Geological Survey Monograph 1, 438 p.

Halverson, M.O., 1961, Regional gravity survey of northwestern Utah and part of southern Idaho: Salt Lake City, University of Utah, M.S. thesis, 33 p.

Harty, K.M., and Christenson, G.E., 1988, Flood hazards from lakes and failure of dams in Utah: Utah Geological and Mineral Survey Map 111, 8 p., scale 1:750,000.

Heylmun, E.B., 1963, Oil and gas possibilities of Utah, west of the Wasatch and north of Washington County, *in* Crawford, A.L., compiler and editor, Oil and gas possibilities of Utah, re-evaluated: Utah Geological and Mineralogical Survey Bulletin 54, p. 287-302.

Hintze, L.F., 1988, Geologic history of Utah: Provo, Utah, Brigham Young University Geology Studies, Special Publication 7, 202 p.

Hogg, N.C., 1972, Shoshonitic lavas in west-central Utah: Brigham Young University Geology Studies, v. 8, no. 19, pt. 2, p. 133-184.

International Conference of Building Officials, 1991, Uniform building code: Whittier, California, International Conference of Building Officials, 1050 p.

Ives, R.L., 1946, Desert ripples: American Journal of Science, v. 244, p. 492-501.

Jones, D.J., 1953, Gypsum-oolite dunes, Great Salt Lake Desert, Utah: American Association of Petroleum Geologists Bulletin, v. 37, no. 11, p. 2530-2538.

Kummel, Bernhard, 1954, Triassic stratigraphy of southeastern Idaho and adjacent areas: U.S. Geological Survey Professional Paper 254-H, p. 165-194.

Kuribayashi, Eiichi, and Tatsuoka, Fumio, 1975, Brief review of liquefaction during earthquakes in Japan: Soils and Foundations, v. 15, no. 4, p. 81-92.

— 1977, History of earthquake-induced liquefaction in Japan: Japan Ministry of Construction, Public Works Research Institute Bulletin, v. 31, 26 p.

Le Bas, M.J., Le Maitre, R.W., Streckeisen, A., and Zanettin, B., 1986, A chemical classification of volcanic rocks based on the total alkali-silica diagram: Journal of Petrology, v. 27, pt. 3, p. 745-750.

Levy, Marjorie, and Christie-Blick, Nicholas, 1989, Pre-Mesozoic palinspastic reconstruction of the eastern Great Basin (western United States): Science, v. 245, p. 1454-1462.

Mabey, M.A., and Youd, T.L., 1989, Liquefaction severity index maps of the state of Utah, *in* Watters, R.J., editor, Engineering geology and geotechnical engineering: Proceedings of the 25th Symposium on Engineering Geology and Geotechnical Engineering, Reno, March 20-22, 1989, p. 305-312.

Maurer, R.E., 1970, Geology of the Cedar Mountains, Tooele County, Utah: Salt Lake City, University of Utah, Ph.D. dissertation, 184 p., 2 geologic maps, scale 1:43,700.

Miller, D.M., Jordan, T.E., and Allmendinger, R.W., 1990, Geologic map of the Crater Island quadrangle, Box Elder County, Utah: Utah Geological Survey Map 128, scale 1:24,000, 16 p.

Murchison, S.B., 1989, Fluctuation history of Great Salt Lake, Utah, during the last 13,000 years: University of Utah Limneotectonics Laboratory Technical Report 89-2, 137 p.

Nolan, T.B., 1928, Potash brines in the Great Salt Lake Desert, Utah, *in* Loughlin, G.F., and Mansfield, G.R., editors, Contributions to economic geology, part 1--Metals and nonmetals except fuels: U.S. Geological Survey Bulletin 795, p. 25-44.

Oviatt, C.G., Currey, D.R., and Miller, D.M., 1990, Age and paleoclimatic significance of the Stansbury shoreline of Lake Bonneville, northeastern Great Basin: Quaternary Research, v. 33, p. 291-305.

Oviatt, C.G., Currey, D.R., and Sack, Dorothy, 1992, Radiocarbon chronology of Lake Bonneville, eastern Great Basin, USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 99, p. 225-241.

Patton, T.L., and Lent, R.L., 1980, Current hydrocarbon exploration activity in the Great Salt Lake, *in* Gwynn, J.W., editor, Great Salt Lake, a scientific, historical, and economic overview: Utah Geological and Mineral Survey Bulletin 116, p. 115-124.

Paull, R.K., 1982, Conodont biostratigraphy of Lower Triassic rocks, Terrace Mountains, northwestern Utah, *in* Nielson, D.L., editor, Overthrust belt of Utah: Utah Geological Association Publication 10, p. 235-246.

Ross, D.S., 1973, Holocene fluctuations of Great Salt Lake, with special reference to evidence from the eastern shore: Salt Lake City, University of Utah, M.S. thesis, 110 p.

Sack, Dorothy, 1990, Quaternary geology of Tule Valley, west-central Utah: Utah Geological and Mineral Survey Map 124, 26 p., scale 1:100,000.

Smith, R.B., and Bruhn, R.L., 1984, Intraplate tectonics of the western U.S. Cordillera: Inferences on structural style from seismic reflection data, regional tectonics, and thermal-mechanical models of brittle/ductile deformation: Journal of Geophysical Research, v. 89, no. 37, p. 5733-5762.

Smith, R.B., and Sbar, M.L., 1974, Contemporary tectonics and seismicity of the western United States with emphasis on the Intermountain seismic belt: Geological Society of America Bulletin, v. 85, p. 1205-1218.

Solomon, B.J., and Black, B.D., 1990, Quaternary geology and geologic hazards of the West Desert Hazardous Industry Area, Tooele County, Utah, *in* Robinson, Lee, editor, Proceedings of the 1990 Annual Symposium on Engineering Geology and Geotechnical Engineerings, no. 26: Pocatello, Idaho State University, Apr 4-6, 1990, p. 5-1 to 5-14.

Stansbury, Howard, 1852, Exploration and survey of the valley of the Great Salt Lake of Utah--for the U.S. Senate: Philadelphia, Lippincott, Grambo, and Co., 487 p.

Stephens, J.C., 1974, Hydrologic reconnaissance of the northern Great Salt Lake Desert and summary hydrologic reconnaissance of northwestern Utah: Utah Department of Natural Resources Technical Publication 42, 55 p.

Stepp, J.C., 1961, Regional gravity survey of parts of Tooele and Box Elder Counties, Utah, and Elko County, Nevada: Salt Lake City, University of Utah, M.S. thesis, 40 p.

Stifel, P.B., 1964, Geology of the Terrace and Hogup Mountains, Box Elder County, Utah: Salt Lake City, University of Utah, Ph.D. dissertation, 173 p., geologic map, scale 1:63,360.

Tanis, J.T., 1963, Isostasy and crustal thickness in Utah and adjacent areas as revealed by gravity profiles: Salt Lake City, University of Utah, Ph.D. dissertation, 92 p.

Turk, L.J., 1969, Hydrology of the Bonneville Salt Flats, Utah: Palo Alto, California, Stanford University, Ph.D. dissertation, 307 p.

Utah State Department of Transportation, undated [about 1963], Materials inventory, Tooele County: Utah State Department of Highways Materials and Research Division, Materials Inventory Section, 25 p., geologic map scale approximately 1:210,000.

Utah State University Engineering Experiment Station in cooperation with Utah State Department of Highways and Bureau of Public Roads, 1962, Salt flat investigations--progress report, parts VI-XIII: Logan, Utah State University, 109 p.

Wardlaw, B.R., Collinson, J.W., and Ketner, K.B., 1979, Regional relations of Middle Permian rocks in Idaho, Nevada, and Utah, *in* Newman, G.W., and Goode, H.D., editors, Great Basin field conference: Rocky Mountain Association of Geologists and Utah Geological Association 1979 Basin and Range Symposium, p. 277-283.

Youd, T.L., 1977, Discussion of "Brief review of liquefaction during earthquakes in Japan," by Kuribayashi, Eiichi, and Tatsuoka, Fumio, 1975: Soils and Foundations, v. 17, no. 1, p. 82-85.

Youd, T.L., Tinsley, J.C., Perkins, D.M., King, E.J., and Preston, R.F., 1978, Liquefaction potential map of the San Fernando Valley, California: Proceedings of the Second International Conference on Microzonation for Safer Construction Research and Application, p. 267-278.