UTAH GEOLOGICAL SURVEY
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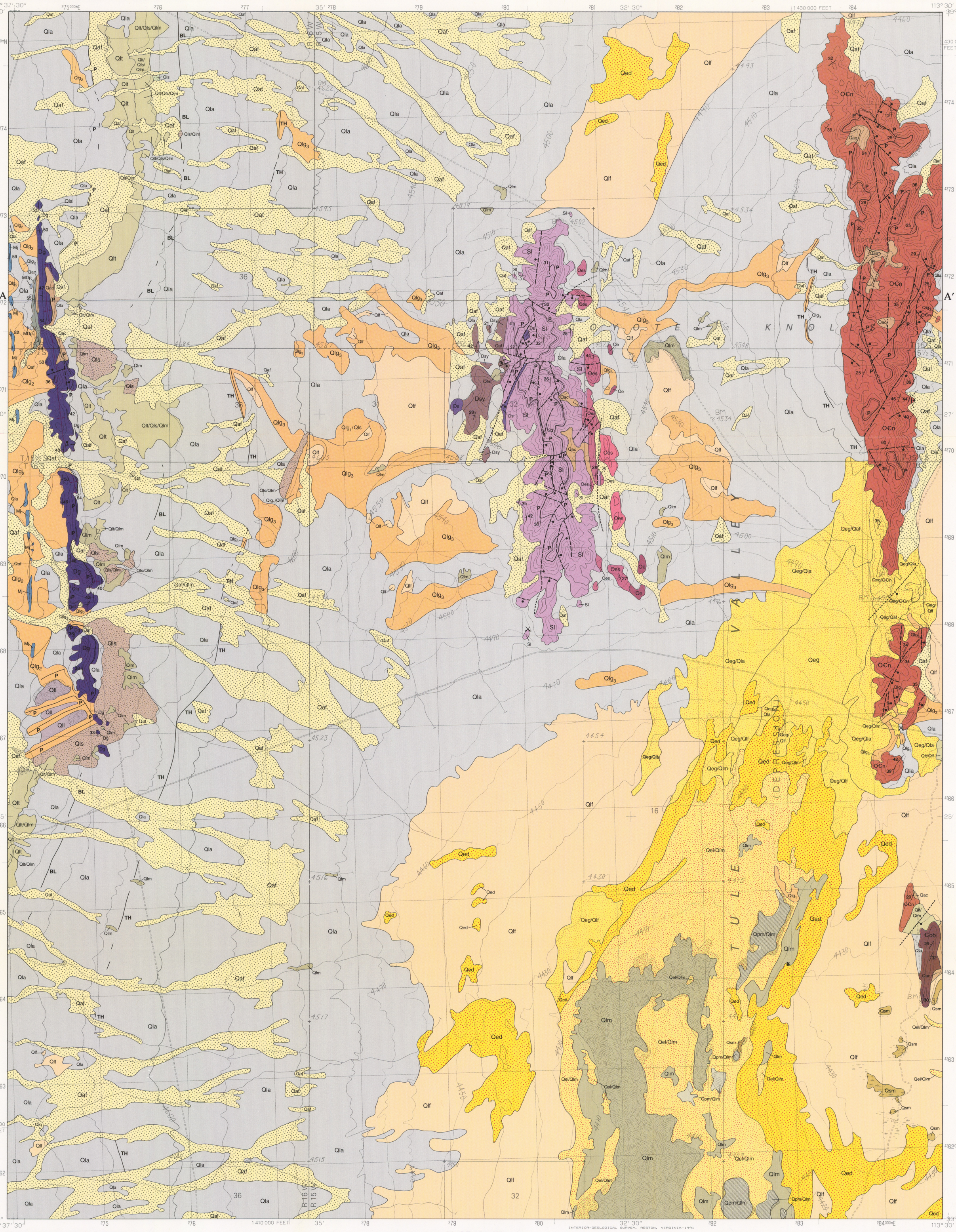


Base map from U.S. Geological Survey Coyote Knolls, Utah Provisional Edition Quadrangle, 1991.

SCALE 1:24 000

KILOMETERS 1 .5 0 1 2
METERS 1000 0 1000 2000
MILES 1 .5 0 1
FEET 1000 0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10 000

Field work completed 1988-89.
Cartography by Patricia H. Speranza.

12°18′ E
218.7 mils

1994 MAGNETIC NORTH DECLINATION AT CENTER OF MAP

UTAH

QUADRANGLE LOCATION

1	2	3
4		5
6	7	8

1 Granite Mountain
2 Middle Range South
3 Sand Pass
4 Big Horseshoe
5 Swasey Peak NW
6 Cowboy Pass
7 Chalk Knolls
8 Swasey Peak SW

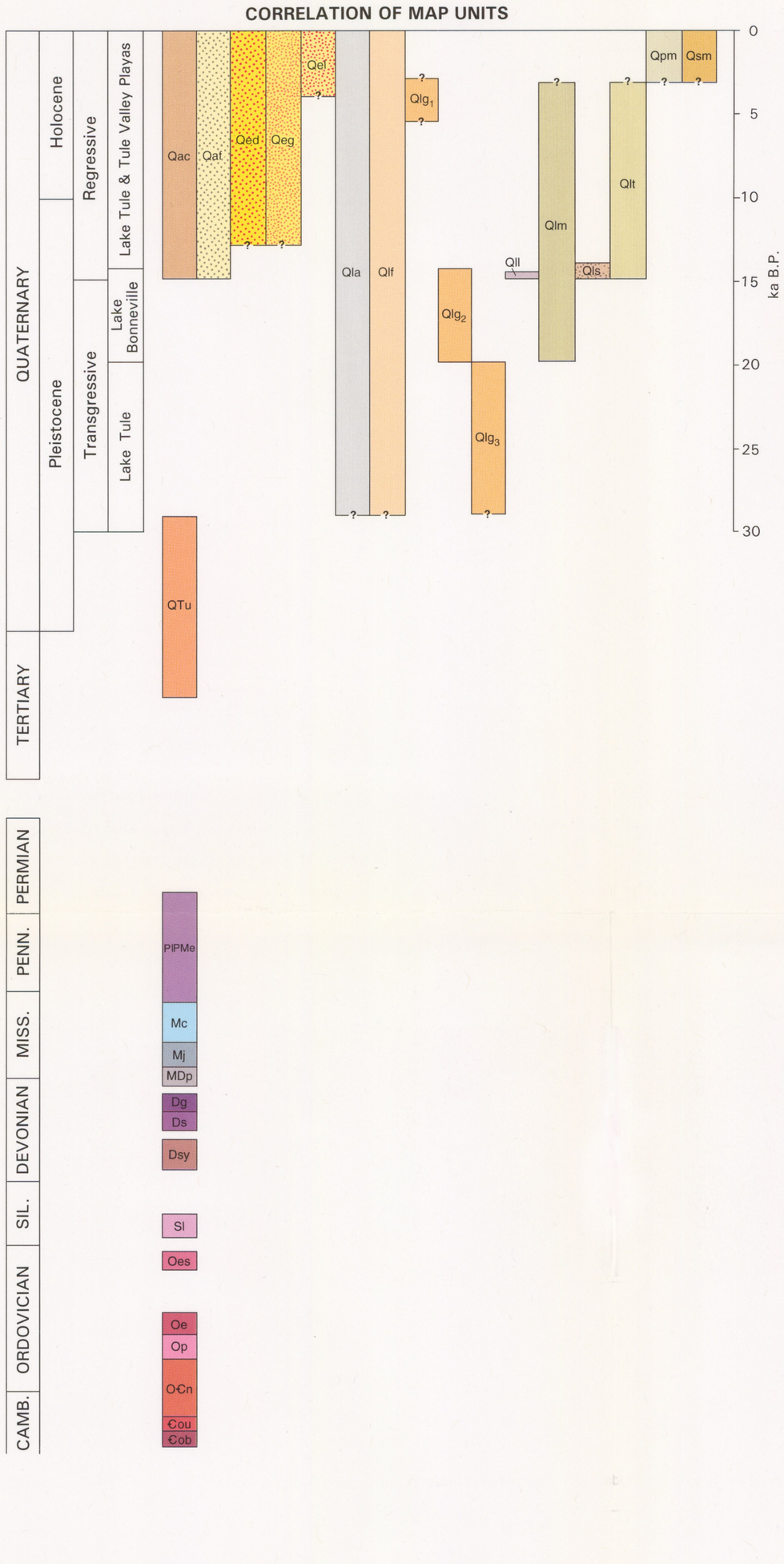
ADJOINING 7.5′ QUADRANGLE NAMES

GEOLOGIC MAP OF THE COYOTE KNOLLS QUADRANGLE, MILLARD COUNTY, UTAH

by
DOROTHY SACK
Ohio University

1994

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Qac UNDIFFERENTIATED ALLUVIUM AND COLLUVIUM (late Pleistocene and Holocene) -- *poorly sorted, primarily coarse- to fine-grained sediments consisting of fluvially reworked colluvium or alluvium with a significant colluvial component; occurs at and above the piedmont junction separating other Quaternary deposits below from bedrock above; estimated maximum thickness is 12 feet (3.7 m).*

Qaf ALLUVIAL-FAN DEPOSITS (late Pleistocene and Holocene) -- *coarse- to fine-grained alluvium and debris-flow sediments deposited on piedmont slopes since regression of Lake Bonneville from the Bonneville shoreline; Qaf deposits are generally finer grained toward the distal portion of alluvial fans, where they may be locally overlain by eolian sediments; estimated maximum thickness is 20 feet (6 m).*

Qed EOLIAN DUNES (late Pleistocene and Holocene) -- *well-sorted sand to poorly sorted mixtures of sand, silt, and clay found in active and stable dunes; composition ranges from primarily gypsum, through mixed gypsum and nongypsum constituents, to primarily non-gypsum minerals; 1.5 to 25 feet (0.5 to 7.6 m) thick.*

Qeg GYPSIFEROUS EOLIAN SHEET SAND (late Pleistocene and Holocene) -- *primarily sand-sized gypsum deposited as a sand sheet mostly northeast of the basin floor, which is the source of the gypsum grains; from a few inches to over 25 feet (7.6 m) thick.*

Qel EOLIAN-REWORKED LACUSTRINE FINES (Holocene) -- *dominantly marly but locally gypsiferous lacustrine fines; entrained from the valley floor as salt-bound marl pellets and redeposited on the valley floor in small shrub-coppice dunes overlying lacustrine marl; typically less than 3 feet (0.9 m) thick.*

Qla UNDIFFERENTIATED LACUSTRINE AND ALLUVIAL DEPOSITS (late Pleistocene and Holocene) -- *poorly sorted, coarse- to fine-grained sediments composed of lake-reworked alluvial-fan deposits, fan-reworked lake deposits, and areas where lake and fan deposits are not distinguishable at the map scale; lake-reworked fan deposits consist of pre-Bonneville alluvial fans etched by shorelines; Qla becomes finer grained in the downslope direction; generally less than 7 feet (2 m) thick.*

Qlf FINE-GRAINED LACUSTRINE DEPOSITS (late Pleistocene and Holocene) -- *poorly sorted mixtures of sand, silt, clay, and marl typically found between the basin-floor marl flats and the piedmont zone; locally gypsiferous, saline, or reworked by fluvial or eolian processes; in many places the contact between Qlf and the marl flats is marked by a Holocene bluff; thickness ranges from a few inches to 20 feet (6 m).*

Qlg_1 YOUNG LACUSTRINE GRAVEL (Holocene) -- *poorly sorted, pebbles and sand in a marly matrix deposited by regressive Lake Tule; many of the pebbles consist of broken tufa clasts or lithified Lake Bonneville marl; approximately 5 feet (1.5 m) thick.*

Qlg_2 INTERMEDIATE LACUSTRINE GRAVEL (late Pleistocene) -- *moderately well-sorted, subrounded to rounded, pebbles and cobbles; deposited by coastal waves and currents of Lake Bonneville between about 19,500 and shortly after 14,000 years B.P.; maximum thickness is about 50 feet (15 m).*

Qlg_3 OLD LACUSTRINE GRAVEL (late Pleistocene) -- *coastal sandy gravel deposited by transgressive Lake Tule between about 30,000 and 19,500 years B.P.; maximum thickness is approximately 20 feet (6m).*

Qll LAGOON DEPOSITS (late Pleistocene) -- *silt, clay, and sand filling lagoons behind Provo shoreline gravel barriers; thickness not observed.*

Qlm LACUSTRINE MARL (late Pleistocene and Holocene) -- *Lake Bonneville pristine white marl and sandy marl reworked by Lake Bonneville, regressive Lake Tule, and post lacustrine fluvial processes; calcareous silt to calcareous sandy silt; ostracodes are abundant and gastropods are occasionally found; locally saline; thickness varies from a few inches to at least 20 feet (6 m) thick.*

Qls LACUSTRINE SAND (late Pleistocene) -- *pebbly, marly sand that in many places overlies lacustrine marl; ooids and ostracode, gastropod, and carbonate-coated gastropod shells are common; deposited 10 to 125 feet (3 to 38 m) below the Provo shoreline during and shortly after Provo shoreline time; maximum thickness is approximately 15 feet (4.6 m).*

Qlt LACUSTRINE TUFA (late Pleistocene and Holocene) -- *calcium carbonate precipitated in nearshore environments during and after Provo shoreline time; includes broken tufa clasts reworked by lacustrine and fluvial processes; principally found as a shelf lying 20 to 60 feet (6 to 18 m) below the Provo shoreline; from a few inches to 2 feet (0.6 m) thick.*

Qpm PLAYA MUD (Holocene) -- *thin deposits of clay, silt, and marl, with small amounts of sand, overlying basin-floor marl; chloride-rich; typically flooded.*

Qsm MARSH DEPOSITS (Holocene) -- *fine-grained sediments and marl found in association with springs and related high-ground-water areas on the basin floor; generally saline and organic-rich; thickness not observed.*

QTu UNDIFFERENTIATED QUATERNARY AND TERTIARY DEPOSITS (Tertiary and early Quaternary) -- *basin fill of interfingering alluvial, eolian, lacustrine, playa, and spring deposits; estimated maximum thickness is 6,900 feet (2,100 m) (see Allmendinger and others, 1983). Shown on cross section only.*

PIPMe ELY LIMESTONE (Permian-Pennsylvanian-Mississippian) -- *primarily cherty limestone that is commonly bioclastic and fossiliferous; not exposed in this quadrangle, but shown in the subsurface on the cross section; about 2,000 feet (600 m) thick.*

Mc CHAINMAN SHALE (Mississippian) -- *primarily dark-gray shale with interbeds of limestone and siltstone; subsurface only in this quadrangle; about 1,500 feet (460 m) thick.*

Mj JOANA LIMESTONE (Mississippian) -- *light- to medium-dark-gray, generally coarsely crystalline fossiliferous limestone; total exposed thickness is 85 feet (26 m); base and top are concealed by Quaternary deposits.*

MDp PILOT SHALE (Mississippian and Devonian) -- *the exposed lower part of the Pilot Shale is mostly thinly interbedded calcareous siltstone, shale, and fine-grained sandstone that includes about 5% silty limestone, which occurs in 1 to 2 foot (0.3 to 0.6 m) beds scattered throughout the section; exposed thickness is 410 feet (125 m); the upper part of the Pilot Shale is buried beneath Quaternary deposits; regional thickness is 700 to 1,090 feet (210-330 m).*

Dg GUILMETTE FORMATION (Devonian) -- *the exposed upper part of the Guilmette Formation is interbedded limestone and dolomite that includes a 33 foot (10 m) yellowish-gray, crossbedded sandstone about 260 feet (80 m) below its top; limestone beds are generally medium gray to medium dark-gray, medium to thick bedded, and medium to coarse grained; dolomite beds are similar to the limestone but are dark brownish gray; spherical stromatoporoids are common in the carbonate units, and "spaghetti" stromatoporoids are abundant in a few beds; the upper Guilmette Formation is resistant and forms the backbone of a hogback; exposed thickness is 360 feet (110 m); regional thickness is 2,000 to 2,650 feet (600-800 m).*

Ds SIMONSON DOLOMITE (Devonian) -- *predominantly medium dark-gray and medium-light-gray, fine- to medium-grained, thin- to thick-bedded dolomite that weathers dark gray to dark yellowish brown; exposed thickness about 150 feet (45 m); complete thickness in nearby areas is 600 to 1,000 feet (180-300 m).*

Dsy SEVY DOLOMITE (Devonian) -- *predominantly medium-gray, finely crystalline, medium-bedded dolomite that weathers light gray to yellowish gray; some beds are laminated; locally scattered quartz grains of thin brown sandstone beds are present; exposed thickness about 700 feet (210 m); regional thickness about 1,200 feet (360 m).*

Sl LAKETOWN DOLOMITE (Silurian) -- *the lower 360 feet (110 m) is dark-brownish-gray, medium-crystalline, medium- to thick-bedded dolomite that forms ledges and cliffs; the upper 560 feet (170 m) includes two conspicuous thick bands of pinkish-gray dolomite separated by bands of dark-gray dolomite; the uppermost dark-gray dolomite includes as much as 20% black chert as bedded nodules, and abundant poorly preserved traces of spherical stromatoporoids, colonial corals, and thin-shelled brachiopods; the Laketown Dolomite is at least 920 feet (280 m) thick.*

Oes ELY SPRINGS DOLOMITE (Upper Ordovician) -- *the lower 530 feet (160 m) is dark-brownish-gray, fine-grained dolomite that contains as much as 2% black chert nodules; the upper 90 feet (27 m) is medium-gray, thin- to medium-bedded, slope-forming dolomite; total thickness 620 feet (187 m).*

Oe EUREKA QUARTZITE (Middle Ordovician) -- *white to yellowish-gray, medium- to thick-bedded quartzite; only the upper 120 feet (37 m) is exposed in this quadrangle; regional thickness is 300 to 500 feet (90-150 m).*

Op POGONIP GROUP (Middle and Lower Ordovician) -- *not exposed in this quadrangle but shown on the cross section in the subsurface; consists of thin-bedded, silty, bioclastic gray limestone, interbedded with light-olive-gray shale; regional thickness 1,900 to 3,400 feet (580-1,000 m).*

O€n NOTCH PEAK FORMATION (Upper Cambrian and Lower Ordovician) -- *the lower exposed 400 feet (120 m) of this formation consists of medium-gray, thick-bedded limestone banded with light-gray layers; it forms light-gray cliffs in the southern exposures; the upper 630 feet (190 m) is mostly dark-brownish-gray dolomite with broad bands which weather moderate orange-pink; total exposed thickness is 1,030 feet (310 m); neither the top nor the bottom of the Notch Peak is exposed in the quadrangle; regional thickness is 1,660 to 1,690 feet (505-515 m).*

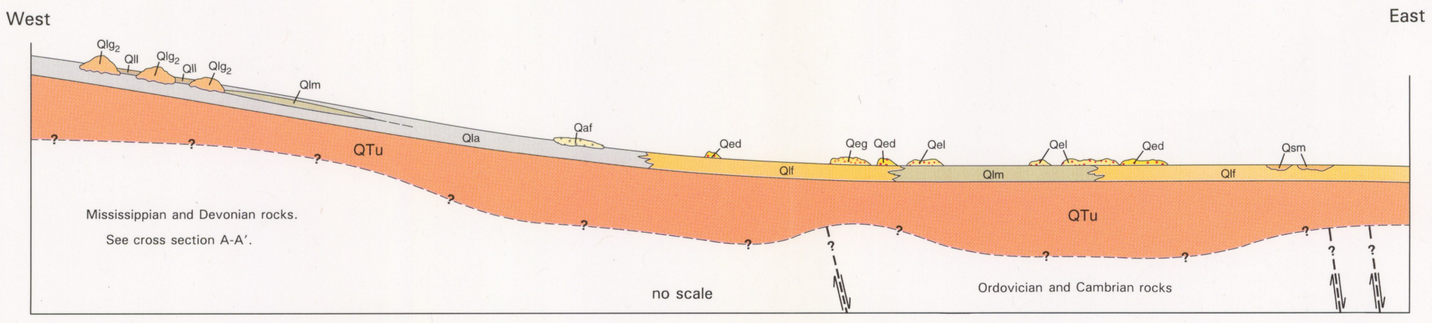
€ou UPPER MEMBERS OF THE ORR FORMATION (Upper Cambrian) -- *interbedded shale and limestone; 600-700 feet (180-215 m) thick; not exposed in the quadrangle but shown on cross section.*

€ob BIG HORSE LIMESTONE OF THE ORR FORMATION (Upper Cambrian) -- *medium-gray, thick-bedded, bioclastic limestone that contains oolites and indistinct biohermal structures; only the upper part of the Big Horse Limestone is exposed in the quadrangle; regional total thickness is 715 feet (218 m).*

Qlg_1/Qlm STACKED MAP UNITS -- *Indicate thin or discontinuous cover of one unit over another unit; the uppermost unit is indicated by color on the map.*

MAP SYMBOLS

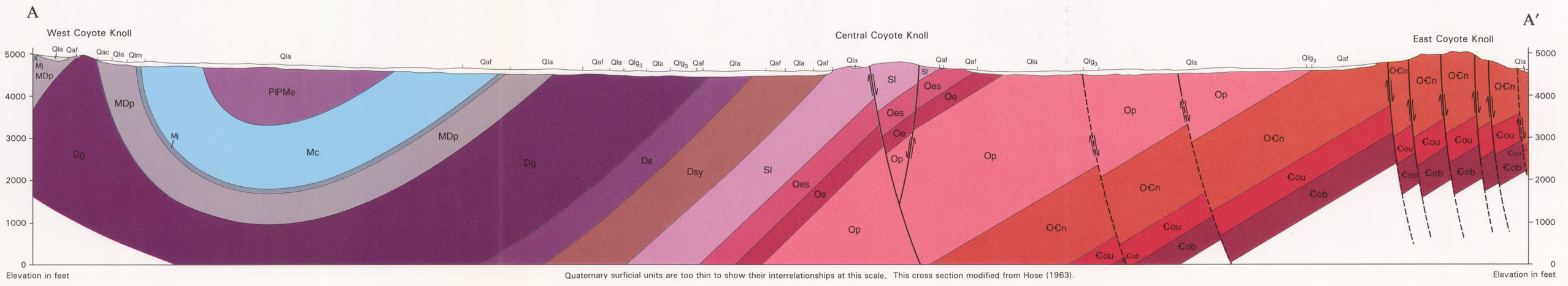
- Contact
- Fault - dashed where inferred; dotted where concealed; bar and ball on downthrown side
- 18 Strike and dip
- Anticline
- P — P Provo level of Lake Bonneville
- BL — BL Lowest Lake Bonneville shoreline in Tule Valley
- TH — TH Highest Lake Tule shoreline (pre-Lake Bonneville)
- * Radiocarbon sample site
- Gravel pit
- Xg Gypsum pit



Schematic cross section showing the relationships of the Quaternary deposits. QTu represents undifferentiated Quaternary-Tertiary basin-fill deposits.

ERA	PERIOD	MAP UNIT		MAP SYMBOL	THICKNESS* feet	THICKNESS* meters	LITHOLOGY
PALEOZOIC	PERMIAN						
	PENNSYLVANIAN	Ely Limestone		PIPMe	2000	600	not exposed
	MISSISSIPPIAN	Chainman Shale		Mc	1500	460	not exposed
		Joana Limestone		Mj	85 (50-200)	26 (15-60)	corals, crinoids
		Pilot Shale		MDp	410 (700-1090)	125 (210-330)	not exposed; weathers yellowish gray
	DEVONIAN	Guilmette Formation		Dg	360 (2000-2650)	110 (600-800)	dark gray; medium dark gray; not exposed
		Simonson Dolomite		Ds	150 (600-1000)	45 (180-300)	medium dark gray; thin sandstone beds
		Sevy Dolomite		Dsy	700 (1200)	210 (360)	fault; medium gray
	SILURIAN	Laketown Dolomite		Sl	920 (1000)	280 (300)	dark gray, cherty; pinkish gray bands; dark brownish gray
	ORDOVICIAN	Ely Springs Dolomite		Oes	620	187	light gray; dark gray
		Eureka Quartzite		Oe	120 (300-500)	37 (90-150)	
		Pogonip Group		Op	2800 (1900-3400)	850 (580-1000)	not exposed
	CAMBRIAN	Notch Peak Formation		O€n	1030 (1700)	310 (520)	dark brownish gray, with pinkish gray bands; medium gray
		Orr Fm.	upper members	€ou	(600-700)	(180-210)	not exposed
			Big Horse Limestone	€ob	135 (715)	41 (220)	oolitic, bioclastic; not exposed

*Regional thickness shown in parentheses



GEOLOGIC MAP OF THE COYOTE KNOLLS QUADRANGLE, MILLARD COUNTY, UTAH

by
Dorothy Sack
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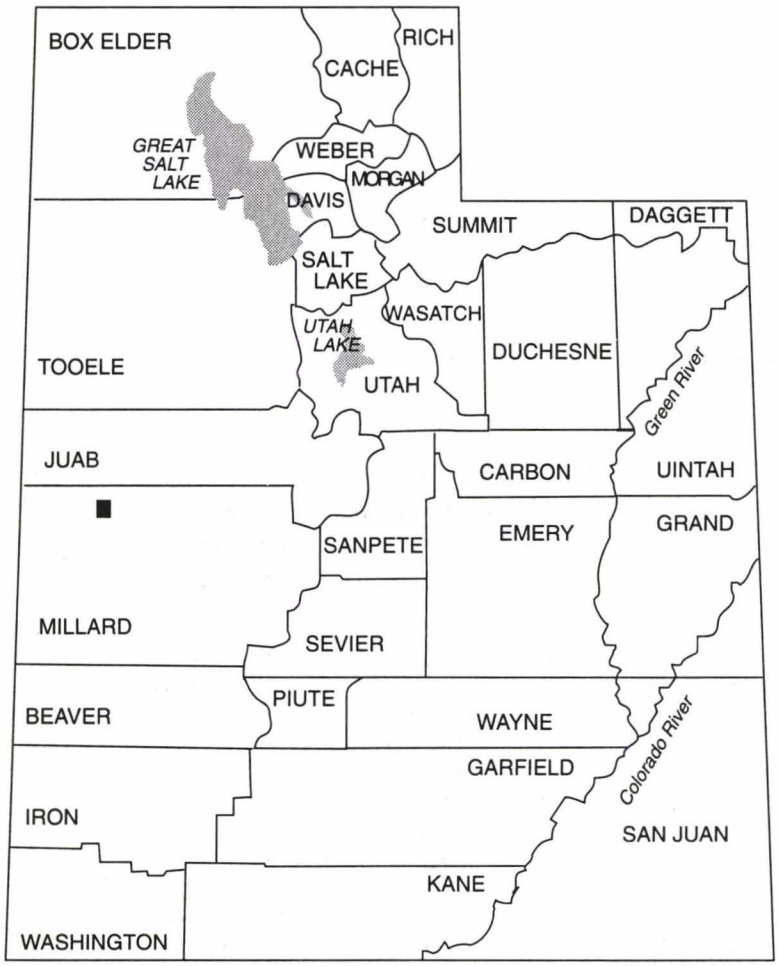

Map 162 **1994**
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES

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GEOLOGIC MAP OF THE COYOTE KNOLLS QUADRANGLE, MILLARD COUNTY, UTAH

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ABSTRACT

The Coyote Knolls quadrangle is located in west-central Tule Valley, about 50 miles (80 km) west of Delta, Utah. It covers portions of the Tule Valley basin floor, the adjacent piedmonts of the Coyote Knolls and Confusion Range, and most of the Coyote Knolls. Elevations range from 4,406 feet (1,343 m) in the southeast corner of the quadrangle to 5,065 feet (1,544 m) atop the central Coyote Knoll in the north-central part of the map area. Bedrock exposures occupy 3.7 square miles (9.6 km^2) of the quadrangle and consist of Cambrian, Ordovician, Silurian, Devonian, and Mississippian sedimentary rocks.

Extensive Quaternary sediments were deposited in late Pleistocene and Holocene time in alluvial, eolian, lacustrine, playa, and spring environments. The Quaternary sediments are divided into 16 map units. Relative ages of these units are determined from geomorphic, stratigraphic, and geochronometric evidence primarily related to the late Quaternary paleolake history of Tule Valley. Tule Valley was occupied by an embayment of Lake Bonneville from about 19,500 to shortly after 14,000 years ago, and by isolated Lake Tule immediately before and after the interval of Lake Bonneville integration.

The piedmonts of the Confusion Range and Coyote Knolls lie in the north and west parts of the map area. These regions are dominated by prelake alluvial-fan deposits that were moderately reworked by coastal processes from Lakes Tule and Bonneville. Postlake alluvial-fan deposits, however, are also widespread in the piedmont zones. Smaller portions of the piedmont were subjected to more intense coastal action, and display mappable accumulations of lacustrine gravel, marl, sand, and tufa.

The transition zone from the piedmont to the Tule Valley basin floor consists largely of fine-grained lacustrine deposits. Desiccation of Lakes Bonneville and Tule left behind barren flats of lacustrine marl and playa mud on the basin floor in the southeast part of the quadrangle. During very late Pleistocene and Holocene time, these sediments have been entrained by the wind and redeposited in eolian dunes, sand sheets, and small shrub coppices.

Although they have not been widely exploited, gravel, gypsum, and marl are the most valuable economic resources in the quadrangle. Geologic hazards consist of flash floods, earthquakes, and blowing sand and dust.

INTRODUCTION

The Coyote Knolls quadrangle is in the Great Basin desert approximately 50 miles (80 km) west of Delta, Utah. The map area lies about 3 miles (5 km) east of the Confusion Range and 9 miles (14 km) west of the House Range in west-central Tule Valley (figure 1). The Coyote Knolls (figure 2) are smaller bedrock hills near the center of Tule Valley that lie almost entirely within the study area. The quadrangle is, however, dominated by Quaternary deposits, which cover approximately 94 percent of the map area (table 1).

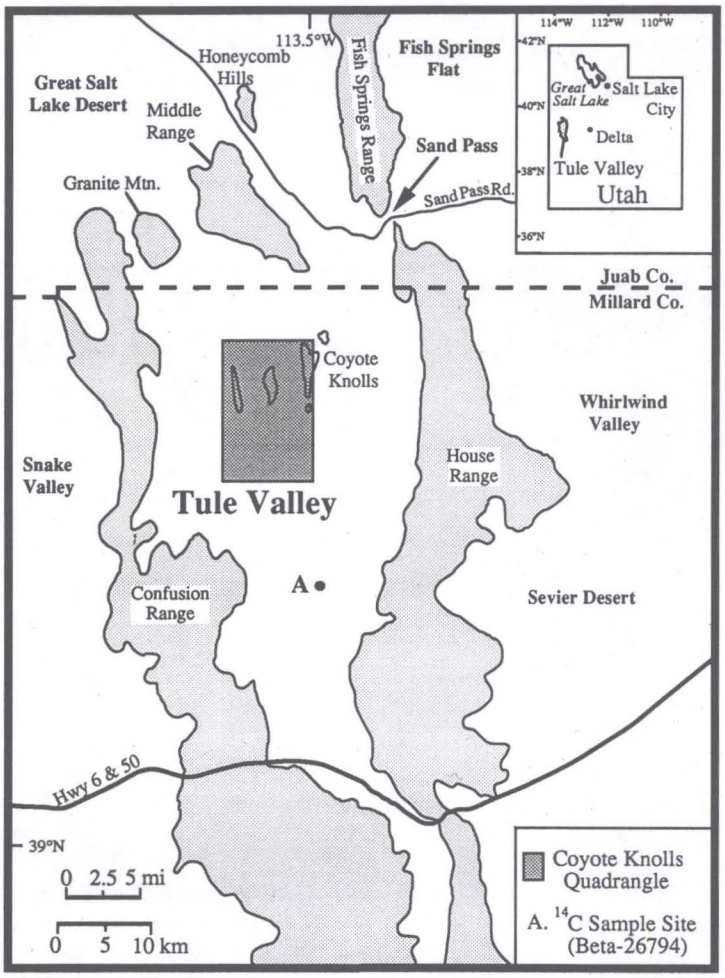

Figure 1. Location map of the Coyote Knolls quadrangle and other sites mentioned in the text.

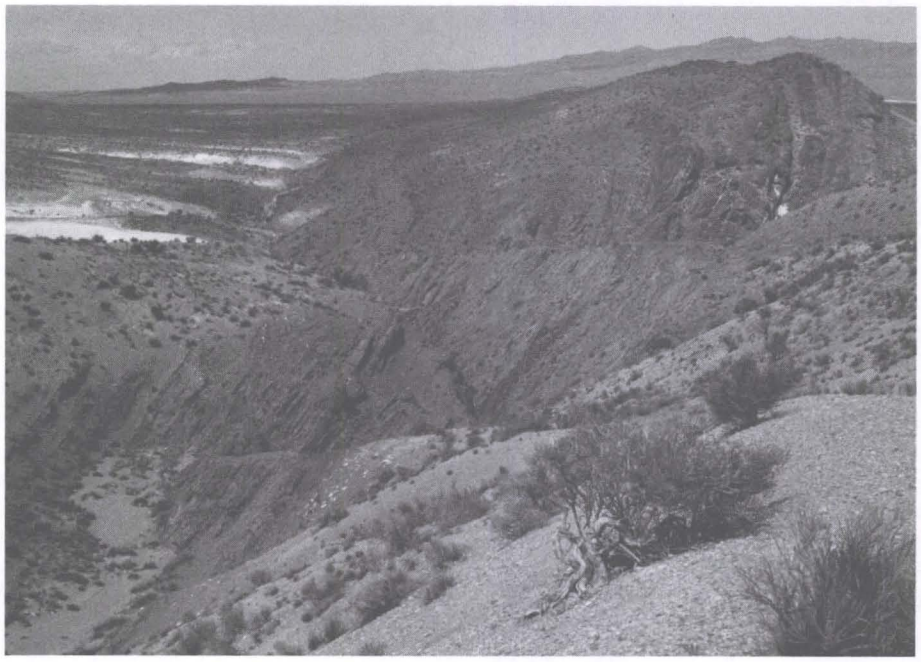

Figure 2. View to the east-southeast through a gap cut in Mississippian-Devonian strata in the north part of the westernmost and lowest of the Coyote Knolls. The south end of the central Coyote Knoll shows through the gap just above the floor of Tule Valley in the middle distance. The House Range forms the skyline. White deposits in the foreground are marl and sand deposits of Lake Bonneville. The upturned Mississippian-Devonian siltstone beds of the Pilot Shale form the sawtooth outcrops on the near side of the ridge. The dark outcrops on the farther and higher part of the ridge are limestones and dolomites in the upper part of the Guilmette Formation.

Table 1.
Map units as percentage of quadrangle surface area.

42.7%	Qla	Undifferentiated lacustrine and alluvial deposits
14.5%	Qaf	Alluvial-fan deposits
14.3%	Qlf	Fine-grained lacustrine deposits
6.3%	- -	Combined Paleozoic bedrock units
4.2%	Qeg	Gypsiferous eolian sheet sand
4.1%	Qed	Eolian dunes
4.0%	Qel	Eolian-reworked lacustrine fines
3.2%	Qlg_3	Old lacustrine gravel
2.6%	Qlm	Lacustrine marl
1.3%	Qlt	Lacustrine tufa
1.2%	Qlg_2	Intermediate lacustrine gravel
0.9%	Qls	Lacustrine sand
0.3%	Qpm	Playa mud
0.2%	Qac	Undifferentiated alluvium and colluvium
0.1%	Qlg_1	Young lacustrine gravel
0.1%	Qll	Lagoon deposits
< 0.1%	Qsm	Marsh deposits

The physical geography and Quaternary geology of Tule Valley have strongly influenced the Quaternary geology of the Coyote Knolls quadrangle. Tule Valley is approximately 50 miles (80 km) long, 19 miles (31 km) wide, and covers 545 square miles (1,412 km^2) (figure 1). It occupies a structural basin of interior drainage in the Great Basin section of the Basin and Range Province. During the Quaternary, the regional climate consisted of long arid intervals separated by periods of greater effective moisture (Gilbert, 1890; Scott and others, 1983; Oviatt and Currey, 1987; Oviatt and others, 1987). As in the present period of aridity, deposition in Tule Valley during previous arid intervals was probably dominated by alluvial-fan, eolian, and playa processes. The most recent major period of greater effective moisture in the region lasted from approximately 30,000 to 13,000 years ago (Currey and Oviatt, 1985; Currey, 1990). It caused numerous lakes to form throughout the Basin and Range Province, including in Tule Valley (Sack, 1990). Lacustrine deposits from that deep-lake cycle are still abundant in Tule Valley, although they have been obliterated to some degree by subsequent subaerial processes (Sack, 1992).

Some previous geologic maps have included the study area, but have not shown its Quaternary geology in detail. Hose (1963) mapped the relatively small bedrock portion of this quadrangle, formerly referred to as the Cowboy Pass NE quadrangle, but employed only one undifferentiated unit for the extensive Quaternary deposits. Likewise, Morris (1978) did not distinguish Quaternary units in his preliminary geologic map of the 1:250,000-scale Delta quadrangle, which includes the study area. Compared to the 1:24,000-scale quadrangle map presented here, Sack's (1990) 1:100,000-scale Quaternary geologic map of Tule Valley is more generalized. In western Utah, Quaternary deposits merit being mapped in detail because they are extensive, of possible economic value, useful in identifying geologic hazards, and important to regional paleoenvironmental reconstructions.

Physical Geography and Land Use

The Coyote Knolls quadrangle covers portions of the Tule Valley basin floor, the adjacent piedmonts of the Coyote Knolls and Confusion Range, and most of the Coyote Knolls (figure 1). The lowest elevation in the study area, 4,406 feet (1,343 m), is found on the valley flats in the southeast corner of the quadrangle. In general, elevation increases to the west, where the Confusion Range piedmont lies. The three principal ridges that form the Coyote Knolls interrupt this topographic trend locally in the northeastern, north-central, and far western parts of the study area. A peak in the north-central Coyote Knoll has the highest elevation in the quadrangle, 5,065 feet (1,544 m).

The climate of the study area is mid-latitude dry, consisting of cold winters, hot summers, low average-annual precipitation, and high average-annual potential evapotranspiration. Mean temperatures are approximately 50°F (10°C) for the year, 27°F (-2.8°C) in January, and 76°F (24.4°C) in July (Stephens, 1977; Stevens and Brough, 1987; Sack, 1990, table 1). Mean annual precipitation is about 7 inches (18 cm) (Stephens, 1977; Stevens and Brough, 1987; Sack, 1990, table 1).

Vegetation in the study area varies with drainage and soil-salinity factors. In the low-elevation southeastern part of the quadrangle, marsh bulrush (*Scirpus paludosis*) and salt grass (*Distichlis stricta*) grow in and around the saline springs and marshes. Nearby low-level marl flats lie close to the groundwater table and are largely unvegetated due to their high salinity and low permeability. Eolian-reworked marl and lake fines are found adjacent to the marl flats, but they are generally associated with a slightly deeper water table and better drainage. They support pickleweed (*Allenrolfea occidentalis*) and greasewood (*Sarcobatus vermiculatus*). To the north and west the lower piedmont zones, which have moderately well-drained and slightly saline soils, are dominated by greasewood and shadscale (*Atriplex confertifolia*). Soils of the middle and upper piedmont zones and the Coyote Knolls are well drained and of low salinity. Sagebrush (*Artemesia tridentata*), Mormon tea (*Ephedra nevadensis*), and shadscale are the principal species in those areas. In addition, some junipers (*Juniperus osteosperma*) grow on the Coyote Knolls.

The study area is owned by the state and federal governments, and much of it is administered by the Bureau of Land Management. There are no permanent residents living in the quadrangle, but sheep and cattle herders sometimes camp there during the winter grazing season. The few small springs in the study area are insufficient to supply livestock needs. Additional water, however, can be obtained from nearby springs in adjacent quadrangles.

Map-Unit Symbols

Map units are identified with letter symbols. The first letter is capitalized and indicates geologic age. For Paleozoic rocks, the lowercase letter represents the formation's name. A hierar-

chical scheme involving two lowercase letter symbols, and in some instances a numeric subscript, is employed to subdivide the Quaternary units. The first lowercase letter of a Quaternary map-unit symbol designates the general depositional environment of the map unit as alluvial, eolian, lacustrine, playa, or spring (table 2). The second lowercase letter provides more detailed information regarding texture, composition, or depositional subenvironment. For example, the symbol Qed designates Quaternary eolian sediments deposited in well-formed dunes. The lacustrine gravel unit (Qlg) is further subdivided on the basis of relative age using numeric subscripts, with the subscript 1 indicating the youngest lacustrine gravel unit (table 2).

Table 2.
Symbols used for map units.

First Letter, Temporal Designation:

Q = Quaternary deposits
M = Mississippian
D = Devonian
S = Silurian)
O = Ordovician
C = Cambrian

Second Letter, General Depositional Environment of Quaternary Units:

a = alluvial
e = eolian
l = lacustrine
p = playa
s = spring

Third Letter, Subenvironment Indicator of Quaternary Units:

Alluvial: c = colluvium
f = alluvial fan

Eolian: d = dunes
g = gypsum
l = lacustrine

Lacustrine: a = alluvial
f = fine-grained
g = gravel
l = lagoon
m = marl
s = sand
t = tufa

Playa: m = mud

Spring: m = marl

Numeric Subscript, Relative-Age Indicator of Quaternary Units:

1 = young
2 = intermediate
3 = old

In some areas of the quadrangle, one relatively thin Quaternary unit covers a different map unit. These areas are depicted on the map by stacking the appropriate material symbols. For stacked units, the designation for the surficial unit is written above the designation for the underlying material (Varnes and Van Horn, 1951; Hunt and others, 1953; Robison and McCalpin, 1987; Oviatt, 1989; Sack, 1990). For example, where lacustrine tufa (Qlt) overlies lacustrine marl (Qlm), the area is labelled Qlt/Qlm. Triple stacking is used where lacustrine sand (Qls) is found between the tufa and marl (Qlt/Qls/Qlm). Areas on the map that consist of stacked units are colored according to the material at the surface. Overlying units are employed in determining the areal extent of map units (table 1).

RELATIVE-AGE CONTROL

Approximate ages of Quaternary map units are determined from geomorphic, stratigraphic, and geochronometric evidence primarily related to the late Quaternary paleolake history of Tule Valley (Sack, 1990). At the beginning and end of the most recent Quaternary deep-lake cycle, which lasted from about 30,000 to 13,000 years ago (Currey and Oviatt, 1985; Currey, 1990), Tule Valley contained an isolated paleolake, called Lake Tule (Sack, 1988). Between those two phases of independent Lake Tule, Tule Valley was occupied by an arm of Lake Bonneville (Gilbert, 1890; Currey and others, 1984; Sack, 1990), the largest late Pleistocene paleolake in western North America. During that period of Bonneville integration, Tule Valley was an embayment in the southwestern portion of Lake Bonneville (figure 3).

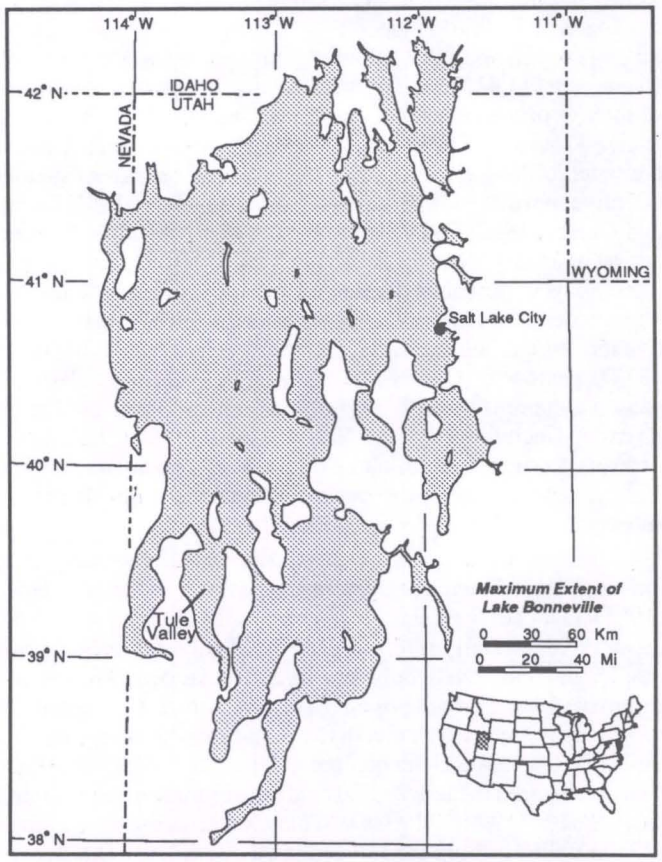

Figure 3. Location of the Tule Valley embayment of Lake Bonneville (Sack, 1992).

Independent Lake Tule probably originated about 30,000 years ago (figure 4) when climatic conditions were also causing Lake Bonneville to expand. This transgressive phase of Lake Tule (TLT on figure 4) lasted until about 19,500 years ago. At approximately that time, Pleistocene Lake Tule became the Tule Valley arm of Lake Bonneville when the transgressing Lake Bonneville spilled over the lowest point on the divide between the two basins (Currey and Oviatt, 1985; Sack, 1990). That spillover occurred at Sand Pass, which has a modern elevation of 4,744 feet (1,446 m) (figure 1). Inflow from Lake Bonneville (I on figure 4) caused the water level in Tule Valley to rise rapidly to the Sand Pass threshold elevation, at which point the Tule Valley water body achieved full integration with Lake Bonneville (Sack, 1990).

When Lake Bonneville stood at the brink of overflow at Sand Pass, it occupied the highest level it had yet attained in the lake cycle (Currey and Oviatt, 1985). By analogy, at the same time Lake Tule must also have occupied its highest level in the lake cycle (Sack, 1990). This Lake Tule level is marked in Tule Valley by a conspicuous shoreline, which lies about 100 feet (30 m) below the modern elevation of Sand Pass. The fact that the shoreline is a Lake Tule feature is apparent from its substantial elevation below Sand Pass. It is known to be from the transgressive, that is, pre-Bonneville integration, phase of Lake Tule because it is overlain by the distinctive white marl deposit of Lake Bonneville. The shoreline is interpreted as the highest transgressive Lake Tule level because remarkably little shoreline evidence occurs between it and the elevation of Sand Pass. In the study area, remnants of this highest, transgressive Lake Tule shoreline extend across the Confusion Range and the Coyote Knolls piedmonts at elevations ranging from 4,634 feet (1,412 m) at the south end to 4,638 feet (1,414 m) at the north end of

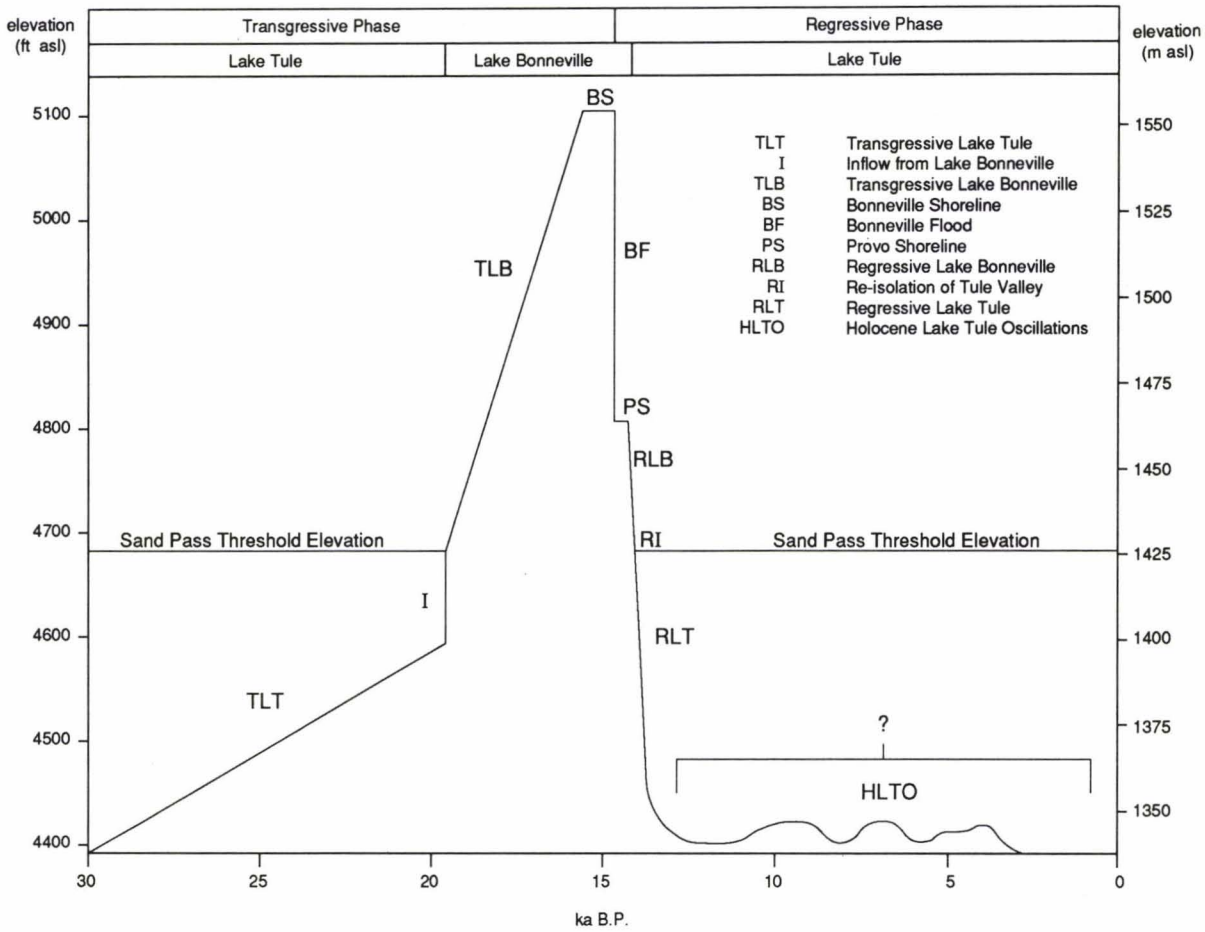

Figure 4. *Schematic time-altitude diagram of late Quaternary lakes in Tule Valley. Late Pleistocene water-level elevations depicted on the diagram are corrected for hydroisostatic rebound according to the formula of Currey and Oviatt (1985). The Sand Pass threshold is the lowest point on the divide between Tule Valley and the main part of the Bonneville basin. Transgressive Lake Tule (TLT) became the Tule Valley arm of Lake Bonneville about 19,500 years ago when Lake Bonneville spilled over the threshold into Tule Valley. The water level in Tule Valley rapidly rose to equilibrate with the level of Lake Bonneville (I). At water-level elevations above Sand Pass, the Tule Valley arm oscillated in unison with the rest of Lake Bonneville. This included the remainder of the Bonneville transgressive phase (TLB), Bonneville shoreline time (BS), the Bonneville flood (BF), Provo shoreline time (PS), and the early part of the climatically induced regression of Lake Bonneville from the Provo shoreline (RLB). Tule Valley became reisolated from Lake Bonneville shortly after 14,000 years ago (RI). Small Holocene water bodies subsequently rose and fell within Tule Valley (HLTO). The upper extent of those water-level oscillations are depicted with some confidence, however, their minimum levels and ages are conjectural.*

the quadrangle. This variation in shoreline elevation is due primarily to differential hydroisostatic rebound caused by Lake Bonneville.

Tule Valley was integrated with Lake Bonneville for less than 6,000 years (Sack, 1990) (figure 4). This interval, however, spans the most dramatic part of Lake Bonneville history. During this period Lake Bonneville completed its transgressive phase (TLB on figure 4) when it reached the lowest elevation on its divide, about 15,350 years ago (Burr and Currey, 1988), and began overflowing into the Snake-Columbia River system. Under this external threshold control, Lake Bonneville constructed its highest shoreline, called the Bonneville shoreline (BS on figure 4). The approximate elevation of the Bonneville shoreline in Tule Valley near the Coyote Knolls quadrangle is 5,165 feet (1,574 m). It, therefore, is not present in the quadrangle, which has a maximum elevation of 5,065 feet (1,544 m). When alluvial material at Lake Bonneville's external threshold failed about 14,500 years ago, the water level rapidly fell 340 feet (104 m) from the Bonneville shoreline in the catastrophic Bonneville flood (BF on figure 4) (Gilbert, 1890; Malde, 1968; Jarrett and Malde, 1987; Burr and Currey, 1988). Discharge eroded the outlet down to a bedrock sill, where the water level restabilized (Gilbert, 1890). At this level, Lake Bonneville constructed the geomorphically prominent Provo shoreline (PS on figure 4). Preserved portions of the Provo shoreline in this quadrangle extend around the Coyote Knolls and across the Confusion Range piedmont. Its elevation ranges from 4,789 feet to about 4,815 feet (1,460 to 1,468 m).

Burr and Currey (1988) estimated that Lake Bonneville began its rapid, climatically induced regression from the Provo shoreline about 14,200 years ago (RLB on figure 4). Because the Sand Pass threshold between Tule Valley and the main part of the Bonneville basin is only 73 feet (22 m) below the local elevation of the Provo shoreline, Tule Valley was probably reisolated from Lake Bonneville soon after Provo shoreline time, perhaps by shortly after 14,000 years ago (RI on figure 4). A shoreline that extends around Tule Valley at the approximate elevation of the Sand Pass threshold is interpreted as a post-Provo Lake Bonneville shoreline because no sites have yet been found where it is overlain by white marl or any other lacustrine deposit. It was apparently formed just before reisolation of Tule Valley, and is therefore interpreted as the lowest and youngest Lake Bonneville shoreline in Tule Valley. Remnants of it are found in the piedmont zone along the west side of the quadrangle ranging from 4,717 feet (1,438 m) at the south to 4,724 feet (1,440 m) at the north end of the map area. The shoreline's elevation in the quadrangle is lower than Sand Pass (4,744 ft; 1,446 m) due to differential hydroisostatic rebound.

Mapped shorelines show anomalously high map elevations in the northwest corner of the quadrangle. The maximum elevation of 4,638 feet (1,414 m) for the highest transgressive Lake Tule shoreline was measured in that area with a Topcon geodetic total station, using the 4,622-foot (1,409-m) benchmark between Ranges 15 and 16 W. as vertical control. Therefore I believe that the anomalous elevations may reflect an error in the contour lines on the USGS topographic base map.

Post-Bonneville, or regressive, Lake Tule (RL on figure 4) apparently desiccated very rapidly then later rose a couple of times to modest levels. The rapid desiccation is inferred by analogy with the precipitous contemporaneous drop of Lake Bonneville (Currey and Oviatt, 1985) and from a radiocarbon age of 13,790 ± 130 yr B.P. (Beta-26794; ^{13}C adjusted) obtained from a tufa sample collected from a Tule Valley locality southeast of the study area (NE¼SE¼ section 35, T. 17 S., R. 15 W.; A on figure 1) (Sack, 1990). The tufa deposit is believed to reflect a Lake Tule water level of approximately 4,490 feet (1,369 m) (Sack, 1990). At this level, the lake was 254 feet (77 m) below Sand Pass, yet still sizeable, having a maximum depth of about 95 feet (29 m).

Subsequent Holocene-age oscillations of the water level (HLTO on figure 4) are inferred from geochronometric and morphostratigraphic evidence from Tule Valley. A radiocarbon age of 9,140 ± 90 yr B.P. (Beta-29185; ^{13}C adjusted) was obtained from gastropod shells collected at an elevation of 4,426 feet (1,349 m) from a site in the southeastern portion of the Coyote Knolls quadrangle (NE¼SW¼ sec. 22, T. 16 S., R. 15 W.; *on map; figure 5). This gastropod-rich unit is widely exposed around Tule Valley at an elevation of 4,426 feet (1,349 m). The gastropods are fresh-water types (*Lymnaea* and *Helisoma*) that probably lived in a marsh just above the lake level. At that elevation, the lake would have been approximately 31 feet (9 m) deep. It is not known whether this Holocene lake was a stillstand in the regression of Lake Tule, or whether it marked a slight readvance of the Tule Valley water plane from very low levels.

The gastropod-rich stratigraphic unit is exposed in a bluff that is continuous around Tule Valley basin floor (figure 5). Because the bluff may have been created by coastal basin floor erosion, it could mark a rise in water level after a regression from the level associated with the gastropod-rich unit. Neither the extent nor the timing of the hypothesized oscillation is known; its depiction on figure 4 is hypothetical.

The occurrence of even later low-level oscillations of the Tule Valley lake is indicated by morphostratigraphic evidence largely from the Swasey Peak NW quadrangle, which adjoins the Coyote Knolls quadrangle on the east. A large compound spit is located in the northwest part of the Swasey Peak NW quadrangle between the 4,406- and 4,416-foot (1,343- and 1,346-m) contours (Sack, 1994). The upper surface of one segment of the compound spit lies at an elevation of approximately 4,410 feet (1,344 m); this segment is overlain by a smaller spit, whose upper surface is about 6 feet (1.8 m) higher. Both parts of the compound feature are composed primarily of pebbles and sand, including reworked, pebble-sized clasts of Lake Bonneville tufa and lithified Lake Bonneville marl. These components indicate that both parts of the compound spit are of post-Bonneville age. Furthermore, the spit is well preserved despite the fact that its two segments lie only 10 to 20 feet (3 to 6 m) below the bluff that exposes the gastropod unit. If the bluff was created by coastal erosion, the split was probably constructed later. Because in the Bonneville basin transgressive coastal landforms are typically better developed than regressive coastal landforms, the compound spit is interpreted as marking two readvances of the Holocene water level. It is suggested that the lake level fell from the prominent bluff to low levels then readvanced to approximately 4,410 feet (1,344 m), where it constructed the larger of the two compound-spit segments. Some-

Figure 5. *The Holocene bluff at 4,426 feet (1,349 m) and the gastropod-rich unit that it exposes (dark band in bluff). Gastropods from this site (*on map) yielded a radiocarbon age of 9,140 ± 90 yr B.P. (Beta-29185; ^{13}C adjusted). Eolian deposits have accumulated on top of the bluff. The view is to the east-northeast and includes the House Range in the background.*

time later the water level rose an additional 6 feet (1.8 m) and constructed the smaller component of the compound spit. A much smaller spit composed of similar, Holocene coastal gravel lies in the southeast part of the Coyote Knolls quadrangle at an approximate elevation of 4,416 feet (1,346 m).

DESCRIPTION OF MAP UNITS

Paleozoic Stratigraphy

Hose (1963) mapped the Paleozoic bedrock units of this quadrangle and included a brief description of them in his map legend. The following descriptions, by Lehi F. Hintze, summarize additional observations made subsequent to publication of Hose's (1963) work. Names and thicknesses of the bedrock formations are shown on plate 2.

Cambrian

Big Horse Limestone Member of the Orr Formation (Ꞓob): This member forms a small hogback along the southeast edge of the quadrangle where a section 135 feet (41 m) thick was measured in this quadrangle. The lowest 12 feet (4 m) is dark-gray, thick-bedded, oolitic and bioclastic limestone, which forms a low ledge; the next 38 feet (12 m) is covered; from 50 to 100 feet (15-30 m) above the base a medium-gray, thick-bedded, bioclastic limestone forms a resistant cliff that holds up the hogback; the uppermost 35 feet (11 m) is mostly medium-gray limestone with large irregular patches of dark-gray limestone, which suggests hydrothermal alteration. This uppermost unit contains indistinct outlines of large biohermal structures; it forms the dip slope on the west side of the hogback.

In the nearby House Range, the Big Horse Limestone is 715 feet (218 m) thick (Hintze and Palmer, 1976). Exposed beds in this quadrangle probably represent only the uppermost one-fifth of the member as known from complete sections in nearby areas in western Utah (Hintze and Palmer, 1976).

Upper members of the Orr Formation (Ꞓou): This unit is not exposed at the surface in this quadrangle but probably underlies surficial deposits in the area between the hogback formed by the Big Horse Limestone and a smaller hogback, a short distance to the west, composed of the Notch Peak Formation. Where exposed in nearby ranges, the upper part of the Orr Formation consists of interbedded shale and limestone 600 to 700 feet (180-215 m) thick (Hintze, 1988). This interval is generally less resistant than the adjacent map units, and is typically concealed by surficial deposits.

Cambrian-Ordovician

Notch Peak Formation (OꞒn): Three members of the Notch Peak Formation in western Utah were defined by Hintze and others (1988). In ascending order, these are the Hellnmaria, Red Tops, and Lava Dam Members. All members are limestone and dolomite; the Red Tops consists of thin-bedded bioclastic lime grainstone, whereas the other members are more massive, finer textured, and commonly include large hemispherical stromatolites.

In this quadrangle the lower Notch Peak (equivalent to part of the Hellnmaria) consists mostly of medium-gray, thick-bedded limestone that forms light-gray cliffs in the southern half of the eastern Coyote Knoll, as shown on figure 6. Exposed thick-

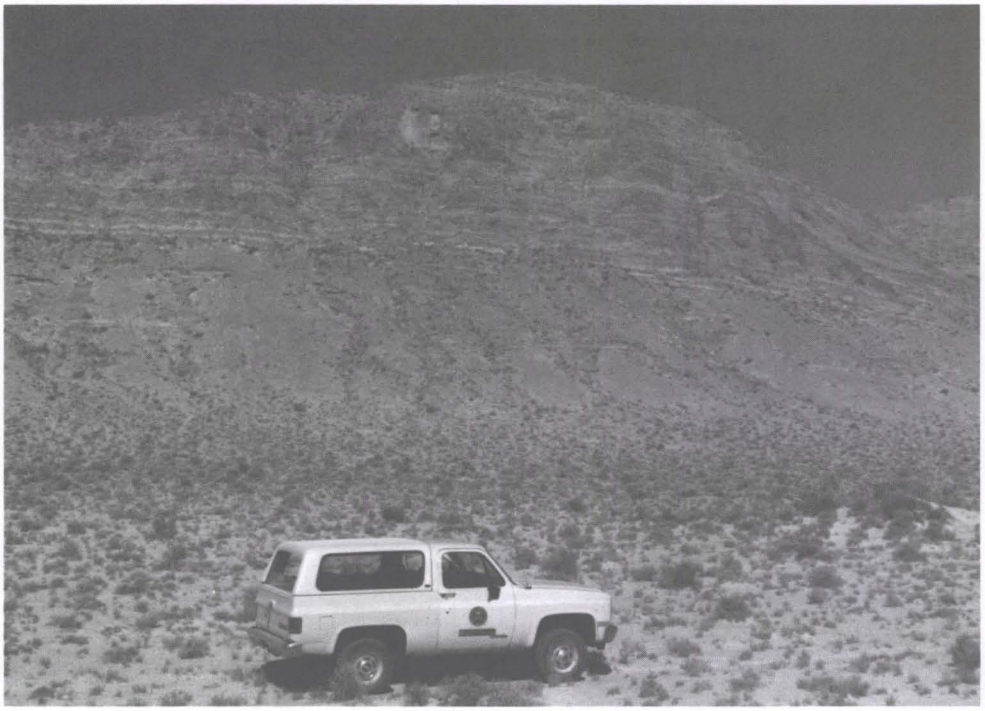

Figure 6. Lower part of the Notch Peak Formation as exposed on the east side of the easternmost Coyote Knoll in section 2, T. 16 S., R. 15 W. Lake Bonneville deposits mantle the lower slopes of the hill.

ness of this unit is about 400 feet (120 m). The upper Notch Peak (Red Tops and Lava Dam equivalents) consists mostly of dolomite, with some limestone interbeds. The upper Notch Peak also forms ledges and cliffs which are mostly dark brownish gray with broad bands that weather moderate orange-pink. As shown on figure 7, 630 feet (192 m) of upper Notch Peak beds were measured in the central part of section 35, T. 15 S., R. 15 W., but the top of the formation is not exposed in the Coyote Knolls. Because neither the top nor the bottom of the Notch Peak Formation is exposed in the Coyote Knolls quadrangle, its total thickness there is not known. Hintze and others (1988) listed the trilobite and conodont fossils found in the Notch Peak Formation and, for the House Range area, showed a thickness of 380 feet (115 m) of Lava Dam Member, 110 feet (33 m) of Red Tops Member, and 1,200 feet (365 m) of Hellnmaria Member. James F. Miller of Southwest Missouri State University (personal communication, 1992) reported that he measured 444 feet (135 m) of Lava Dam Member, 117 feet (36 m) of Red Tops Member, and 1,100 feet (335 m) of Hellnmaria Member in the Chalk Knolls, which lie 10 miles (16 km) south of the southernmost exposures of Notch Peak Formation in the Coyote Knolls quadrangle.

Ordovician

Pogonip Group (Op): The Pogonip Group in western Utah consists of thin-bedded, silty, bioclastic, gray limestone interbedded with light-olive-gray shale (Hintze, 1951, 1973). The Pogonip Group is not exposed at the surface in this quadrangle probably because it forms the least resistant portion of the lower Paleozoic stratigraphic section in western Utah. It likely underlies much of the valley area between the eastern and central Coyote Knolls. Where it is exposed in the southern House and Confusion Ranges, about 30 miles (50 km) south of this quadrangle, the Pogonip Group is about 3,400 feet (1,000 m) thick (Hintze, 1988). In the Fish Springs Range, 15 miles (26 km) north of the Coyote Knolls, it is about 1,900 feet (580 m) thick (Hintze, 1988). Its subsurface thickness in this quadrangle is estimated to be about 2,800 feet (850 m).

Eureka Quartzite (Oe): The upper part of the Eureka Quartzite is exposed in a small area on the southeast side of the central Coyote Knoll, where it is a white to yellowish-gray, vitreous quartzite that forms massive outcrops showing planar bedding partings spaced 1 to 3 feet (0.3 to 1 m) apart. The contact with the overlying Ely Springs Dolomite is exposed and reveals a 1-foot (0.3-m) dolomitic sandstone transitional bed at the base of the Ely Springs. Exposed thickness of the Eureka Quartzite in the Coyote Knolls quadrangle is 120 feet (37 m). Its thickness in nearby mountains of western Utah ranges from 300 to 500 feet (90 to 150 m) (Hintze, 1988).

Ely Springs Dolomite (Oes): Hose (1963) used the northern Utah term "Fish Haven" for the Upper Ordovician dolomite in this quadrangle. However, Budge and Sheehan (1980), as a result of their regional appraisal of these strata, recommended using the name "Ely Springs" from the southern Great Basin for these rocks. At Spor Mountain in the Thomas Range, about 20 miles (32 km) northeast of the Coyote Knolls, they recognized two members in the Ely Springs Dolomite: an unnamed lower member consisting of resistant dolomite that forms dark-gray cliffs, and an upper member, the Floride Member, that is light gray and less resistant, generally forming a scree-covered slope.

The same two members are present in the Coyote Knolls quadrangle, and a complete section was measured for this study at the most southeasterly exposure of the central Coyote Knoll.

Figure 7. *Upper part of the Notch Peak Formation as exposed on the east side of the easternmost Coyote Knoll. The Notch Peak beds dip away from the observer. The dark ledge that cuts across the Paleozoic rocks just below the top of the ridge is a Lake Bonneville tufa deposit at the Provo shoreline.*

There the lower member consists mostly of dark-brownish-gray, fine-grained dolomite that contains as much as 2 percent black chert as small bedded nodules, and interbeds of bluish-gray noncherty dolomite. The lower member is generally medium- to thick-bedded and forms ledges and cliffs. It is 530 feet (160 m) thick. The Floride Member is medium-gray, fine-grained, thin- to medium-bedded dolomite that generally forms a scree-covered slope. It is 90 feet (27 m) thick.

Silurian

Laketown Dolomite (Sl): The Laketown Dolomite is a resistant formation that forms the crest of the central Coyote Knoll. Its least faulted exposure is on the east face of hill 5065 in section 32, T. 15 S., R. 15 W., as shown on figure 8. There it consists of a dark-brownish-gray cliff-forming sequence that forms the lower 360 feet (110 m) of the formation, and a slightly less resistant sequence that is made up of two broad bands of pinkish-gray dolomite which are separated by bands of dark-brownish-gray dolomite. These broad bands of dolomite make up the upper 560 feet (170 m) of the formation and are conspicuous both in the field and on aerial photographs.

The lower 120 feet (37 m) of Laketown Dolomite is dark-brownish-gray, thin- to medium-bedded, medium-crystalline dolomite which contains thin light-gray markings that may be poorly preserved replacements of corals, algae, and thin-shelled brachiopods. The next 240 feet (73 m) is mostly dark-brownish gray with a few beds of medium-brownish-gray, laminated dolomite. It is thick bedded and coarsely to medium crystalline, and contains abundant poorly preserved traces of algae, stromatoporoids, and brachiopods in its upper half. It contains less than 1 percent chert and forms the steepest cliff along the east face of the central Coyote Knoll.

The upper 560 feet (170 m) of Laketown Dolomite consists of, in ascending order, 165 feet (50 m) of pinkish-gray, coarsely to medium-crystalline, thick-bedded dolomite, which contains no chert or fossil traces; 75 feet (23 m) of dark-brownish-gray, mottled, thick-bedded dolomite, which has as much as 10 percent bedded chert nodules in its upper third; 200 feet (61 m) of pinkish-gray, massive to thick-bedded, mottled, vuggy, coarsely to medium-crystalline dolomite with some bedded chert; 120 feet (37 m) of dark-brownish-gray, medium-crystalline, massive to thick-bedded dolomite, which contains 10 to 20 percent black chert as bedded nodules and abundant poorly preserved fossil traces of spherical stromatoporoids, colonial corals of the halysitid and favositid type, and thin-shelled brachiopods. This upper cherty and fossiliferous sequence is the most distinctive part of the Laketown Dolomite in the Coyote Knolls. Unfortunately, its top is cut off by a fault in the measured section. Elsewhere the contact with the overlying Sevy Dolomite is taken at the sharp change in color from the dark beds at the top of the Laketown to the light-gray beds that make up the base of the Sevy.

Names of members of the Laketown Dolomite that were

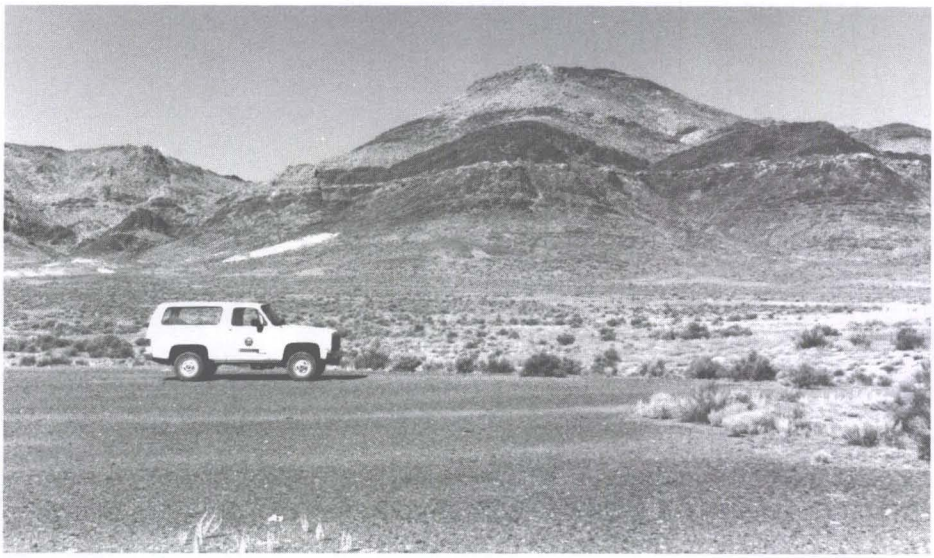

Figure 8. Laketown Dolomite exposed on the east side of hill 5065 in the central Coyote Knoll. The Upper Ordovician Ely Springs Dolomite is present at the base of the hill, partly covered by Lake Bonneville deposits. The horizontal ledge midway up the hillside is a tufa-cemented deposit along the Provo shoreline of Lake Bonneville. The two broad bands of pinkish-gray dolomite in the upper part of the Laketown can be seen near the top of the hill, above the Provo shoreline.

proposed by Budge and Sheehan (1980) and Staatz and Osterwald (1959) have not been used in the above descriptions because there are differences in thicknesses and lithologic detail between the Silurian rocks in the Coyote Knolls and those in the Thomas and southern Confusion Ranges.

Devonian

Sevy Dolomite (Dsy): The Sevy Dolomite is mostly medium-gray, finely crystalline, medium-bedded dolomite that weathers light gray to yellowish gray. Some beds are laminated. In the upper part of the formation, frosted quartz sand grains float in some dolomite beds, and some thin, yellowish-brown sandstone beds are present locally. Map measurements show that the Sevy Dolomite on the west side of the central Coyote Knoll is about 700 feet (210 m) thick. It is likely that some of the Sevy there has been cut out by faults but, because of the lack of marker beds within the uniform lithology of the Sevy, the faults are hard to recognize. Thickness of the Sevy in nearby ranges averages about 1,200 feet (360 m) (Hintze, 1988).

Simonson Dolomite (Ds): The Simonson is predominantly medium-dark-gray and medium-light-gray, fine- to medium-grained dolomite that weathers dark gray to dark yellowish brown. It is thin to thick bedded and generally forms low ledges. About 150 feet (45 m) of the Simonson is exposed in the central Coyote Knoll. Its complete thickness in nearby ranges is between 600 and 1,000 feet (180 and 300 m) (Hintze, 1988).

Guilmette Formation (Dg): The upper part of the Guilmette is the only portion of the formation that is exposed in the quadrangle, and it forms the backbone of the hogback along the west edge of the map. There, the following section was measured in SW¼, section 35, T. 15 S., R. 16 W.:

Unit	Feet	Meters
7. Limestone, silty, banded medium-gray and yellowish-gray, thin- to medium-bedded, forms low ledges, less resistant than unit 6. Transitional into Pilot Shale.	35	11
6. Limestone, dark gray, massive, bedding partings spaced 0.5 to 3 feet (1.27 cm - 1m) apart. Contains indistinct spherical stromatoporoid outlines, forms cliffs.	75	23
5. Limestone, medium gray, thick bedded to massive. In upper 20 feet (6 m) some beds are bioclastic grainstones that fill in a spherical stromatoporoidal framework.	92	28
4. Dolomite, dark brownish-gray, thick bedded; includes white calcite replacement along uneven bedding surfaces.	20	6
3. Dolomite, dark brownish-gray, medium to thick bedded, some beds mottled; 12 feet (4 m) below top this unit contains a 2-foot (0.6-m) thick, ribbon stromatoporoid bed, above which spherical stromatoporoids are common.	40	12
2. Sandstone, light yellowish-gray, medium grained, thin to medium bedded, many cross-bedded layers 1-2 feet (0.3-0.6 m) thick, forms low ledges.	33	10
1. Limestone, medium dark-gray, some beds mottled with light gray, thick bedded, medium grained, some beds include small algal structures and spherical stromatoporoids. Unit forms low ledges on east side of hogback.	65	20
Total exposed thickness of Guilmette Formation	360	110

Contact with the overlying Pilot Shale is well exposed, conformable, and transitional. Stratigraphy summary sections in Hintze (1988) show that the entire Guilmette Formation in this area is 2,000 to 2,650 feet (600-800 m) thick.

Mississippian-Devonian

Pilot Shale (MDp): The lower half of the Pilot Shale is unusually well exposed in stream channels along the west edge of the quadrangle where 410 feet (125 m) of strata have been measured by Charles A. Sandberg (personal communication, 1992). Sandberg and others (1988, 1989) have summarized some of their conodont zonation and lithologic interpretations of this unusual exposure of the Pilot Shale. At this locality the Pilot includes much siltstone and fine-grained sandstone. Sandberg and others (1988) presented an illustration of large flow rolls with thin turbidites that they said probably represent a lower-slope marine environment of deposition.

The exposed section is in two parts. The lower 235 feet (73 m) are separated from the upper 110 feet (34 m) by a 65-foot (20-m) covered interval. The lower beds are interbedded thin-bedded, medium-dark-gray, silty, calcareous shale that weathers to banded yellowish gray and medium gray. The beds are generally not resistant, but are well exposed along banks of the dry stream channels, as shown on figure 2. Three 2-foot (0.6-m), ledge-forming beds of silty limestone are spaced several feet apart 80 to 170 feet (24-52 m) above the base of the section.

The upper exposed 110 feet (34 m) consists of thin-bedded, shaly siltstone with four evenly spaced 1-foot (0.3-m) beds of silty limestone. The top of the section is overlain unconformably by Quaternary Lake Bonneville deposits.

Mississippian

Joana Limestone (Mj): A portion of the Joana Limestone forms a low hogback that rises about 10 feet (3 m) above Quaternary deposits. Total exposed thickness of the Joana is 85 feet (26 m). The lower 23 feet (7 m) is light-medium-gray, coarsely crystalline, bioclastic limestone that forms a massive ledge and contains scattered syringoporoid corals. The upper 62 feet (19 m) is medium-dark-gray limestone with interbeds of medium-gray, coarsely to medium-crystalline, thin- to thick-bedded limestone. The upper part forms low ledges and contains bioclastic beds which include crinoid columnals and a few brachiopods and gastropods. Total thickness of the Joana Limestone in this part of western Utah generally ranges between 50 and 200 feet (15 and 60 m).

Chainman Shale (Mc): The Chainman Shale is primarily dark-gray shale with interbeds of limestone and siltstone. It only occurs in the subsurface in this quadrangle and is about 1,500 feet (460 m) thick.

Permian-Pennsylvanian-Mississippian

Ely Limestone (PIPMe): The Ely Limestone is mostly cherty limestone that is commonly bioclastic and fossiliferous. It is only in the subsurface in this quadrangle and is about 2,000 feet (600 m) thick.

Quaternary Map Units

Alluvial Deposits

Undifferentiated alluvium and colluvium (Qac): Poorly sorted, fine- to coarse-grained sediments that consist of fluvially reworked colluvium or alluvium with a significant colluvial component are mapped as undifferentiated alluvium and colluvium. This map unit is found at and above the piedmont junction of the Coyote Knolls, which separates exposures of bedrock upslope from topographically lower Quaternary deposits. The undifferentiated alluvium and colluvium unit has an estimated maximum thickness of 12 feet (3.7 m). Deposition of Qac began just after the Bonneville flood and continues to the present.

Alluvial-fan deposits (Qaf): Alluvial-fan deposits are composed of poorly sorted, coarse- to fine-grained alluvium and debris-flow sediments deposited on piedmont slopes since regression of Lake Bonneville from the Bonneville shoreline. These sediments are widely scattered across the western and northern parts of the quadrangle. They are generally finer grained toward the distal portion of the piedmont, where they may locally be overlain by eolian sediments. Thickness of the alluvial-fan deposits varies from a few inches to an estimated 20 feet (6 m). Qaf covers 14.5 percent of the quadrangle, and is therefore the second most extensive map unit (table 1). It is late Pleistocene and Holocene in age.

Eolian Deposits

Eolian dunes (Qed): Eolian sediments deposited in well-formed dunes are mapped as Qed. The dune sediments range in texture from well-sorted sand to poorly sorted mixtures of sand, silt, and clay. Material composition ranges from primarily gypsum, through mixed gypsum and nongypsum constituents, to primarily nongypsum minerals. Observed dune forms include barchans, dome dunes, climbing and falling dunes, blowouts, shrub-coppice dunes, and lunettes. The lunettes consist of mixed sand, silt, and clay, and form dune ridges on top of valley-floor bluffs. Varying stages of dune activity are present in the quadrangle, from stabilized to currently active. All, however, indicate southwesterly effective winds. Eolian dunes occupy 4.1 percent of the map area and are most common in the southeast part of the quadrangle. Their location below an elevation of 4,500 feet (1,372 m) reflects material sources in the lower piedmont and on the valley floor. Eolian dune sediments are 1.5 to 25 feet (0.5 to 7.6 m) thick. Some of the dunes may be as old as very late Pleistocene, but most are of Holocene age.

Gypsiferous eolian sheet sand (Qeg): A large region in the east-central part of the quadrangle consists primarily of sand-sized gypsum deposited as a sheet of eolian sand rather than in well-formed dunes, although gypsum dunes are found in this unit locally. Most of the eolian gypsum is located on the northeast margin of the basin floor downwind from both eolian-reworked lacustrine fines (Qel) and lacustrine marl (Qlm). Sand-sized gypsum grains probably began precipitating from the sulfate-rich desiccating water body in very late Pleistocene time. Gypsum grains continue to be blown off the basin floor and trans-

ported to the northeast, where they cover alluvial-fan deposits (Qaf), undifferentiated lacustrine and alluvial deposits (Qla), lacustrine fine-grained deposits (Qlf), lacustrine marl (Qlm), and Paleozoic bedrock. Eolian gypsum deposits range from a few inches to more than 25 feet (7.6 m) thick. They cover 4.2 percent of the map area and are very late Pleistocene and Holocene in age.

Eolian-reworked lacustrine fines (Qel): Eolian-reworked lacustrine fines are composed of dominantly marly, but locally gypsiferous, lacustrine fines blown off the basin floor and redeposited on the basin floor a short distance downwind in small shrub-coppice dunes. In this quadrangle, eolian-reworked lacustrine fines are only found overlying lacustrine marl, that is, as Qel/Qlm. Qel/Qlm is found adjacent to the barren marl flats in the southeast corner of the quadrangle, and especially to the east and northeast of the marl flats. The eolian-reworked lacustrine fines are transported by the wind as salt-bound marl pellets. This unit is typically less than 3 feet (0.9 m) thick and accounts for 4 percent of the map area. This unit is of Holocene age.

Lacustrine Deposits

Undifferentiated lacustrine and alluvial deposits (Qla): Sediments mapped as Qla consist of lake-reworked alluvial-fan deposits, fan-reworked lake deposits, and intertonguing alluvial-fan and lake sediments that are not resolvable at the map scale. Qla is found exclusively in the piedmont zone. It is the most extensive map unit in the quadrangle, occupying 42.7 percent of the map area (table 1). Undifferentiated lacustrine and alluvial deposits are comprised of poorly sorted, coarse- to fine-grained sediments, with grain size generally decreasing downslope. In the middle piedmont, Qla is mainly prelake alluvial-fan deposits that were only moderately reworked by lacustrine processes, so that the lacustrine gravel layer is thin. In these areas the unit is expressed geomorphically as prelake alluvial fans etched by Lake Tule and Lake Bonneville shorelines. Smaller areas of Qla consist of lacustrine deposits that have been slightly reworked by postlake alluvial-fan processes. Undifferentiated lacustrine and alluvial deposits are generally less than 7 feet (2 m) thick. Qla is late Pleistocene and Holocene in age.

Fine-grained lacustrine deposits (Qlf): Fine-grained lacustrine deposits are typically poorly sorted mixtures of sand, silt, clay, and marl (figure 9). Qlf locally contains gypsum, displays efflorescing salts, or is reworked by fluvial or eolian processes. Most exposures of fine-grained lacustrine deposits are found in the transition zone between the lower piedmont and the basin floor. In many places the margin between Qlf and the basin floor is marked by the Holocene bluff at an approximate elevation of 4,426 feet (1,349 m). Fine-grained lacustrine deposits are a few inches to 20 feet (6 m) thick, and cover 14.5 percent of the map area. They are of late Pleistocene and Holocene age.

Young lacustrine gravel (Qlg_1): Young lacustrine gravel is a coastal deposit of a low-level post-Bonneville Tule Valley water body. It is a poorly sorted mixture of pebbles and sand in a marly matrix. Its post-Bonneville age is determined from its low elevation (about 4,416 ft; 1,346 m) and from the fact that many of the constituent pebbles are broken tufa clasts and lithified pieces of Lake Bonneville white marl. Young lacustrine gravel

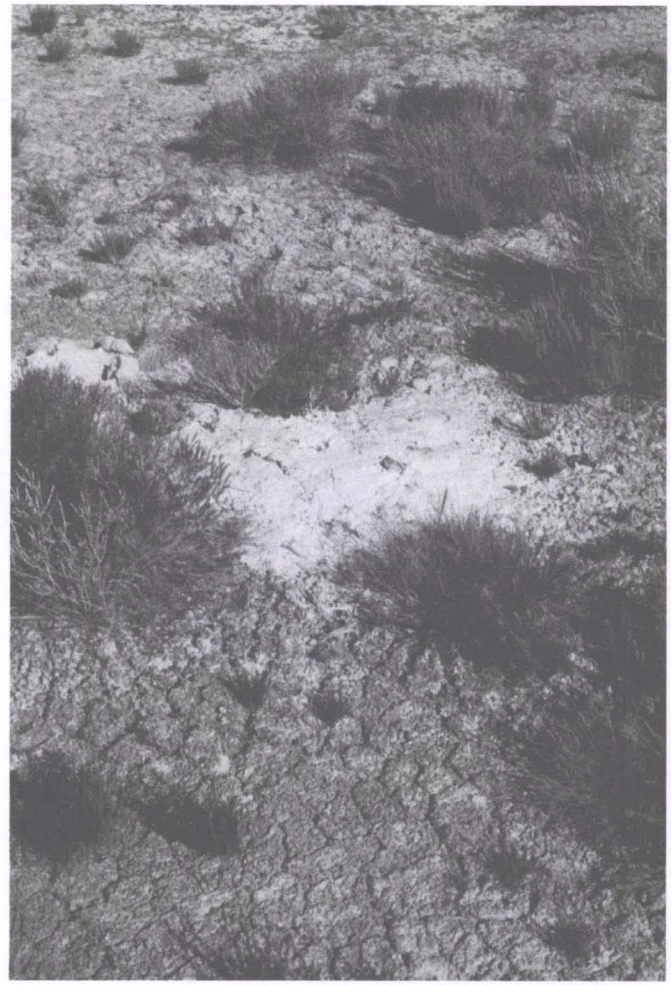

Figure 9. Typical field appearance of lacustrine fine-grained deposits (Qlf) along the eastern edge of the quadrangle.

crops out in only one location, in a spit in the southeastern part of the Coyote Knolls quadrangle, but similar deposits are exposed at the same elevation in the adjacent Swasey Peak NW quadrangle (Sack, 1994). In addition to cropping out at a lower elevation, young lacustrine gravel is finer grained than the intermediate and old lacustrine gravel units (Qlg_2 and Qlg_3). Maximum thickness of Qlg_1 is 5 feet (1.5 m). Young lacustrine gravel was deposited during the Holocene Epoch.

Intermediate lacustrine gravel (Qlg_2): Gravel deposited by coastal waves and currents of Lake Bonneville is mapped as Qlg_2 (figure 10). Intermediate lacustrine gravel is typically moderately well sorted, subrounded to rounded, pebbles and cobbles. Intermediate lacustrine gravel was deposited in beaches, barriers, and tombolos between the elevations of 4,717 and 5,065 feet (1,438 and 1,544 m) near the western margin of the quadrangle. Qlg_2 is the second most extensive lacustrine gravel unit in the study area (table 1), and has a maximum thickness of about 50 feet (15 m). Intermediate lacustrine gravel was deposited in the interval between about 19,500 years ago to shortly after 14,000 years ago (figure 4), therefore is of late Pleistocene age.

Figure 10. *Two Provo-level barriers and their lagoons. The barriers (Qlg_2) are the long linear features extending from middle left to upper right of the photograph; the lagoon deposits (Qll) are the light-colored sediments behind each barrier. View is to the southwest from the southern end of the westernmost Coyote Knoll.*

Old lacustrine gravel (Qlg_3): Approximately 3.2 percent of the Coyote Knolls quadrangle consists of lacustrine sandy gravel deposited by waves and currents of transgressive Lake Tule (TLT on figure 4; figure 11). Old lacustrine gravel was deposited in barriers, spits, and beaches, which are locally overlain by unmappable amounts of lacustrine fine-grained deposits (Qlf) and lacustrine marl (Qlm). Old lacustrine gravel is found below an elevation of 4,638 feet (1,414 m) in the central part of the study area. Maximum thickness is about 20 feet (6 m). Qlg_3 is late Pleistocene in age; it was deposited before about 19,500 years ago (figure 4).

Lagoon deposits (Qll): Lagoon deposits are fine-grained sediments that were deposited landward of coastal barriers. They are found only behind the Provo-level bayhead barriers at the south end of the western Coyote Knoll (figure 10). Lagoon sediments include lake-deposited sand, clay, and especially silt, and fine-grained sediments that were deposited in the lagoon by slope-wash and eolian processes. Thickness of the lagoon deposits was not observed. This unit dates from the late Pleistocene.

Lacustrine marl (Qlm): Deposits mapped as lacustrine marl are composed of Lake Bonneville pristine white marl (Gilbert, 1890) and sandy, reworked marl. The latter includes white marl reworked by Lake Bonneville and by post-Bonneville Tule Valley lakes and playas, as well as marl that was washed basinward by postlacustrine fluvial processes. The marl ranges from calcareous silt to calcareous sandy silt. Ostracodes are abundant and gastropods are occasionally found in the marl, which is locally gypsiferous and chloride rich. Marl is mapped primarily in the southeast part of the quadrangle on the Tule Valley basin floor, where it is found either exposed at the surface or covered by eolian (Qel/Qlm) or playa (Qpm/Qlm) sediments. Although these basin-floor marl flats could be called playas, distinguishable playa deposits are not common except in those areas mapped as playa mud overlying lacustrine marl (Qpm/Qlm). Pristine Lake Bonneville marl is generally about 3 feet (0.9 m) thick, but may be eroded to a very thin layer. On the marl flats, the unit is at least 12 feet (3.7 m) thick (Tinl and Pierce, 1984), and is probably more than 20 feet (6 m) thick. Qlm (unstacked) accounts for 2.6 percent of the map area. Lacustrine marl is of late Pleistocene and Holocene age.

Lacustrine sand (Qls): Lacustrine sand is composed of pebbly, marly sand which in many places overlies lacustrine marl. Most lacustrine sand in the quadrangle lies 10 to 125 feet (3 to 38 m) below the Provo shoreline on the east side of the western Coyote Knoll. The sand was deposited when Lake Bonneville was at and falling from the Provo shoreline (figure 4). Ostracodes, gastropods, carbonate-coated reworked gastropods, and ooids are commonly found within the lacustrine sand. Maximum thickness of this map unit is about 15 feet (4.6 m). Lacustrine sand is very late Pleistocene in age.

Lacustrine tufa (Qlt): Lacustrine tufa is comprised of calcium carbonate precipitated in nearshore environments during and after the Provo phase of Lake Bonneville (figure 4). Areas mapped as Qlt contain tufa in its original position or display significant deposits of broken tufa clasts, reworked by fluvial or lacustrine processes. Lacustrine tufa is a dull orange color (5YR 6/3) and occurs principally as a shelf lying 20 to 60 feet (6 to 18 m) below erosional segments of the Provo shoreline. In many map areas, tufa overlies lacustrine sand (Qls) and marl (Qlm). The thickness of this map unit varies from a few inches to about 2 feet (0.6 m). Tufa covers 1.3 percent of the map area and is of late Pleistocene and Holocene age.

Playa Deposits

Playa mud (Qpm): Playa mud contains clay, silt, and marl, with small amounts of sand. These sediments are chloride rich and occur as thin deposits over basin-floor marl in the southeastern part of the quadrangle. Areas mapped as playa mud are occasionally flooded. Playa mud is a Holocene-age map unit.

Figure 11. A transgressive Lake Tule tombolo (Qlg_3). Photo station is just across the east-central border of the map in the adjoining Swasey Peak NW quadrangle. View is to the west, extending into the Coyote Knolls quadrangle, toward the southern end of the easternmost Coyote Knoll.

Spring Deposits

Marsh deposits (Qsm): Small areas of marsh deposits are associated with modern springs and related high-water-table zones on the basin floor. The marsh deposits are generally composed of organic and marly fines, which are locally saline. Thickness of this unit was not observed. Marsh deposits are probably late Holocene in age.

LATE QUATERNARY GEOLOGIC HISTORY

The late Quaternary geologic history of the Coyote Knolls quadrangle is interpreted from the nature and distribution of its deposits and shorelines and from knowledge about the late Quaternary histories of Tule Valley (Sack, 1990) and the Bonneville basin (Scott and others, 1983; Currey and Oviatt, 1985; McCoy, 1987; Burr and Currey, 1988; Oviatt, 1989; Currey, 1990). Assuming that the topography of Tule Valley has been approximately constant over the Quaternary, the study area would likely have been at least partially inundated during the lake cycles which are known to have preceded the Bonneville lacustral cycle: the pre-Pokes Point (>600,000 years ago), Pokes Point (about 200,000 years ago), Little Valley (about 140,000 years ago), and Cutler Dam (about 50,000 years ago) lake cycles. Apparently only the Little Valley lake rose high enough in the Bonneville basin to integrate Tule Valley like Lake Bonneville did (McCoy, 1987; Oviatt and others, 1987; Sack, 1990). Tule Valley likely contained isolated lakes early and late in the Little Valley lake cycle and during the other known pre-Bonneville lake cycles. However, direct physical evidence for only the Bonneville lake cycle has been observed in the study area.

Before the start of the Bonneville lacustral cycle, the study area, along with the rest of the Bonneville basin, experienced a long period of aridity (Gilbert, 1890). This is evident from the large size of pre-Bonneville alluvial fans, which are only superficially reworked into Lake Bonneville coastal landforms (Gilbert, 1890). Inferring from the present arid geomorphology of the Coyote Knolls quadrangle, this long pre-Bonneville epoch of aridity fostered development of alluvial fans on the piedmont, dunes and eolian sheet sand on the lower piedmont, and playas, springs, dunes, and eolian sheet sand on the valley floor.

Early in the Bonneville lacustral cycle, as Lake Tule rose in its transgressive phase (TLT on figure 4), it reworked the pre-Bonneville subaerial deposits to at least some extent. Sand, silt, and clay on the valley floor and from the lowest part of the piedmont were entrained and transported by coastal waves and currents. They were probably deposited lakeward of their initial position. With the continued transgression of Lake Tule, coastal waves and currents eventually reached coarse-grained alluvial-fan sediments somewhat higher on the piedmont. Coastal reworking of these deposits created gravel beaches, barriers, and tombolos of transgressive Lake Tule (Qlg_3), and at least superficially reworked subaerial deposits on the rest of the quadrangle's lower piedmont (Qla).

Lake Bonneville spilled into Tule Valley about 19,500 years ago (Sack, 1990), and the water level in Tule Valley rapidly rose to the level of the main body of Lake Bonneville (I on figure 4). Deposition of lacustrine marl (Qlm) began in the quadrangle soon after this water-level equilibration. From the beginning of the Lake Bonneville transgressive phase in Tule Valley (TLB on figure 4) until the lake reached the highest elevation in the quadrangle 5,065 feet (1,544 m), Lake Bonneville coastal waves and currents reworked piedmont alluvium and colluvium. Gravel barriers, beaches, and tombolos were constructed (Qlg_2), especially in the western part of the quadrangle. In other locations, transgressive Lake Bonneville coastal processes only superficially reworked the prelake piedmont sediments, leaving undifferentiated lacustrine and alluvial deposits (Qla). The entire map area was submerged from about 16,500 years ago, when

Lake Bonneville transgressed to the highest point in the quadrangle, until the initial phase of the Bonneville flood, which occurred about 14,500 years ago (Burr and Currey, 1988) (late TLB through early BF on figure 4). During the submerged interval, lacustrine marl (Qlm) was the dominant sediment accumulating in the quadrangle. With restabilization of the water level after the Bonneville flood, lagoons (Qll) and gravel barriers, beaches, and tombolos (Qlg_2) were constructed at the Provo shoreline (PS on figure 4). At this time alluvial-fan sedimentation (Qaf) began on the piedmont above the Provo shoreline. Deposition of lacustrine tufa (Qlt) and sand (Qls) in nearshore environments occurred during and after Provo shoreline time (PS through RLT on figure 4).

As depicted on figure 4, Lake Bonneville dropped rapidly from the Provo shoreline about 14,200 years ago (Burr and Currey, 1988). As the lake level fell, alluvial-fan deposition (Qaf) spread to the newly exposed piedmont sectors. Tule Valley was soon reisolated from Lake Bonneville (RI on figure 4), and regressive Lake Tule continued the rapid fall to very low levels (RLT on figure 4). Since very late Pleistocene time, sulfates have precipitated out of mineral-rich desiccating water bodies on the basin floor. Subaerially exposed lacustrine fines, sand-sized gypsum grains, and salt-bound pellets of dried marl have been entrained by the wind and redeposited to the northeast of the basin floor in dunes (Qed), sand sheets (Qeg), and shrub coppices (Qel). The water level in the basin has remained at low levels; only small map areas of playa (Qpm) and spring deposits (Qsm) have accumulated in the quadrangle during the Holocene.

STRUCTURAL GEOLOGY

Hose (1963, 1977) emphasized the bedrock structure and stratigraphy of this quadrangle but made no Quaternary subdivisions. Mapping and structural interpretations of bedrock areas are based in large part on his work.

Four linear north-south bedrock ridges are present across the quadrangle. For purposes of discussion, the two closely spaced ridges near the west margin of the quadrangle are referred to as west Coyote Knoll. The bedrock ridge near the center of the map is termed central Coyote Knoll, and the bedrock ridge near the east margin of the quadrangle is called east Coyote Knoll (cross section AA′).

Dips and strikes on west Coyote Knoll indicate that the easternmost part of these ridges is the axis of a north-trending anticline with steep dips on both sides. Strata in the central Coyote Knoll and east Coyote Knoll dip to the west, thus forming a large syncline underlying most of the quadrangle. The strata of central Coyote Knoll and east Coyote Knoll are extensively faulted. Most of the faults are normal and have a down-to-the-east displacement.

One or more compressive events created the anticline and syncline sometime between Late Jurassic and Oligocene time (Hose, 1977). A later interval of extensional tectonism formed the approximately north-south-trending, tilted fault-block structure that dominates the topography of the region today. That interval of basin-and-range tectonics may have started as early as the Oligocene and continues through the present (Nolan, 1943). It caused the faulting in the central and east Coyote Knoll, the relative uplift and eastward tilting of the House Range, and the relative downdropping of the Tule Valley basin which also dips to the east (Gilbert *in* Hunt, 1982; Allmendinger and others, 1983; Hunt, 1987). East of the map area, the House Range piedmont is crossed by scarps of the high-angle, normal House Range fault, along which the House Range was elevated relative to Tule Valley. The fault has an estimated 9,000 feet (2,700 m) of displacement (Powell, 1958), and soles into a Mesozoic thrust which has reactivated as a normal fault (Allmendinger and others, 1983)..

No known recent shallow seismic work or drilling that would clarify subsurface relationships have been conducted in this quadrangle. Allmendinger and others (1983) presented an interpretation of deep crustal structure along a traverse a few miles south of the Coyote Knolls, but their deep seismic survey was not designed to resolve the structures within the valley fill of Tule Valley. Hose's (1963, 1977) structural interpretation, therefore, has been followed on cross section AA′ (plate 2). Thickness of some of the Paleozoic units on this cross section have been modified slightly from that shown by Hose (1963) in accordance with more recent estimates of regional stratigraphic thickness variations (Hintze, 1988).

Paleozoic rocks are believed to shallowly underlie most or all of the quadrangle. The schematic cross section on plate 2 is intended to show this as well as the relationships among the Quaternary deposits.

ECONOMIC GEOLOGY

Gravel constitutes the most valuable economic resource in the Coyote Knolls quadrangle. Intermediate and old lacustrine gravel (Qlg_2 and Qlg_3) and undifferentiated lacustrine and alluvial deposits (Qla) have the greatest potential gravel resources. Intermediate lacustrine gravel is the best sorted and thickest of the three units, but covers the smallest map area. No pits have yet been excavated. Old lacustrine gravel is generally less well sorted than intermediate lacustrine gravel, but covers over twice as much area (table 1). Although this map unit has not been exploited for gravel in the Coyote Knolls quadrangle, a pit has been dug in old lacustrine gravel in the Swasey Peak NW quadrangle just beyond the east-central margin of the study area (Sack, 1994). Two gravel pits have been dug in the Coyote Knolls quadrangle in undifferentiated lacustrine and alluvial deposits (table 3). Small amounts of gravel have been removed for local road surfacing. Of the three units, Qla is the thinnest and least well sorted, but covers 42.7 percent of the quadrangle. Although significant quantities of well-sorted gravel exist in the

Table 3.
Location of gravel and gypsum pits.

Material	Location
Gravel	SW¼NW¼NE¼ section 8, T. 16 S., R. 15 W.
Gravel	SE¼SE¼SW¼ section 11, T. 16 S., R. 15 W.
Gypsum	SW¼SE¼SW¼ section 10, T. 16 S., R. 15 W.

map area, the long distance to present major construction sites probably precludes economically feasible, large-scale recovery, at least for some time.

Gypsum sand has been removed from a dune area in the eastern part of the quadrangle (table 3). Besides agricultural uses, gypsum is a component of cement, plaster, and sheetrock (Reeves, 1978). Because the nondunal gypsum sand (Qeg) typically overlies and is therefore partially mixed with other units, the best source of extractable gypsum in the map area is sand dunes.

Lacustrine marl (Qlm) may also be considered an economic resource. Its high calcium carbonate content may make it useful as agricultural lime. Tinl and Pierce (1984) noted that marl from a site in Tule Valley south of the quadrangle was significantly diatomaceous.

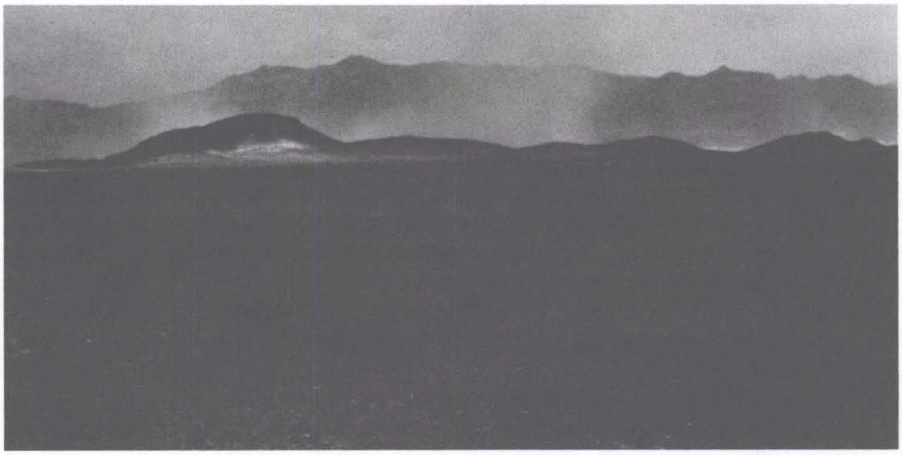

Figure 12. Blowing dust at the southern end of the easternmost Coyote Knoll. The view is to the east and includes the House Range in the background.

GEOLOGIC HAZARDS

Geologic hazards within the study area include flash floods, earthquakes, and blowing sand and dust. Because the Coyote Knolls quadrangle is located at least 3 miles (5 km) east and in the lee of the Confusion Range, flash-flood hazards would likely arise only from intense thunderstorms developing directly over the map area. Such thunderstorms are occasional summer events.

Although no piedmont fault scarps have been found in the Coyote Knolls quadrangle, the size and extent of piedmont fault scarps along the west side of the nearby House Range (figure 1) indicate the area's seismic hazard (Bucknam and Anderson, 1979; Piekarski, 1980; Sack, 1990, 1994). Bucknam and others (1980) estimate that these House Range scarps resulted from earthquakes in the Richter magnitude range of 7.0 to 7.5. Age of these scarps can be estimated from cross-cutting relationships with Lake Bonneville shorelines and from their morphology (for example, see Wallace, 1977). These data suggest that the House Range piedmont fault scarps may be about 12,000 years old (Sack, 1990). Hazards within the Coyote Knolls quadrangle associated with earthquakes along the House Range include ground shaking, ground cracking, and rockfall near the knolls. If a large-magnitude earthquake occurs when soils are saturated, ground shaking may trigger liquefaction on the valley floor.

Blowing dust occurs in the quadrangle during periods of moderate winds (figure 12). Under high wind velocities sand is also saltated by the wind. The main hazards associated with these phenomena are reduced visibility and damage to automobiles and other machinery.

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