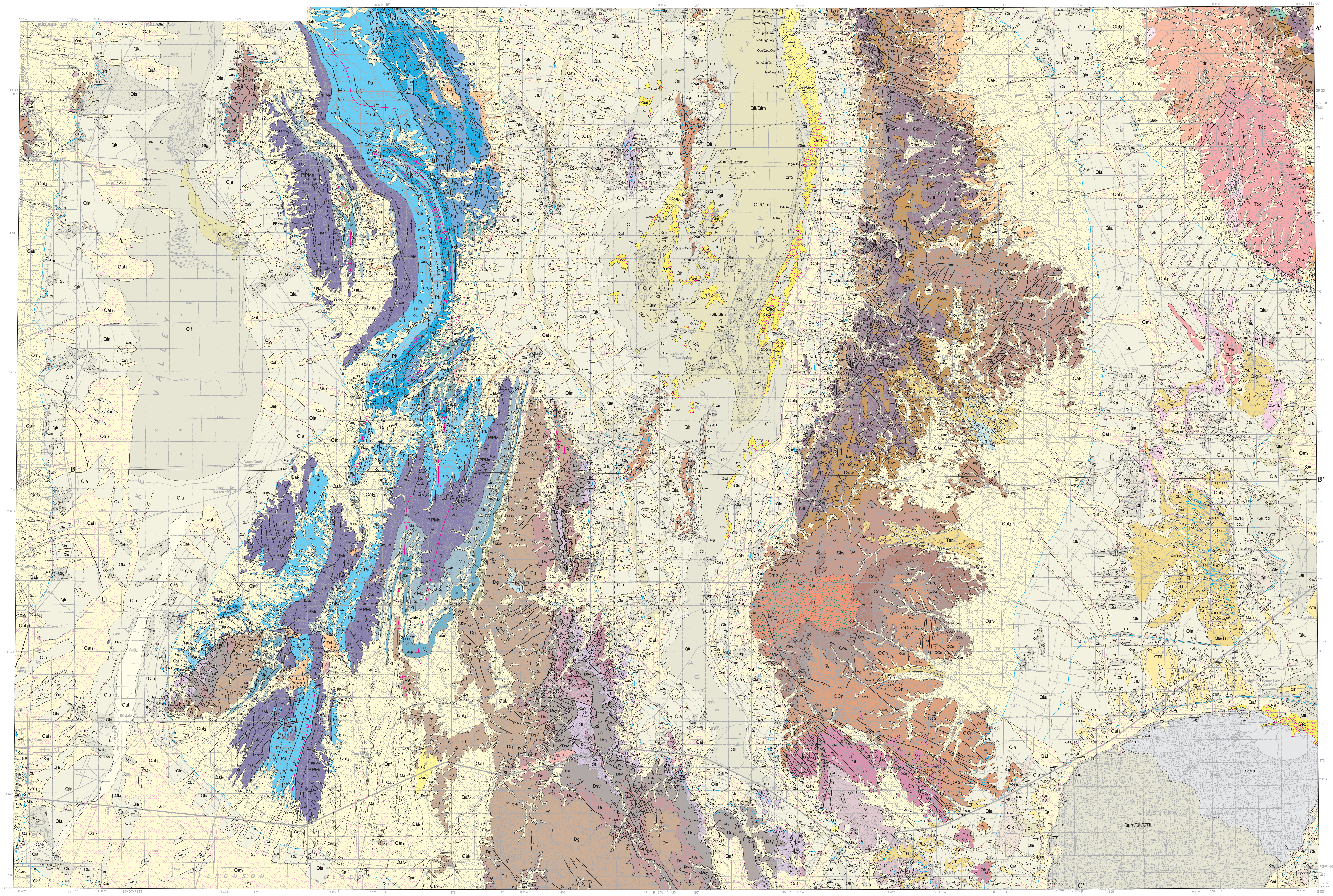

SCALE 1:100,000
Contour interval 40 meters
Supplementary contour interval 10 meters

2 1 0 2 4 6 8 10 Kilometers

2 1 0 2 4 Miles

Base from U.S.G.S. Tule Valley, Ely, Fish Springs, and Kern Mountains 30' x 60' quadrangles

13 30'
240 MILS

2002 MAGNETIC DECLINATION AT CENTER OF SHEET

GEOLOGIC MAP OF THE TULE VALLEY 30' x 60' QUADRANGLE AND PARTS OF THE ELY, FISH SPRINGS, AND KERN MOUNTAINS 30' x 60' QUADRANGLES, NORTHWEST MILLARD COUNTY, UTAH

by

Lehi F. Hintze and Fitzhugh D. Davis

2002

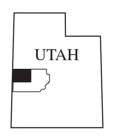

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Plate 1 of 2
Map 186
Utah Geological Survey
a division of
Utah Department of Natural Resources
***in cooperation with* U.S. Geological Survey**
Statemap Agreement No. 00HQAG109

GIS compilation: Basia Matyjasik and Angela Wadman
Cartographer: James Parker
Project Manager: Jon King

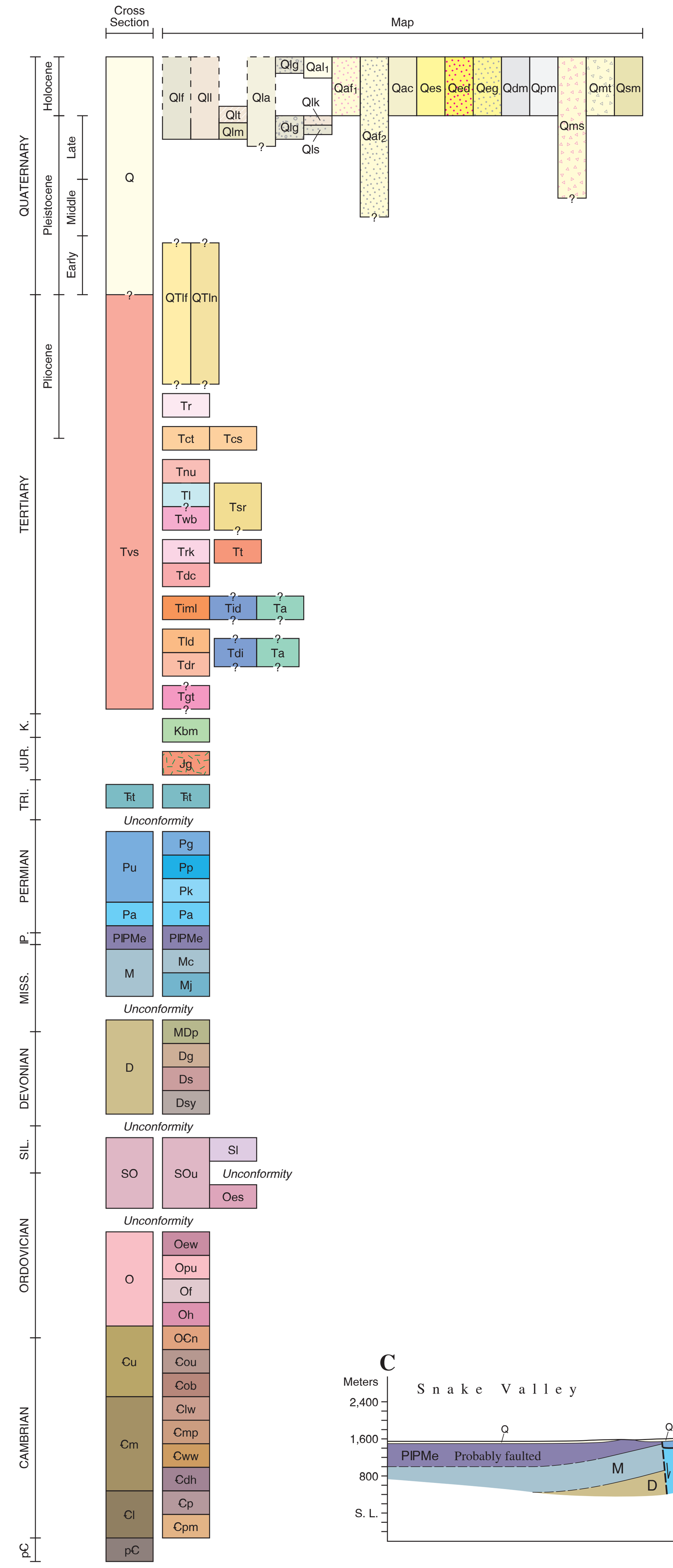
PLATE 2 of 2

Map 186
Geologic Map of the Tule Valley 30' x 60' Quadrangle, and parts of the Ely, Fish Springs and Kern Mountains 30' x 60' Quadrangles, Northwest Millard County, Utah

by
Lehi F. Hintze and Fitzhugh D. Davis
2002

UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
in cooperation with
THE UNITED STATES GEOLOGICAL SURVEY
STATEMAP Agreement No. 00HQAG109

CORRELATION OF GEOLOGIC UNITS



DESCRIPTION OF GEOLOGIC UNITS

Q Quaternary surficial units, undivided--Cross section only; for included units see correlation chart and descriptions.

Qlf Fine-grained lacustrine deposits--Grayish-tan, tan, and light-gray, calcareous silts that are deep-water sediments of Lake Bonneville, Lake Tule, Lake Gunnison (all late Pleistocene), and Sevier Lake (when it contained surface water in the Holocene); locally includes younger alluvium; thickness 10 feet (3 m) or less.

Qll Lacustrine lagoon deposits--Sand, silt, clay, and silty marl that accumulated in lagoons behind gravel barrier beaches of Lake Bonneville; locally includes younger alluvium; generally less than 10 feet (3 m) thick.

Qlt Lacustrine tufa--White to light-gray, shore-zone tufa deposited in Lake Tule; 1 to 4 feet (0.3-1.2 m) thick.

Qlm Lacustrine marl--Fine-grained, thinly bedded to laminated, white to light-gray, offshore to deep-water marl deposited in Lake Bonneville; ostracodes abundant throughout marl and, locally, gastropods present at top and base of marl; 0 to 30 feet (0-9 m) thick.

Qla Lacustrine and alluvial deposits, undifferentiated--Mixed and reworked, gravelly lacustrine and alluvial deposits on piedmont slopes; grades from pebbly sand and silt to sandy pebble gravel; 0 to 12 feet (0-3.7 m) thick, but may be thicker locally.

Qlg Lacustrine gravel--Shore-zone gravel deposited in Lake Bonneville, Lake Tule, Lake Gunnison, and Sevier Lake; chiefly silty, fine- to coarse-grained sand and gravel; gravel content is generally greater than 50 percent; 0 to 18 feet (0-5.5 m) thick; gravel of Lake Bonneville, Lake Tule, and Lake Gunnison is late Pleistocene. Beach gravel of Sevier Lake is adjacent to playa mud (Qpm) and is Holocene.

Qlk Lacustrine carbonate sand--Lacustrine sand and pebbly sand that consists of white and light-gray, carbonate pellets, carbonate-coated gastropods, and ooids deposited in Lake Bonneville; 0 to 10 feet (0-3 m) thick.

Qls Lacustrine sand-- Fine- to coarse-grained sand, marly sand, and pebbly sand deposited in Lake Bonneville as beaches, spits, and offshore bars; 0 to 30 feet (0-9 m) thick.

Qal₁ Alluvium, late Holocene--Youngest alluvium in the channel and floodplain of Baker Creek; consists of sand, silt, and clay with probable lenses of gravel; generally 0 to 20 feet (0-6 m) thick, but may be thicker locally.

Qaf₁ Younger alluvial-fan deposits-- Poorly sorted silt, sand, and pebble, cobble, and boulder gravel deposited by streams, sheetwash, debris flows, and flash floods on alluvial fans, and in canyons and mountain valleys; post-Bonneville shoreline in age; generally 0 to 40 feet (0-12 m) thick, but locally may exceed 60 feet (18 m).

Qaf₂ Older alluvial-fan deposits--Poorly sorted silt, sand, and pebble, cobble, and boulder gravel deposited by streams, debris flows, and flash floods on alluvial fans, and in canyons and mountain valleys above the Bonneville shoreline; includes colluvium in canyons and mountain valleys; mostly Pleistocene and pre-Lake Bonneville in age, but locally includes younger material; up to 200 feet (60 m), or more, in thickness.

Qac Alluvium and colluvium, undifferentiated--Mixed alluvial and colluvial deposits that consist of fluvially reworked, coarse-grained colluvium and/or alluvium with a significant colluvial component; also includes talus; only mapped on margins of Tule Valley; generally 0 to 50 feet (0-15 m) thick, but may be thicker locally.

Qes Eolian sand--Windblown sand in sheets, low irregular mounds, shrub-coppice dunes, and narrow, northeast-trending ridges that are largely stabilized by vegetation; mostly silty, well-sorted, fine-grained quartz sand; 0 to 10 feet (0-3 m) thick.

Qed Eolian dunes--Chiefly parabolic, linear, and dome dunes in Tule Valley that are active and not stabilized by vegetation; mostly well-sorted, fine-grained quartz sand, but some calcite and gypsum sand is present; 3 to 30 feet (1-9 m) thick.

Qeg Eolian gypsum--Sand-sized gypsum deposited in windblown sand sheets in the central and eastern parts of Tule Valley; 0 to 10 feet (0-3 m) thick.

Qdm Deltaic mud--Holocene mud of the Sevier River delta at the northeastern end of the Sevier Lake playa; likely 0 to 30 feet (0-9 m) thick.

Qpm Playa mud--Laminated, silty fine sand, silt, and clayey silt that are infused with various salts, chiefly gypsum and calcium carbonate; saline mud is as much as 900 feet (274 m) thick beneath the Sevier Lake playa but only the uppermost few feet are Quaternary; thickness of salty mud in the other playas is probably 20 feet (6 m) or less.

Qms Mass movements, slides, and slumps--Primarily mapped in the Swasey Peak area of the northern House Range where limestone blocks of the Dome Limestone and Marjum Formation have slid downslope on the less resistant Chisholm Formation and Wheeler Shale, respectively; small, isolated slides or slumps are present in many mountainous areas, but are too small to show at 1:100,000 scale; generally 0 to 120 feet (0-37 m) thick, but may be thicker in places.

Qmt Mass movements, talus--Poorly sorted, angular boulders with minor fine-grained interstitial material on and at the base of steep slopes at one site in the House Range, and in the Drum Mountains; only the largest deposits can be shown at map scale; 0 to 60 feet (0-18 m) thick.

Qsm Marsh deposits associated with springs--Gray to black, organic silt, clayey silt, and sandy silt; Tule Valley marsh deposits tend to be carbonate-rich and saline; possibly up to 20 feet (6 m) thick.

QTlf Fine-grained lacustrine deposits of Sevier Desert--Brown and light-olive-gray, calcareous, lacustrine silt and silty clay with minor sand; offshore to deep-water sediments that are Pliocene to middle Pleistocene in age; 0 to 872 or more feet (0-265+ m) thick.

QTln Near-shore lacustrine limestone of Sevier Desert--Light-gray limestone and conglomeratic limestone that comprise the shoreline facies of QTlf; up to 90 feet (27 m) thick.

Tvs Tertiary volcanic and sedimentary units, undivided--Cross section only; for included units see correlation chart and descriptions.

Tr Rhyolite of Whirlwind Valley--Light-gray, flow-layered, microfelsitic, devitrified rhyolite that may be a Miocene intrusive dome similar to ~6 Ma topaz rhyolites to north in Juab County.

Tcs Conglomerate and tuffaceous sandstone--Weakly consolidated, pebble to cobble conglomerate and sandstone with interbedded tuffaceous sandstone on the northeast flank of the House Range; dips valleyward about 10 degrees; about 1,000 feet (300 m) exposed.

Tct Conglomerate and tuff of Confusion Range--Light-gray, tuffaceous siltstone, sandstone, limestone, and conglomerate and air-fall, micaceous tuff; dips 20 degrees into valley; up to about 2,000 feet (600 m) thick; base less exposed.

Tnu Upper Needles Range Group--Crystal-rich, dacitic ash-flow tuff, mainly of the Wah Wah Springs Tuff; age about 30.5 Ma; thickness up to 400 feet (120 m).

Tsr Skull Rock Pass Conglomerate--Unconsolidated, bouldery conglomerate of Paleozoic clasts that lies above Tunnel Spring and Red Knolls Tuffs and beneath tuffs of the Needles Range Group; matrix is locally tuffaceous and contains rare igneous rock clasts; as much as 320 feet (98 m) thick.

Tl Lacustrine limestone and breccia--Light-gray limestone that locally contains plant and fresh-water snail fossils; as much as 100 feet (30 m) thick in House Range and up to 200 feet (60 m) thick in Mile-and-a-Half Canyon in Confusion Range. Thinner similar limestones in Confusion Range are included in unit Tct. Basal cemented breccia of Cambrian dolomite and limestone fragments, as much as 115 feet (35 m) thick, is present only in House Range.

Twb Windous Butte Tuff--Pink, rhyolite ash-flow tuff; small exposures at Toms Knoll in the Conger Range, and south of Wheeler Amphitheater in the House Range; Ar/Ar age 31.4±0.5 Ma; may be younger than unit Tl; less than 20 feet (6 m) exposed.

Tt Tunnel Spring Tuff--White, crystal-rich, poorly welded, rhyolite ash-flow tuff that contains abundant xenoliths of Paleozoic rocks; characterized by well-formed, small, doubly terminated, quartz crystals; K-Ar age 35.4 Ma; maximum thickness about 50 feet (15 m) in map area.

Trk Red Knolls Tuff--Grayish-pink, crystal-rich, dacite ash-flow tuff found east of the House Range; Ar/Ar age 36.5 Ma; about 200 feet (60 m) thick.

Tdc Volcanic sequence of Dennison Canyon--Mostly a volcanic conglomerate of sub-rounded boulders, cobbles, and pebbles in an ashy volcanic matrix; includes basal pink ash-flow tuff about 500 feet (150 m) thick, overlain by about 1,500 feet (460 m) of andesitic volcanic debris flows with 500 feet (150 m) of interbedded hornblende-andesite lava flows and lesser debris flows at top of sequence; Ar/Ar ages 36.7 to 37.1 Ma; thickness about 2,000 to 2,500 feet (600-760 m).

Ta Altered Cambrian and Tertiary rocks--Includes altered Cambrian strata and Tertiary rocks in the Drum Mountains and altered Cambrian strata on the west side of House Range. Age of alteration is thought to be about 36 Ma, the same as the adjacent Tertiary intrusions in the Drum Mountains; but, the age is Tertiary(?) in Cambrian strata elsewhere on the map.

Tdi Drum Mountains intrusions--Two small intrusive bodies of dark-gray, finely crystalline diorite in the Drum Mountains.

Tid Diorite dikes in the House Range--Two northeasterly trending dikes, one between Marjum Pass and Wheeler Amphitheater, the other in Sawtooth Canyon east of Notch Peak.

Timl Mt. Laird intrusive dikes--Rhyodacitic porphyry dikes that cut the Drum Mountains Rhyodacite in the Little Drum Mountains; age 37 Ma; as much as 900 feet (275 m) wide.

Tld Little Drum Formation--Intercalated andesitic tuff and boulder volcanic conglomerate; Ar/Ar ages 37.6 and 38.5 Ma; overlies Drum Mountains Rhyodacite; thickness 1,500 to 2,325 feet (450-708 m).

Tdr Drum Mountains Rhyodacite--Rusty- and maroon-weathering flows and breccias, and dark-green, vesicular lavas; Ar/Ar ages ~37 Ma, but may be reset by Mt. Laird and Drum Mountain intrusions; thickness about 2,000 feet (600 m). Pyroxene latite of Black Point, about 1,000 feet (300 m) thick, is also included in this map unit.

Tgt Welded tuff near Gandy--Isolated, small outcrop of brown, glassy, crystal-poor, welded tuff; about 50 feet (15 m) thick; age unknown.

Kbm Breccia along tear faults in the House Range--Breccia with horizontal slickensides is present along most of the east-southeasterly tear faults in the northern House Range; widest breccia is mapped along the North Swasey tear fault, where it is about 30 feet (9 m) wide (width exaggerated on map).

Jg Notch Peak quartz monzonite--Coarsely crystalline, porphyritic, quartz monzonite stock with sills that intrude Middle Cambrian strata; K-Ar age 170 Ma.

Ŧt Thaynes Formation--Yellowish-gray claystone, platy siltstone, fine-grained sandstone, and brown limestone; maximum thickness about 1,935 feet (590 m).

Pu Upper Permian, undivided--Cross section only; for included units see correlation chart and descriptions.

Pg Gerster Limestone--Light-brownish-gray, ledge-forming, bioclastic limestone interbedded with shaly limestone; abundant invertebrate marine fossils; maximum thickness about 1,100 feet (335 m).

Pp Plympton Formation--Yellow- or olive-gray, fine-grained, cherty dolomite with interbeds of siltstone, sandstone, and gypsum in upper half; thickness 690 feet (210 m).

Pk Kaibab Limestone--Massive, light-gray, cherty, bioclastic limestone and limy dolomite; thickness 480 to 600 feet (146-180 m).

Pa Arcturus Formation--Mostly fine-grained, poorly indurated, yellowish-gray sandstone, with some 6-10 foot (2-3 m) interbeds of limestone and limy dolomite that are cyclically spaced; more than 2,700 feet (820 m) thick.

PIPMe Ely Limestone--Cyclic alternations of medium-gray, ledge-forming, bioclastic limestone and slope-forming, platy, silty limestone; chert common throughout as nodules, concretions, and irregular beds; corals, brachiopods, crinoids, and other invertebrate fossils are common; thickness 1,850 to 2,000 feet (560-610 m).

M Mississippian, undivided--Cross section only; for included units see correlation chart and descriptions.

Mc Chainman Formation--Interbedded mudstone, clayey limestone, siltstone, black shale, sandstone, and gritstone; mostly thin-bedded but with some thick-bedded, resistant limestone beds; generally forms low topography and poor exposures; thickness 1,600 to 1,800 feet (490-550 m), thinning northward.

Mj Joana Limestone--Medium-gray, thick-bedded to massive limestone; common fossils are corals, gastropods, crinoid stems, and brachiopods; cherty beds in lower third; thins from 300 feet (90 m) in the southern part of the map area to zero at Granite Mountain north of map area.

D Devonian, undivided--Cross sections only; for included units see correlation chart and descriptions.

MDp Pilot Shale--Yellow-weathering, platy, calcareous siltstone and shale with thin beds of dolomitic siltstone; generally non-resistant and poorly exposed; 830 feet (250 m) thick.

Dg Guilmette Formation--Chertless, gray dolomite and limestone that forms resistant ledges and cliffs; stromatoporoids abundant in some beds; contains thin sandstone beds in upper third; basal 650 feet (200 m) is massive solution-cavern limestone breccia; thickness is 2,550 to 2,650 feet (775-810 m).

Ds Simonson Dolomite--Interbedded dark-brownish-gray, sugary dolomite and light-gray, laminated dolomite; poorly preserved stromatoporoids abundant in some beds; typically about 660 feet (200 m) thick.

Dsy Sevy Dolomite--Light- to medium-gray, medium-bedded, locally laminated, unfossiliferous dolomite; upper third contains frosted quartz sand grains; typically about 1,300 feet (400 m) thick.

SO Silurian-Upper Ordovician, undivided--Cross section only; for included units see correlation chart and descriptions.

SOu Laketown and Ely Springs Dolomites, undivided--Mapped in the vicinity of Mile and a Half Canyon in the Confusion Range, where the geology is structurally complex, and near Gandy.

Sl Laketown Dolomite--Banded dark- and light-brownish-gray, cherty, cliff-forming dolomite; silicified corals and brachiopods common in upper part; 920 to 1,100 feet (280-336 m) thick.

Oes Ely Springs Dolomite--Dark-brownish-gray, generally unfossiliferous, ledge- and cliff-forming dolomite; 552 to 620 feet (168-189 m) thick.

O Middle and Lower Ordovician, undivided--Cross section only; for included units see correlation chart and descriptions.

Oew Eureka-Crystal Peak-Watson Ranch Formations, undivided--These formations are too thin to show individually at the 1:100,000 scale; listed from the top downward. Eureka Quartzite is light-gray, medium- to fine-grained quartzite that weathers reddish-brown; characteristically pitted with pock-marks about 0.5 inch (1 cm) across; forms orange cliffs conspicuous among the gray carbonate rocks; thickness 450 feet (137 m). Crystal Peak Dolomite is interbedded, thin-bedded, light-olive-gray dolomite and bluish-gray, silty limestone; *Eofletcheria* coral fossils are common; thickness 90 feet (27 m). Watson Ranch Quartzite is interbedded orangish-brown, fucoidal quartzite and bluish-gray, silty limestone and dolomite; thickness 200 feet (60 m).

Opu Upper Pogonip Group, undivided--Consists of four formations too thin to show individually at the 1:100,000 scale; listed from the top downward. Lehman Formation--Interbedded, bluish-gray, silty limestone and shale; abundant ostracodes, brachiopods, trilobites, and other fossils; thickness is 200 feet (60 m). Kanosh Shale--Light-olive-gray, fissile shale with interbeds of thin-bedded, bioclastic limestone made up of brachiopod, ostracode, trilobite, and echinoderm fragments; up to 550 feet (170 m) thick. Juab Limestone--Medium-gray, medium- to thick-bedded, silty, ledge-forming limestone; contains orthid brachiopods; about 160 feet (50 m) thick. Wah Wah Limestone--Medium-gray, medium- to thick-bedded, silty limestone interbedded with olive shale; fragmented trilobites common in some beds; about 250 feet (75 m) thick.

Of Fillmore Formation--Medium-gray, thin- to medium-bedded limestone and intraformational, flat-pebble, limestone conglomerate interbedded with light-olive and yellowish-gray shale; about 1,800 feet (550 m) thick.

Oh House Limestone--Medium-bluish-gray, thick-bedded to massive, cherty limestone; thickness about 500 feet (152 m).

Ꞓu Upper Cambrian, undivided--Cross section only; for included units see correlation chart and descriptions.

OꞒn Notch Peak Formation--Dark-brownish-gray dolomite and gray limestone that commonly contain stromatolites; some beds cherty; forms massive cliffs; about 1,700 feet (520 m) thick.

Ꞓou Orr Formation, upper members, undivided--Consists of four members, in descending order: Sneakover Limestone Member, Corset Spring Shale Member, Johns Wash Limestone Member, and Candland Shale Member; shale members carry several trilobite zones; aggregate thickness about 860 feet (260 m) where exposed in House Range.

Ꞓob Orr Formation, Big Horse Limestone Member--Medium- to dark-gray, mottled limestone; oolitic and bioclastic in upper half, which bears *Crepicephalus* sp. trilobites; barren in lower half; forms ledges and cliffs; 715 feet (218 m) thick where exposed in House Range.

Ꞓm Middle Cambrian, undivided--Cross section only; for included units see correlation chart and descriptions.

Ꞓlw Lamb Dolomite and Trippe Limestone, or Weeks Limestone, undivided --Weeks Limestone is a trilobite-bearing, platy, silty limestone found only in the central House Range; 1,200 feet (366 m) thick; equivalent strata in other areas are mostly barren limestone and dolomite of the Lamb and underlying Trippe formations, which include a number of distinctive, white, laminated dolomite beds; thickness 1,180 to 1,290 feet (360-395 m).

Ꞓmp Marjum or Pierson Cove Formation--In the central House Range the Marjum Formation is a sequence of trilobite-bearing, dark-gray limestone and limy shale; 530 to 1,410 feet (162-430 m) thick; equivalent strata elsewhere are dark-gray, mottled, massive, dolomitic limestone and thin-bedded, light-gray dolomite of the Pierson Cove; 800 to 1,200 feet (243-370 m) thick.

Ꞓww Wheeler-Swasey-Whirlwind Formations, undivided--Listed from top downward. Wheeler Shale is olive, platy, calcareous shale about 460 to 900 feet (140-275 m) thick, with abundant *Elrathia* trilobites; Swasey Limestone is a gray, massive, cliff-forming limestone 180 to 250 feet (55-76 m) thick; Whirlwind Formation is interbedded, thin-bedded limestone and shale, with coquinas of *Ehmaniella* trilobites, and is about 140 feet (43 m) thick.

Ꞓdh Dome-Chisholm-Howell Formations, undivided--Listed from top downward. Dome Limestone is massive, forms cliffs, and is about 320 feet (98 m) thick; Chisholm Formation is interbedded, thin-bedded, fossiliferous limestone and olive shale, and is about 215 feet (66 m) thick; Howell Limestone forms a massive cliff that is dark-gray in the lower half and light-gray above, and is 330 to 645 feet (101-196 m) thick.

Ꞓl Lower Cambrian, undivided--Cross section only; for included units see correlation chart and descriptions.

Ꞓp Pioche Formation--Dark-green, micaceous phyllite interbedded with light-brown to greenish-black quartzite; trace-fossil tubular trails and vertical *Skolithus* tubes are common; orange-weathering dolomite beds common in uppermost Pioche; thickness about 415 to 600 feet (127-183 m).

Ꞓpm Prospect Mountain Quartzite--Pinkish-gray, medium- to coarse-grained quartzite; small-scale cross-bedding and thin beds of grit and pebble conglomerate are common; estimated thickness 4,000 feet (1,200 m) or more.

pꞒ Precambrian, undivided--Cross section only.

LITHOLOGIC COLUMN

AGE		MAP SYMBOL	MAP UNIT	THICKNESS FEET	THICKNESS METERS	OTHER INFORMATION
Q.		Q-various	Alluvial, lacustrine, eolian, and playa deposits	0-200	0-60	
TERTIARY	P.-H.	QTlf,QTln	Fine lake sediments (lf); shoreline deposits (ln)	0-870+	0-265+	Pliocene to mid-Pleistocene
TERTIARY	MIO.-PLIO.	Tr	Rhyolite of Whirlwind Valley	Intrusion?		Age uncertain; less than 20 Ma
TERTIARY	MIO.-PLIO.	Tcs	Conglomerate and tuffaceous sandstone	0-1,000+	0-300+	
TERTIARY	MIO.-PLIO.	Tct	Conglomerate and tuff (of Confusion Range)	0-2,000+	0-600+	Includes air-fall tuffs with small biotite flakes
TERTIARY	OLIGOCENE	Tnu	Upper Needles Range Group	0-400	0-120	30.5 Ma ash-flow tuffs
TERTIARY	OLIGOCENE	Tsr,Tl	Skull Rock Pass Cg (Tsr); Lacustrine limestone (Tl)	0-320	0-100	
TERTIARY	OLIGOCENE	Twb	Windous Butte Tuff	<20	<6	31.4 Ma Ar/Ar
TERTIARY	OLIGOCENE	Trk,Tt	Red Knolls Tuff (Trk);Tunnel Spring Tuff (Tt)	0-200	0-60	Trk 36.5 Ma Ar/Ar; Tt 35.4 Ma
TERTIARY	OLIGOCENE	Tdc	Volcanic sequence of Dennison Canyon	0-2,500±	0-760±	36.7-37.1 Ma Ar/Ar
TERTIARY	EOCENE	Ta	Altered Cambrian and Tertiary rocks	---	---	In Drum Mts. and west of House Range
TERTIARY	EOCENE	Tdi,Tid,Timl	Drum Mts. intrusion (Tdi); Diorite dike (Tid); Mt. Laird intr. (Timl)			Tdi and Timl 36-37 Ma
TERTIARY	EOCENE	Tld	Little Drum Formation	0-2,300	0-700	37.6 and 38.5 Ma Ar/Ar
TERTIARY	EOCENE	Tdr	Drum Mountains Rhyodacite and pyroxene latite	0-2,000	0-600	36.9 and 37.6 Ma Ar/Ar (reset?)
TERTIARY	EOCENE	Tgt	Welded tuff near Gandy	50	15	Age unknown
K.		Kbm	Breccia along tear faults in the House Range	0-30 ft (0-10 m) wide		
J.		Jg	Notch Peak granitic intrusion in the House Range	Intrusion		170 Ma
TRIASSIC		Ŧt	Thaynes Formation	1,935	590	Ammonites, sponges
PERMIAN		Pg	Gerster Limestone	1,100	335	*Punctospirifer pulcher*
PERMIAN		Pp	Plympton Formation	690	210	
PERMIAN		Pk	Kaibab Limestone	480-600	146-180	
PERMIAN		Pa	Arcturus Formation	2,700+	820+	Gypsum beds in upper part
PENN.		PIPMe	Ely Limestone	1,850-2,000	560-610	Fusulinids near top; Cyclic cherty fossiliferous limestone
MISSISSIPPIAN		Mc	Chainman Formation	1,600-1,800	490-550	Fossils common near top
MISSISSIPPIAN		Mj	Joana Limestone	0-300	0-90	Thins northward
DEVONIAN		MDp	Pilot Shale	830	250	
DEVONIAN		Dg	Guilmette Formation	2,550-2,650	775-810	Spaghetti stromatoporoids common; Massive limestone breccia
DEVONIAN		Ds	Simonson Dolomite	540-930	165-283	
DEVONIAN		Dsy	Sevy Dolomite	1,300-1,600	400-490	Light-gray dolomite
SIL.	SOu	Sl	Laketown Dolomite	920-1,100	280-335	Cherty dolomite
ORDOVICIAN	SOu	Oes	Ely Springs Dolomite	550-620	168-189	
ORDOVICIAN		Oew	Eureka - Crystal Peak - Watson Ranch Fms, undivided	700-740	214-226	
ORDOVICIAN	Pogonip Group	Opu	Lehman - Kanosh - Juab - Wah Wah Fms, undivided	1,160	353	Many fossils
ORDOVICIAN	Pogonip Group	Of	Fillmore Formation	1,800	550	Thin-bedded intraformational conglomerate and olive shale
ORDOVICIAN	Pogonip Group	Oh	House Limestone	500	152	*Symphysurina*
CAMBRIAN		OꞒn	Notch Peak Formation	1,700	520	Algal stromatolites
CAMBRIAN		Ꞓou	Orr Formation, upper members, undivided	860	260	*Dunderbergia*
CAMBRIAN		Ꞓob	Orr Formation, Big Horse Limestone Member	715	218	*Crepicephalus*; Bioclastic limestone
CAMBRIAN		Ꞓlw	Lamb - Trippe / Weeks Formations, undivided	1,180-1,290	360-395	White laminated dolomite
CAMBRIAN		Ꞓmp	Marjum - Pierson Cove Formations	530-1,400	162-430	Dark-gray limestone
CAMBRIAN		Ꞓww	Wheeler - Swasey - Whirlwind Fms, undivided	880-1,227	268-374	*Elrathia kingi*; *Ehmaniella*
CAMBRIAN		Ꞓdh	Dome - Chisholm - Howell Fms, undivided	865-1,185	264-361	*Glossopleura*
CAMBRIAN		Ꞓp	Pioche Formation	415-600	127-183	Phyllite with tracks and burrows; *Olenellus* trilobites
CAMBRIAN		Ꞓpm	Prospect Mountain Quartzite	4,000±	1,200±	Pink and orange quartzite
pꞒ		pꞒ	Precambrian metasedimentary rocks	---	---	On cross section only

Diagram is schematic--- no fixed thickness scale

MAP AND CROSS-SECTION SYMBOLS

CONTACT--Dashed where location inferred.

NORMAL FAULT--Dashed where location inferred; dotted where concealed; queried where speculative on cross section; bar and ball on downthrown side; arrows show relative movement on cross section. (On map) (Shown vertical or inclined on cross section)

NORMAL FAULT--Inferred and delineated from gravity data; concealed; bar and ball on downthrown side.

TEAR FAULT--High-angle fault with strike-slip offset; dotted where concealed; arrows show relative movement on map; T means toward and A means away on cross section A-A'. (Map) (Cross section)

REVERSE FAULT--Dotted where concealed; R on upthrown side; arrows show relative movement on cross section. (Map) (Cross section)

STEEPLY DIPPING FAULT--Includes faults where sense of motion not known or complex; dashed where location inferred; dotted where concealed.

THRUST FAULT--Dashed where location inferred; dotted where concealed; queried where speculative on cross section; barbs on upper plate; arrows show relative movement on cross sections. (Map) (Cross section)

ATTENUATION FAULT--Younger over older rocks with strata thinned or cut out between; barbs on upper plate; arrows show relative movement on cross section C-C'. (Map) (Cross section)

LINEAMENT--Linear features visible on aerial photographs; present in Drum Mountains Rhyodacite in Little Drum Mountains; probably joints or steeply dipping faults with small offset.

FOLD AXES--Location approximate; arrows on axes show plunge; dotted where concealed.
- anticline
- syncline
- overturned syncline

65 42 STRIKE AND DIP OF BEDDING--Inclined, overturned.

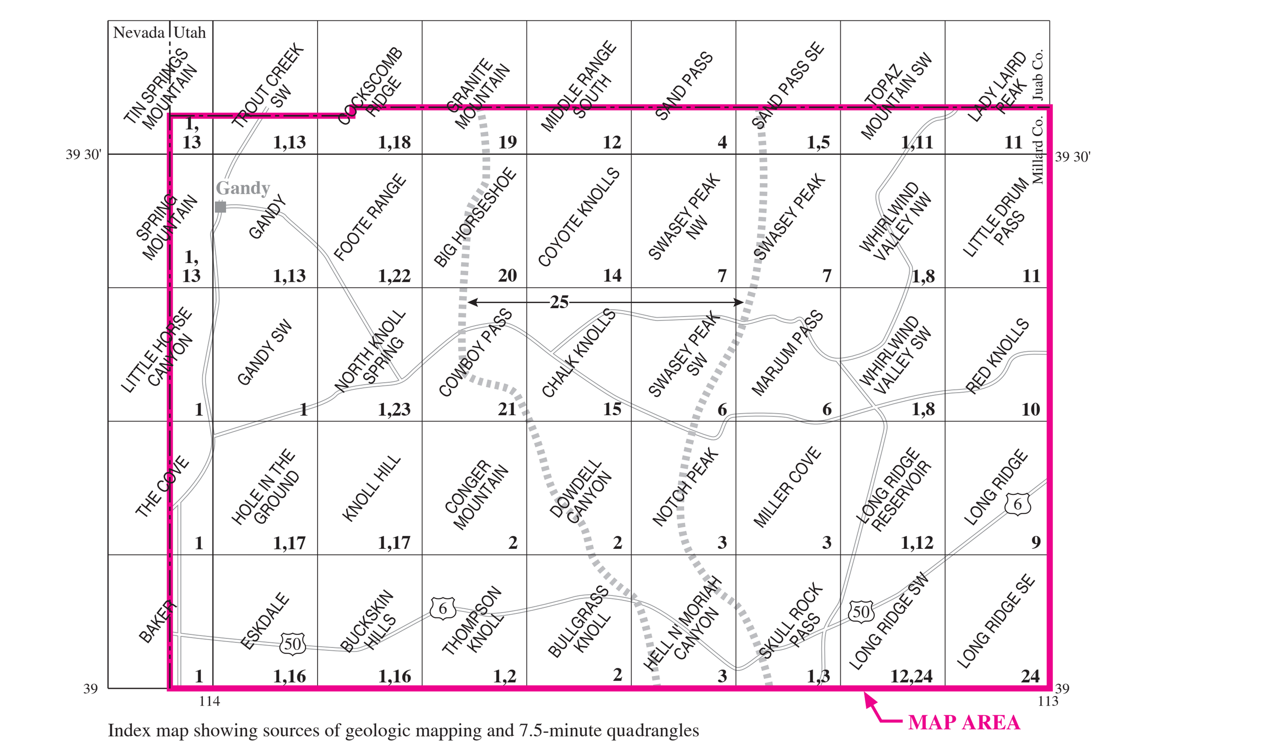
6 STRIKE AND DIP OF PLANAR FEATURES IN VOLCANIC ROCK--Present in Little Drum Mountains.

DEEP EXPLORATION WELL--Map symbol on left, cross-section symbol on right.

SINKHOLE-- In Ely Limestone on east side of Snake Valley (section 8, T. 19 S., R. 18 W.); host unit uncertain on east flank of House Range (N1/2 section 35-36 line, T. 18 S., R. 13 W.).

SHORELINES--Dashed were inferred, dotted where concealed.
- G Lake Gunnison shoreline
- P Provo shoreline of Lake Bonneville
- B Bonneville shoreline of Lake Bonneville

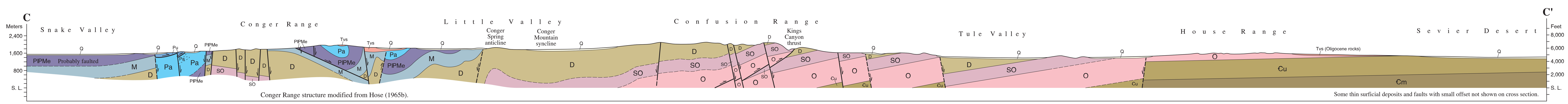
Qlf/QTaf Indicates thin cover of the first unit overlying the second unit.



Index map showing sources of geologic mapping and 7.5-minute quadrangles

TULE VALLEY 30' x 60' source list for geologic mapping

1. Davis, F.D., 1990-1995, unpublished mapping of surficial geology of the valley areas for this publication, scales 1:24,000 and 1:100,000, except those parts covered by Oviatt (1989) and Sack (1990).
2. Hintze, L.F., 1974, Preliminary geologic map of the Conger Mountain [15'] quadrangle, Millard County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-634, scale 1:48,000.
3. Hintze, L.F., 1974, Preliminary geologic map of the Notch Peak [15'] quadrangle, Millard County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-636, scale 1:48,000.
4. Hintze, L.F., 1980, Preliminary geologic map of the Sand Pass quadrangle, Juab and Millard Counties, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1151, scale 1:24,000.
5. Hintze, L.F., 1980, Preliminary geologic map of the Sand Pass NE and Sand Pass SE quadrangle, Juab and Millard Counties, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1150, scale 1:24,000.
6. Hintze, L.F., 1981, Preliminary geologic map of the Marjum Pass and Swasey Peak SW quadrangles, Millard County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1332, scale 1:24,000.
7. Hintze, L.F., 1981, Preliminary geologic map of the Swasey Peak and Swasey Peak NW quadrangles, Millard County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1333, scale 1:24,000.
8. Hintze, L.F., 1981, Preliminary geologic map of the Whirlwind Valley NW and Whirlwind Valley SW quadrangles, Millard County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1335, scale 1:24,000.
9. Hintze, L.F., and Davis, F.D., 1992, Geologic map of the Long Ridge quadrangle, Millard County, Utah: Utah Geological Survey Map 141, 10 p., scale 1:24,000.
10. Hintze, L.F., and Davis, F.D., 1992, Geologic map of the Red Knolls quadrangle, Millard County, Utah: Utah Geological Survey Map 142, 10 p., scale 1:24,000.
11. Hintze, L.F., 1987-91, unpublished mapping, scale 1:24,000, includes bedrock and surficial geology in Little Drum Pass quadrangle; revision of Leedom, S.H., 1974, Little Drum Mountains, an early Tertiary shoshonitic volcanic center in Millard County, Utah: Brigham Young University Geology Studies, v. 21, part 1, p. 73-108, scale 1:48,000; Pierce, C.R., 1974, Geology of the southern part of the Little Drum Mountains, Utah: Brigham Young University Geology Studies, v. 21, part 1, p. 109-129, scale 1:48,000; Dommer, M.L., 1980, The geology of the Drum Mountains, Millard and Juab Counties, Utah: Brigham Young University Geology Studies, v. 27, part 3, p. 55-72, scale 1:40,000; and Nutt, C.J., Thorman, C.H., Zimbelman, D.R., and Gloyn, R.W., 1991, Geologic setting and trace-element geochemistry of the Detroit mining district, west-central Utah, *in* Raines, G.L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., editors, Geology and ore deposits of the Great Basin, symposium proceedings: Reno, Geological Society of Nevada, p. 491-509.
12. Hintze, L.F., 1990, 1993-94, unpublished mapping of Cambrian, Ordovician, Devonian, and Tertiary bedrock for this publication, scale 1:24,000.
13. Hintze, L.F., 1993-94, unpublished bedrock mapping for this publication, scale 1:24,000; modifying mapping later partially published as Gans, P.B., Miller, E.L., and Lee, Jeffrey, 1999, Geologic map of the Spring Mountain quadrangle, Nevada and Utah; Nevada Bureau of Mines and Geology, Field Studies Map 18, 12 p., scale 1:24,000.
14. Hose, R.K., 1963a, Geologic map and section of the Cowboy Pass NE quadrangle, Confusion Range, Millard County, Utah: U.S. Geological Survey Miscellaneous Investigations Map I-377, scale 1:24,000.
15. Hose, R.K., 1963b, Geologic map and sections of the Cowboy Pass SE quadrangle and adjacent area, Confusion Range, Millard County, Utah: U.S. Geological Survey Miscellaneous Investigations Map I-391, scale 1:24,000.
16. Hose, R.K., 1965a, Geologic map and sections of the Conger Range SE quadrangle and adjacent area, Confusion Range, Millard County, Utah: U.S. Geological Survey Miscellaneous Investigations Map I-435, scale 1:24,000.
17. Hose, R.K., 1965b, Geologic map and sections of the Conger Range NE quadrangle and adjacent area, Confusion Range, Millard County, Utah: U.S. Geological Survey Miscellaneous Investigations Map I-436, scale 1:24,000; additional outcrops to west from L.F. Hintze, 1989, unpublished mapping for this publication; mapping of Tertiary units modified locally by L.F. Hintze for this publication.
18. Hose, R.K., 1974, Geologic map of the Trout Creek SE quadrangle, Juab and Millard Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Map I-827, scale 1:24,000.
19. Hose, R.K., 1974, Geologic map of the Granite Mountain SW quadrangle, Juab and Millard Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Map I-831, scale 1:24,000; mapping of Tertiary units modified locally by L.F. Hintze for this publication.
20. Hose, R.K., and Repenning, C.A., 1963, Geologic map and sections of the Cowboy Pass NW quadrangle, Confusion Range, Millard County, Utah: U.S. Geological Survey Miscellaneous Investigations Map I-378, scale 1:24,000; mapping of Tertiary units modified locally by L.F. Hintze for this publication.
21. Hose, R.K., and Repenning, C.A., 1964, Geologic map and sections of the Cowboy Pass SW quadrangle, Confusion Range, Millard County, Utah: U.S. Geological Survey Miscellaneous Investigations Map I-390, scale 1:24,000.
22. Hose, R.K., and Ziony, J.I., 1963, Geologic map and sections of the Gandy NE quadrangle, Confusion Range, Millard County, Utah: U.S. Geological Survey Miscellaneous Investigations Map I-376, scale 1:24,000; mapping of Tertiary units modified locally by L.F. Hintze for this publication.
23. Hose, R.K., and Ziony, J.I., 1964, Geologic map and sections of the Gandy SE quadrangle, Confusion Range, Millard County, Utah: U.S. Geological Survey Miscellaneous Investigations Map I-393, scale 1:24,000.
24. Oviatt, C.G., 1989, Quaternary geology of part of the Sevier Desert, Millard County, Utah: Utah Geological and Mineral Survey Special Studies 70, 41 p., scale 1:100,000.
25. Sack, Dorothy, 1990, Quaternary geologic map of the Tule Valley, west-central Utah: Utah Geological Survey Map 124, scale 1:100,000, locally modified by F.D. Davis and L.F. Hintze.

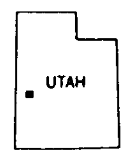


D. Sack QUATERNARY GEOLOGY OF TULE VALLEY, WEST-CENTRAL UTAH

QUATERNARY GEOLOGY OF TULE VALLEY, WEST-CENTRAL UTAH

by

Dorothy Sack



UGMS MAP 124

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QUATERNARY GEOLOGY OF TULE VALLEY, WEST-CENTRAL UTAH

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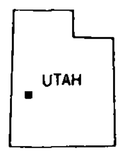

UTAH GEOLOGICAL AND MINERAL SURVEY
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QUATERNARY GEOLOGY OF TULE VALLEY, WEST-CENTRAL UTAH

by

Dorothy Sack[1]

ABSTRACT

Tule Valley contained an independent paleolake before and after its isotope stage 2 integration with Lake Bonneville. Tule Valley probably also experienced a period of Bonneville basin integration during the Little Valley lake cycle of isotope stage 6. In interlacustral intervals, alluvial-fan, playa, and eolian processes dominated Tule Valley's depositional system. The study area currently displays a wide variety of Quaternary sediments, including material deposited in alluvial, eolian, lacustrine, mass-wasting, playa, and spring environments. The Quaternary geologic map portrays sediments deposited within several subenvironments of these categories. Alluvial and lacustrine sediments are the most common deposits.

The Bonneville, Provo, top of the null zone, and bottom of the null zone shorelines are included on the Quaternary geologic map. The null zone is a strip without shorelines that extends around the basin from about the 4645- to the 4740-foot (1416 to 1445 m) contour. Geomorphic and stratigraphic evidence indicate that the shoreline at the bottom of the null zone is the highest transgressive Lake Tule shoreline and the one occupied when Lake Bonneville overflowed into Tule Valley about 19,500 yr B.P. The shoreline at the top of the null zone is the lowest, and either the first or last Lake Bonneville shoreline to have formed in the study area. It is hypothesized that no distinct shorelines are found within the 95-foot (29 m) high null zone because the water level rose too rapidly when Lake Bonneville spilled into Tule Valley.

Morphostratigraphic evidence in Tule Valley reveals that a major transgressive Lake Bonneville stillstand or oscillation occurred just below the elevation of the regressive Provo shoreline. The sub-Provo transgressive shoreline may have formed about 17,700 yr B.P. and cannot be attributed to a stillstand caused by Lake Bonneville's overflow into Tule Valley. The apparent large size of the Provo-level features throughout the Bonneville basin may be due in part to the location of the Provo shoreline just above the elevation of the transgressive sub-Provo shoreline.

During Provo shoreline time and the early stages of Lake Bonneville regression, lacustrine tufa was deposited in the Tule Valley embayment. After re-isolation of Lakes Bonneville and Tule, the Tule Valley water level may have fallen as rapidly as 1.2 ft/yr (36.5 cm/yr). Although a large portion of the valley bottom consists of lacustrine marl rather than true playa deposits, significant amounts of calcium sulfate precipitated out of the desiccating water body. In Holocene time, eolian processes have transported gypsum from the valley floor and siliceous sand from the eastern piedmont northeast across the valley, forming sand sheets and dunes. The very small modern playa is currently precipitating chlorides.

People have extracted gravel, marl, and gypsum from Tule Valley. Thermal springs occur along a north-northeasterly trend, a probable fault zone, in the center of the basin. Geologic hazards consist of debris flows, flash floods, valley-floor flooding, earthquakes, and blowing sand and dust. The valley contains almost 5 miles (8 km) of piedmont fault scarps. One profiled fault scarp has an estimated age between 19,000 and 12,000 yr B.P.

[1]*Department of Geography, University of Wisconsin, Madison, Wis.*

INTRODUCTION

Tule Valley is located about 130 miles (209 km) southwest of Salt Lake City and 45 miles (72 km) west of Delta, Utah, in Juab and Millard Counties (figures 1 and 2). It has previously been called Coyote Valley (Gilbert *in* Hunt, 1982) and White Valley (e.g., Simpson, 1876; Gilbert, 1890; Powell, 1958; Hanks, 1962; Berge, 1964; Crosson, 1964). Tule Valley occupies a structural basin of interior drainage in the Basin and Range physiographic province. Most of the valley is bordered by the House Range on the east and the Confusion Range on the west, but portions of the Fish Springs Range, Middle Range, and Honeycomb Hills lie adjacent to it at the north end (figure 3). In spite of its current topographic closure, geomorphologists describe Tule Valley as a subbasin of the Bonneville basin because it was integrated with Lake Bonneville for part of the late Pleistocene Bonneville lacustral cycle (Gilbert, 1890; Meinzer, 1911; Eardley and others, 1957; Snyder, 1963; Currey, Atwood, and Mabey, 1984; Currey and Oviatt, 1985; Sack, 1988). During the highest stages of Lake Bonneville, Tule Valley was an embayment in the southwest portion of the lake (figure 4).

The purpose of this study is to 1) map the Quaternary deposits, major shorelines, and piedmont fault scarps of Tule Valley at the scale of 1:100,000 (plate 1, in pocket), and 2) interpret the late Quaternary history of Tule Valley. This project contributes to the geologic map coverage of the state, improves our understanding of Utah Quaternary geology, and provides information regarding regional economic geology and geologic hazards.

Most geologic maps have traditionally portrayed Quaternary deposits in one or at most a few general units. In western Utah, however, these deposits merit being mapped in the detail typically reserved for pre-Quaternary rocks because of their great extent, possible economic value, usefulness in identifying modern geologic hazards, role in estimating hazard recurrence intervals, and importance to regional Quaternary paleoenvironmental reconstructions. Quaternary mapping is also warranted here because the basins of western Utah are often under consideration as sites for large construction projects, such as the MX missile, nuclear waste storage, and the superconducting supercollider. Christenson and others (1982) have demonstrated the potential utility of Quaternary maps for early identification of areas that are not suited for such projects.

Tule Valley is an exemplary subbasin of the Great Basin yet has been the subject of very little previous geomorphic or Quaternary stratigraphic research. It has a complex lacustrine history involving not only Lake Bonneville but also the independent Lake Tule that existed before and after the period of Bonneville integration (Sack, 1988). As the late Quaternary climate-forced hydrologic balance oscillated between negative and positive, the dominant geomorphic processes acting in Tule Valley varied from alluvial-fan/playa/dune to lacustrine processes. As a result, Tule Valley displays a wide variety of Quaternary deposits that potentially contain considerable paleoenvironmental information. Its piedmont zone consists of large coalescing alluvial fans on which are found lacustrine shorelines, recent debris flows, and Quaternary fault scarps. Lacustrine fines, efflorescing salts, and eolian deposits occur on the valley floor.

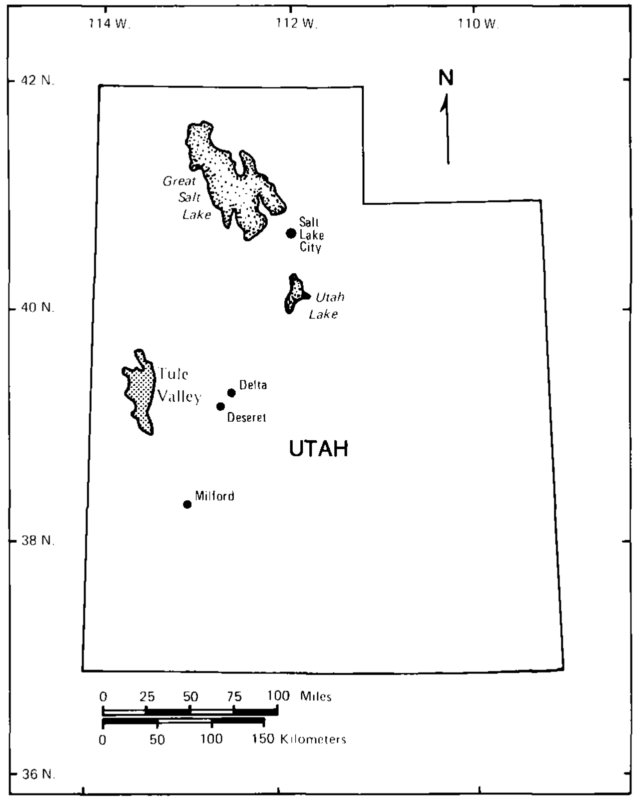


Figure 1. *Location map of Tule Valley, Utah.*

The most recent deep-lake cycle in the Bonneville basin, the Bonneville lacustral cycle (Currey and others, 1983, p. 63), lasted from about 32,000 to 10,000 years ago (Currey and James, 1982). According to current interpretations of the chronology of Lake Bonneville, transgression of the lake was well underway by about 25,000 yr B.P. (Mehringer, 1977; Spencer and others, 1984). The lake experienced a major oscillation, the Stansbury double oscillation (Currey and Oviatt, 1985, p. 11), between about 22,500 and 20,500 yr B.P. (D.R. Currey, 1988, personal communication). This oscillation resulted in the formation of the Stansbury shoreline. After Stansbury shoreline time, the transgressive trend continued until the lake reached the elevation of the lowest point on its divide with the Snake-Columbia River drainage basin, thereby transforming the lake into an open-basin system. This occurred after 16,400 yr B.P. (Currey and Oviatt, 1985, p. 12), and perhaps as late as 15,500 to 15,000 yr B.P. (D.R. Currey, 1988, personal communication). Under this threshold control, Lake Bonneville created its highest shoreline, which Gilbert (1875) named the Bonneville beach. The climate-forced Keg Mountain oscillation caused the lake to regress from the Bonneville shoreline about 145 feet (44 m), then retransgress back to threshold control (Oviatt, 1984; Currey and Oviatt, 1985).

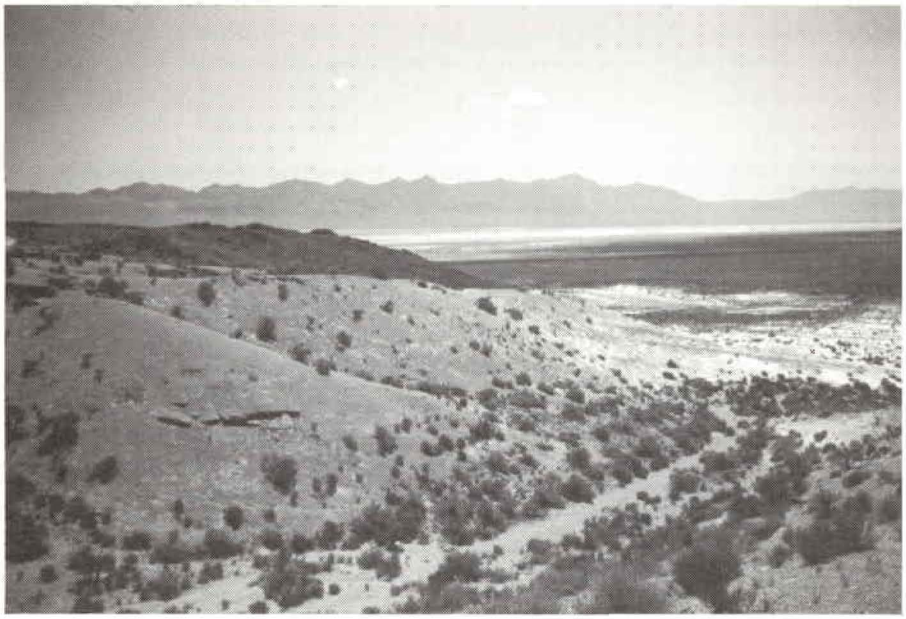


Figure 2. *View to southwest across Tule Valley to the House Range.*

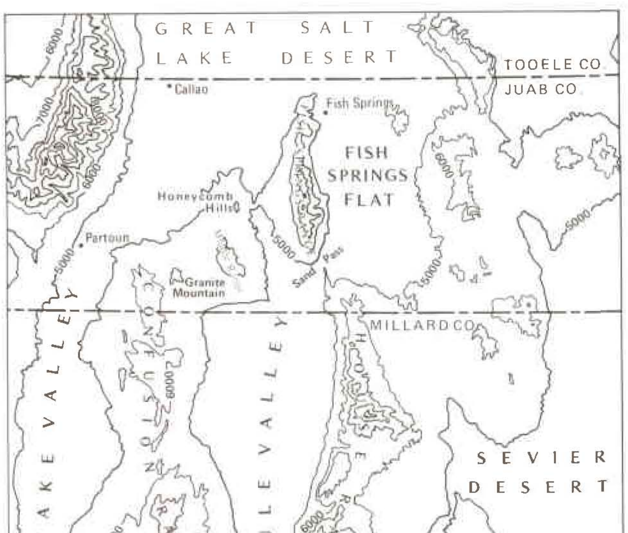


Figure 3. *Map showing major geographic features of west-central Utah.*

The alluvial material at the threshold, however, soon failed, resulting in the catastrophic Bonneville flood and approximately 355 feet (108 m) of rapid downcutting to a bedrock sill (Gilbert, 1890; Malde, 1968; Jarrett and Malde, 1987). While stabilized at this lower threshold, the lake formed the very prominent Provo shoreline (Gilbert, 1875, 1890). In his classic U.S. Geological Survey Monograph on Lake Bonneville, Gilbert (1890, p. 127) attributed the magnitude of Provo shoreline features to a long period of threshold-controlled open-basin conditions. About 14,000 years ago, climatic factors induced regression from the Provo level, and the lake returned to closed-basin conditions (Currey and Oviatt, 1985, p. 13). This regression was so rapid that within about 2000 years the lake level was below the elevation of the present Great Salt Lake (Currey and Oviatt, 1985, p. 13).

During the transgressive phase of Lake Bonneville a lake also formed in Tule Valley. Even though the main portion of the Bonneville basin was much deeper than the Tule Valley basin, Lake Bonneville had a proportionally much greater volume of stream inflow than did Lake Tule. As a result, Lake Bonneville rose faster than Lake Tule. When the transgressing Lake Bonneville attained the elevation of Sand Pass (figures 3 and 5), the lowest point on the divide between the two basins, it spilled into Tule Valley (Currey and Oviatt, 1985, p. 11). The period of basin integration included Bonneville and Provo shoreline time. While Tule Valley was an arm of Lake Bonneville, its water level fluctuated in unison with the rest of the lake. Because the elevation of Sand Pass (4744 feet; 1446 m) is not far below the local elevation of the Provo shoreline (4817 feet; 1468 m), the two basins re-isolated soon after Lake Bonneville began its rapid regression from the Provo level.

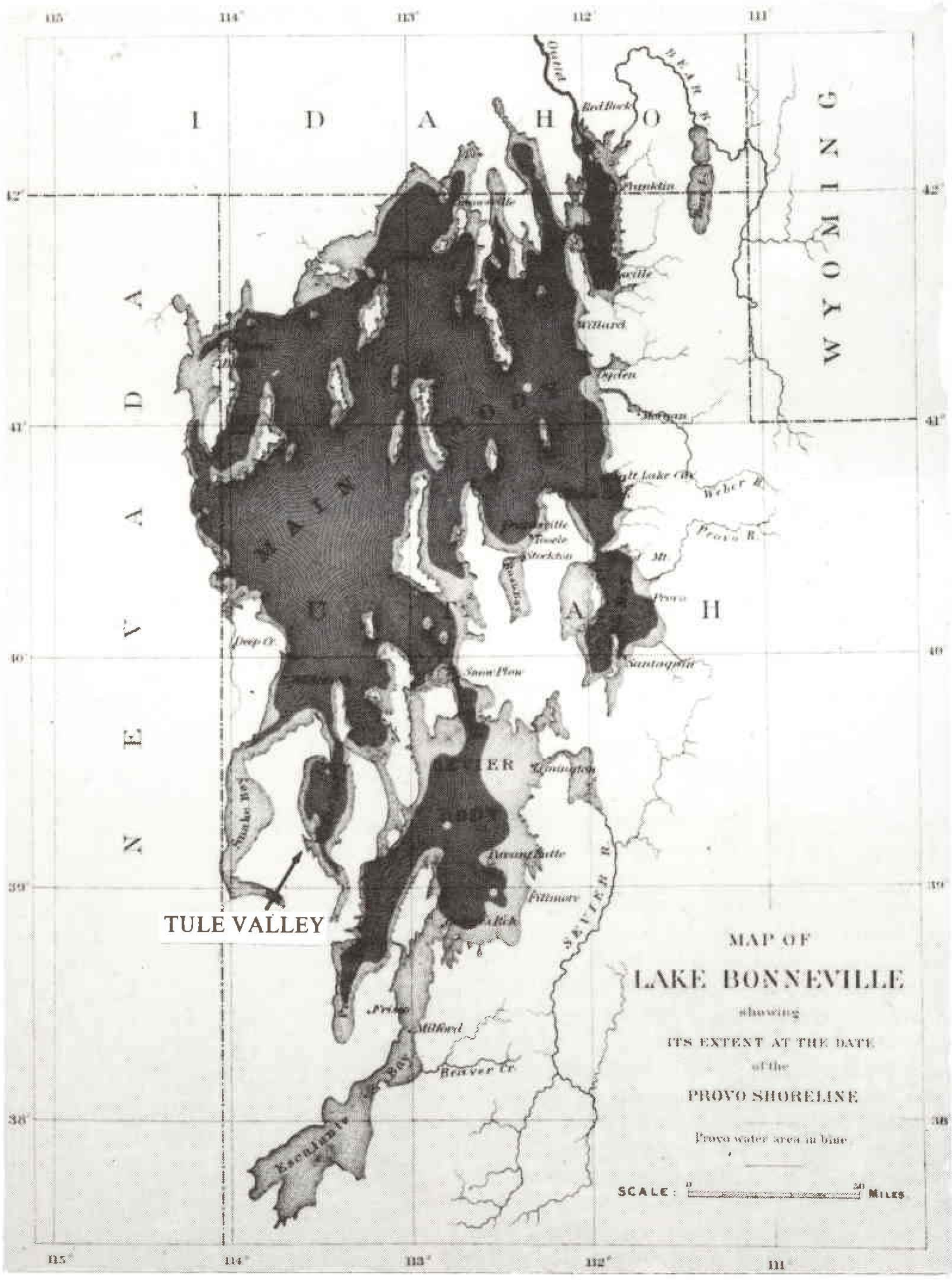


Figure 4. *Gilbert's (1890, p. 128a, Plate XIII) map showing the extent of the Bonneville and Provo shorelines.*

Figure 5. *Aerial photograph of the Sand Pass area of northeast Tule Valley (north is at top). Sand Pass and the steep portion of the inflow feature are located at the upper right corner; the hypothesized distal portion of the inflow feature ends just south of the west-northwest bend in the road on the right side of the photo. (Photo from EROS Data Center.)*

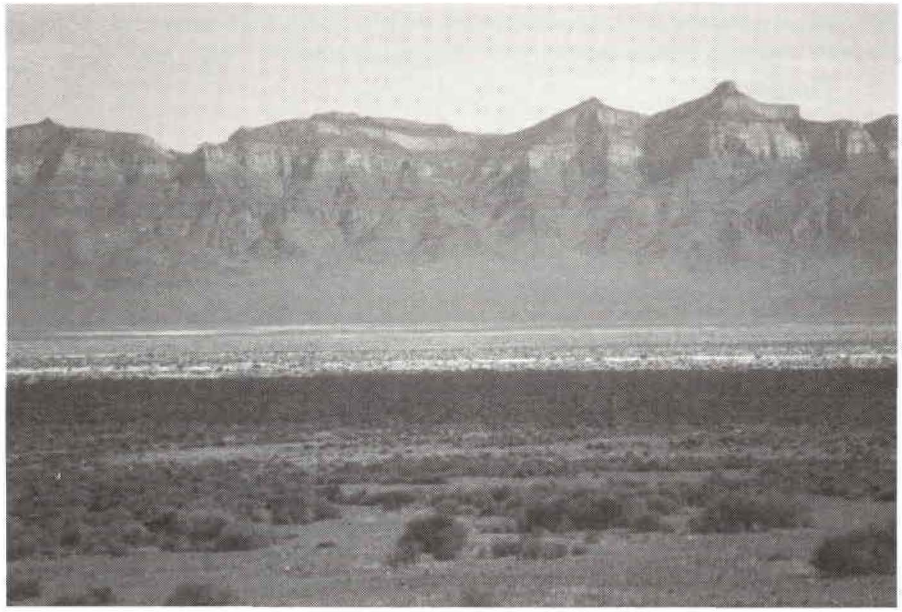


Figure 6. *The Tule Valley basin floor, House Range piedmont, and the House Range.*

STUDY AREA

The research area consists of the Tule Valley basin floor, the piedmonts of the surrounding mountain ranges, and small portions of unconsolidated material on the adjacent uplands just above the piedmont junction (figure 6). The perimeter of the study area approximately separates zones of unconsolidated material at lower elevations from higher zones of bedrock. In the non-mountainous region to the north, it follows the drainage divide with the main body of the Bonneville basin. The 39th parallel constitutes the southern boundary. The area included in this investigation is about 50 miles (80 km) long, has a maximum width of approximately 19 miles (31 km), and covers about 545 square miles (1412 km^2). There is over 1 mile (1.6 km) of vertical relief between the lowest point on the valley floor, at an elevation about 4395 feet (1340 m), and the highest peak in the House Range, Swasey Peak, at an elevation of 9678 feet (2950 m). The study area covers portions of the Conger Mountain, Cowboy Pass, Granite Mountain, and Notch Peak U.S. Geological Survey 15-minute topographic quadrangles, and portions of the Marjum Pass, Sand Pass, Sand Pass NW, Sand Pass SE, Swasey Peak, Swasey Peak NW, and Swasey Peak SW 7.5-minute topographic quadrangles.

Late Cenozoic crustal extension formed the dominant north-south-trending fault-block topography that visually dominates most of the Basin and Range physiographic province, including the research area (Hintze, 1973, p. 113). Mountain ranges adjacent to Tule Valley consist primarily of Paleozoic limestone, dolomite, shale, and quartzite (e.g., Morris, 1978). A quartz monzonite stock was intruded in the House Range during Jurassic time (Hintze, 1973, p. 72). Mesozoic and early Cenozoic compression deformed the rocks of the House and Confusion Ranges (Hintze, 1973, p. 7; Hose, 1977). Allmendinger and others (1983, p. 534-535, fig. 3) suggest that the high-angle Cenozoic normal fault on the Tule Valley (west) side of the House Range soles into a Mesozoic thrust reactivated as a normal fault. The Honeycomb Hills at the north end of the valley consist of rhyolitic flows, rhyolitic tuffs, and basalt flows (Congdon, 1987, p. 6, fig. 2). These rocks are about 4.7 Ma (Lindsey, 1977; Turley and Nash, 1980).

Tule Valley lies in a region of mid-latitude dry climate. It has cold winters, hot summers, and low average annual precipitation. Table 1 lists relevant climatic statistics for the six Utah weather stations that are closest to Tule Valley, of approximately the same elevation as the study area, and in a similar environmental setting (see figures 1 and 3). Averaged over their measurement periods, each of the six stations has lowest mean monthly temperature in January and highest mean monthly temperature in July. From these data it may be inferred that Tule Valley has an approximate mean annual temperature of 50° F (10° C), January temperature of 27° F (-2.8° C), July temperature of 76° F (24° C), and annual precipitation of 7.0 inches (17.8 cm).

Climatological data from Milford, Utah, approximately 60 miles (97 km) southeast of the study area (figure 1), show that fastest winds come most frequently from the southwest (National Oceanic and Atmospheric Administration, 1972-1986). Informal observations made during fieldwork in Tule Valley support the hypothesis that in the study area fastest winds also blow most frequently from the southwest, before the passage of cold fronts. The concentration of eolian sand dunes in the northeastern part of Tule Valley and their northeasterly orientation provide further evidence in favor of this hypothesis. After cold fronts move through the valley, strong northerly winds occur. This wind direction is reflected in the

Table 1.
Climatological variables for stations near Tule Valley

Station [ft asl]	Years of record	Mean annual temperature (°F)	Mean Jan. temperature (°F)	Mean July temperature (°F)	Mean annual precipitation (in.)
Callao* [4320]	38	49.3	26.7	73.3	5.53
Delta* [4623]	48	50.0	26.0	75.7	7.90
Deseret* [4585]	58	49.2	26.0	74.5	7.92
Eskdale* [4980]	20	50.6	28.7	74.9	6.05
Fish Springs+ [4335]	13	52.9	28.7	80.0	7.48
Partoun+ [4750]	23	49.8	26.9	75.2	6.00

**Data are from Stevens and Brough (1987).*
+Data are from Stephens (1977).

dominant location of sand shadows on the south side of shrubs growing on Tule Valley eolian sand. The northerly winds usually do not last as long as the prefrontal southwesterly winds, but evidence of them is preserved in the sand-shadow orientation because they typically blow after the southwesterly winds. The north-south alignment of Tule Valley probably modifies the wind direction to some extent from the ideal southwesterly and northwesterly wind directions associated with model frontal storms (Stevens and Brough, 1977, p. 36).

Vegetation in Tule Valley varies with elevation, drainage, and soil-salinity factors. In general, the upper part of the piedmont zone is well drained and has low-salinity soils. The lower piedmont zone tends to have poorer drainage and slightly saline soils. Soils on the basin floor are typically poorly drained and saline. Table 2 lists the dominant vegetation types in the study area according to these generalized subenvironments.

The Federal Government and the State of Utah own Tule Valley. Sheep and cattle operations use it for winter range. Herders stay in the valley during the grazing season, but at present no one resides there permanently. Apparently very few people have ever established permanent residence in Tule Valley (Meinzer, 1911; Berge, 1964).

PREVIOUS WORK

In an 1859 expedition across the Great Basin, Simpson (1876, p. 123) named the region between the House and Confusion Ranges White (now Tule) Valley because it was "very generally white with alkaline efflorescence ...." Gilbert crossed the northern and central parts of the study area for the Wheeler Survey in 1872, but the structure of the House Range interested him more than the characteristics of the adjacent basin (Gilbert, 1875, p. 25-28). In 1880 Gilbert again visited the study area, this time focusing on its Lake Bonneville features (Hunt, 1982, p. 150-154). Besides noting shorelines and lacustrine tufa, Gilbert recorded field observations on Tule Valley springs and soils. In his Lake Bonneville monograph Gilbert (1890, p. 104) described Tule Valley as "a barren plain," and revealed that he had delegated parts of it for his assistants to investigate (Gilbert, 1890, p. 18a, plate III). Gilbert (1928, p. 70) returned to the valley in 1901, but again the structure of the House Range commanded his attention. Davis (1905) also travelled to Tule Valley in order to study the House Range, but included in his report descriptions of the study area's lake sediments, shorelines, alluvial fans, playas, springs, and dunes.

Table 2.
Common vegetation types in Tule Valley

MIDDLE AND UPPER PIEDMONT ZONE

Sagebrush *(Artemisia tridentata)*
Mormon tea *(Ephedra nevadensis)*
Shadscale *(Atriplex confertifolia)*
Rabbitbrush *(Chrysothamnus sp.)*
Cheatgrass *(Bromus tectorum)*
Indian ricegrass *(Oryzopsis hymenoides)*
Horsebrush *(Tetradymia glabrata)*
Yucca *(Yucca sp.)*
Various cacti

LOWER PIEDMONT ZONE

Greasewood *(Sarcobatus vermiculatus)*
Shadscale *(Atriplex confertifolia)*
Halogeton *(Halogeton glomeratus)*
Winterfat *(Eurotia lanata)*

BASIN FLOOR

Greasewood *(Sarcobatus vermiculatus)*
Pickleweed *(Allenrolfea occidentalis)*
Salt cedar *(Tamarix sp.)*
Marsh bulrush *(Scirpus paludosis)*
Salt grass *(Distichlis stricta)*

Gilbert's (1890, p. 128a, plate XIII) map showing the extent of Lake Bonneville at the Bonneville and Provo shorelines (figure 4) included the first delineation of lake levels in the study area. According to Gilbert's map, during Bonneville shoreline time the Tule Valley embayment communicated with the main part of the lake through two straits, one at Sand Pass in the northeast corner of the basin and the other near the Honeycomb Hills area of extreme northern Tule Valley (figure 3). Many years later, Jones (1940, p. 13) portrayed the Bonneville-level integration as being only through Sand Pass. On Fisher's (1974, p. 5, fig. 2) map, the Bonneville-level Tule Valley embayment is connected to the main portions of the lake at both north end locations and with Wah Wah (formerly Preuss) Valley to the south. In addition to the Sand Pass, Honeycomb Hills, and Wah Wah Valley straits, Williams and Bedinger (1984) depicted the Bonneville-level Tule Valley embayment as being connected to the Sevier Desert to the east. Nevertheless, recent intensive Lake Bonneville mapping projects uphold Gilbert's original mapping of the Bonneville shoreline in the study area (Currey, 1982; Currey, Atwood, and Mabey, 1984; Sack, this report).

Gilbert's (1890, p. 128a, plate XIII) rendition of the Provo shoreline (figure 4) shows the Tule Valley embayment connected to Lake Bonneville only near the Honeycomb Hills. Alternatively, Meinzer (1911, p. 122) suggested that, as at the Bonneville level, the Provo-level Tule Valley embayment was connected to the main part of the lake at both Sand Pass and the Honeycomb Hills. Jones (1940) disagreed and accepted Gilbert's (1890, p. 19-21) original interpretation. The latest mapping of the Provo shoreline reveals that the water bodies actually communicated only through Sand Pass (Currey, 1982; Currey, Atwood, and Mabey, 1984; Sack, this report).

A few geologic maps broadly portray Tule Valley Quaternary deposits. Powell (1958) and Piekarski (1980) categorized small portions of the House Range piedmont as either lacustrine or alluvial deposits. With one exception, geologic quadrangle maps that cover portions of Tule Valley show Quaternary deposits as a single, undifferentiated unit (Hose, 1963a, 1963b, 1974; Hose and Repenning, 1963, 1964; Hintze, 1974a, 1974b, 1980a, 1980b, 1981a, 1981b). Hintze (1980c) divided the Fish Springs Range piedmont into either a Quaternary or an older Quaternary/Tertiary (?) map unit.

Previous research projects have emphasized various geological characteristics of the study area. Crosson (1964) conducted a gravity survey across the region. He concluded that southern Tule Valley contains approximately 5000 feet (1524 m) of basin fill, whereas depth to bedrock is much shallower in the northern part of the basin (Crosson, 1964, p. 16-18). Other investigators (e.g., Bucknam and Anderson, 1979; Bucknam and others, 1980; Piekarski, 1980; Wilberg and Stolp, 1985) mapped portions of the House Range piedmont fault scarps. In addition, they used scarp morphology to estimate scarp age and the possible Richter magnitude of associated earthquakes. Tinl and Pierce (1984) interpreted Lake Bonneville depositional environments from a 12-foot (3.7 m) core of diatomaceous marl.

Several ground-water studies provide information on Tule Valley. Meinzer (1911) included this basin in his comprehensive western Utah ground-water investigation. He located Tule Valley springs and attributed hummocky topography on the basin floor to eolian processes (Meinzer, 1911, p. 122). Snyder (1963) classified the study area as topographically closed and hydrologically undrained (p. 498, table 2) but realized that some ground water may leak northward out of the basin to the Great Salt Lake Desert (p. 514) (figure 3). Recent hydrologic investigations of western Utah demonstrate that ground water probably flows into Tule Valley from neighboring basins on the west, south, and east, and from Tule Valley to Fish Springs Flat, northeast of Sand Pass (Stephens, 1977; Bolke and Sumsion, 1978; Gates and Kruer, 1981; Bedinger and others, 1984; Holmes, 1984; Wilberg and Stolp, 1985; Gates, 1987) (figure 3).

METHODOLOGY

After an initial period of intensive fieldwork, the study area was mapped on 1:25,000 and 1:80,000 vertical aerial photographs. The air-photo mapping was field checked and information transferred onto the 1:100,000-scale base map.

Table 3.
Symbols used for Quaternary deposits

	FIRST LETTER TEMPORAL DESIGNATIONS
	Q = Quaternary
	B = pre-Quaternary bedrock
	SECOND LETTER GENERAL DEPOSITIONAL ENVIRONMENT
	a = alluvial
	e = eolian
	l = lacustrine
	m = mass movement
	p = playa
	s = spring
	THIRD LETTER DEPOSITIONAL SUBENVIRONMENT INDICATOR
Alluvial:	c = colluvium
	f = fan
	fa = fan, abandoned
Eolian:	a = alluvial
	d = dune
	g = gypsum
	s = silica
Lacustrine:	a = alluvial
	f = fine-grained
	g = gravel
	l = lagoon
	m = marl
	s = sand
	t = tufa
Mass movement:	f = flow
	t = talus
Playa:	m = mud
Spring:	m = marsh

Table 3 shows the map-unit symbol designations. Initial letter B represents pre-Quaternary undifferentiated bedrock; the letter Q symbolizes a Quaternary deposit. A lower case letter follows the age designation and describes the general geomorphic environment of deposition: alluvial (a), eolian (e), lacustrine (l), mass movement (m), playa (p), or spring (s) environments. Some of the third letters of the map units, such as dune (d), flow (f), lagoon (l), or marsh (m), directly describe the subenvironment of deposition. Others indirectly describe the subenvironment through a material modifier, such as gravel (g), marl (m), sand (s), or tufa (t). These material modifiers also supply information about the subenvironment because, for example with lacustrine deposits, gravel (Qlg) is deposited in a relatively high-energy environment, marl (Qlm) in a low-energy environment, and sand (Qls) in an environment of intermediate energy. One Quaternary unit, abandoned alluvial fan (Qafa), is represented by a four-letter symbol in order to represent its abandoned character yet maintain the alluvial-fan (Qaf) designation.

Some deposits consist of a relatively shallow cover of one material type overlying a different map unit. Those places are represented by stacking the appropriate material symbols, surficial unit above underlying material (Varnes and Van Horn, 1951; Hunt and others, 1953; Robinson and McCalpin, 1987; Oviatt, 1989). In a few places a mixture of two surficial eolian deposits, both occurring in significant amounts, overlie a third type of material. In these instances the two surficial units appear in the numerator of the stacked symbol and the underlying material appears as usual in the denominator. Whichever part of the surface sediments appears to be present in the larger amount is listed as the first symbol of the numerator.

Outlining the Quaternary history of Tule Valley required the collection of data in addition to those used to compile the map. Besides the field observations made for the map regarding depositional environments and general stratigraphic relationships, geomorphic and stratigraphic information relevant to deciphering the general Quaternary history of Tule Valley was gathered by studying the regional Quaternary literature, interpreting aerial photographs and topographic maps, measuring stratigraphic sections, constructing topographic profiles, surveying shoreline elevations, and describing a soil profile. Amino-acid and radiocarbon analyses of four carbonate samples provide some degree of age control on Tule Valley deposits.

DESCRIPTION OF MAP UNITS

Plate 1 shows surficial deposits, piedmont fault scarps, and four shorelines. Three of the four delineated shorelines were created by Lake Bonneville: the Bonneville, Provo, and the lowest Lake Bonneville shoreline in Tule Valley (top of the null zone shoreline). The fourth is the highest Lake Tule transgressive shoreline (bottom of the null zone shoreline). Specific localities referred to in the text are represented on the map with a letter symbol. The approximate correlation of Quaternary map units is given in figure 7. Table 4 lists the percentage of each map unit occurring in the study area.

ALLUVIAL DEPOSITS

Deposits mapped as Qac consist primarily of coarse-grained alluvially reworked colluvium, or alluvium with a significant colluvial component. This unit includes alluvial cones. Qac occurs on the mountain front at or above the piedmont junction, generally separating bedrock from piedmont alluvial or lacustrine sediments. These deposits are late Pleistocene to latest Holocene in age.

Alluvial-fan deposits (Qaf) include coarse- to fine-grained alluvium and debris-flow sediments deposited on piedmont slopes primarily after regression of the lake from the Bonneville shoreline (figure 8). Alluvial-fan deposits found below the Bonneville level are of post-Bonneville shoreline age; the small areas of alluvial-fan deposits found above the Bonneville level may partially consist of sediments deposited before Bonneville shoreline time. Gravel pavements, locally with rock varnish, are common on fan surfaces. The texture of Qaf deposits generally fines down the fan slope, and fan toes downslope from quartzitic and quartz monzonitic outcrops of the House Range tend to be quite sandy. Qaf deposits have been accumulating from late Pleistocene time, through the Holocene, to the present.

Abandoned alluvial-fan deposits (Qafa) are dominantly coarse-grained alluvium and debris-flow deposits found on piedmont slopes above the Bonneville shoreline. Qafa deposits consist primarily of alluvial fans that were abandoned when Lake Bonneville regressed from its highest level. In many places loess has accumulated on the surface of abandoned alluvial fans. A soil profile in abandoned alluvial-fan deposits displayed a II+ stage of carbonate morphology (terminology after Gile and others, 1966; Machette, 1985). Qafa areas may contain small amounts of much older (Tertiary?) abandoned alluvial-fan deposits (Hintze, 1980c), therefore the unit is designated as late Tertiary(?) to late Pleistocene in age.

Table 4.

Map units as percentage of study area

30.3%	Qla	Undifferentiated lacustrine and alluvial deposits
25.4%	Qaf	Alluvial-fan deposits
20.2%	Qlf	Fine-grained lacustrine deposits
6.5%	Qafa	Abandoned alluvial-fan deposits
5.1%	Qlg	Lacustrine gravel
3.4%	B	Undifferentiated bedrock
2.5%	Qlm	Lacustrine marl
1.8%	Qed	Morphologically well-developed eolian dunes
1.7%	Qes	Siliceous eolian sand
1.2%	Qeg	Eolian gypsum deposits
0.8%	Qlt	Lacustrine tufa
0.4%	Qls	Lacustrine sand
0.4%	Qac	Undifferentiated alluvium and colluvium
0.1%	Qpm	Playa mud
0.1%	Qll	Lacustrine lagoon deposits
<0.1%	Qmf	Debris-flow deposits
<0.1%	Qsm	Marsh deposits
<0.1%	Qea	Alluvially reworked eolian deposits
<0.1%	Qmt	Scree

EOLIAN DEPOSITS

Small areas of the central House Range piedmont consist of primarily sand-sized material that was deposited by the wind and subsequently reworked by minor streams and slopewash (Qea). These local sites occur between the Bonneville and Provo shorelines. Provo-level lacustrine nearshore sand was entrained by the wind and deposited on the alluvial-fan slopes. These alluvially reworked eolian deposits are of late Pleistocene to Holocene age.

Most Tule Valley dunes are sand-dominated, but many also contain considerable amounts of silt and clay. In some dunes the sand is mostly gypsum; the sand in other dunes is mostly silica. All morphologically well-developed dunes are mapped as Qed. The main dune forms are shrub-coppice, dome, linear, and parabolic. Active dunes tend to occur on the central valley floor downwind from gypsum-rich marl flats, and along the basin floor-piedmont margin in the northeastern and east-central part of the valley. Probable fossil dunes lie at the east-central edge and in the central portion of the valley floor. Some linear dunes located on the eastern side of the basin seem to have formed along former low-level Lake Tule or Tule playa-lake shorelines. This phenomenon of eolian sand being preferentially deposited along former shorelines has been noted elsewhere in the Bonneville basin (Dennis, 1944; Ross, 1973; Currey, 1980). Tule Valley dunes are largely of Holocene age, but some may have started accumulating in late Pleistocene time.

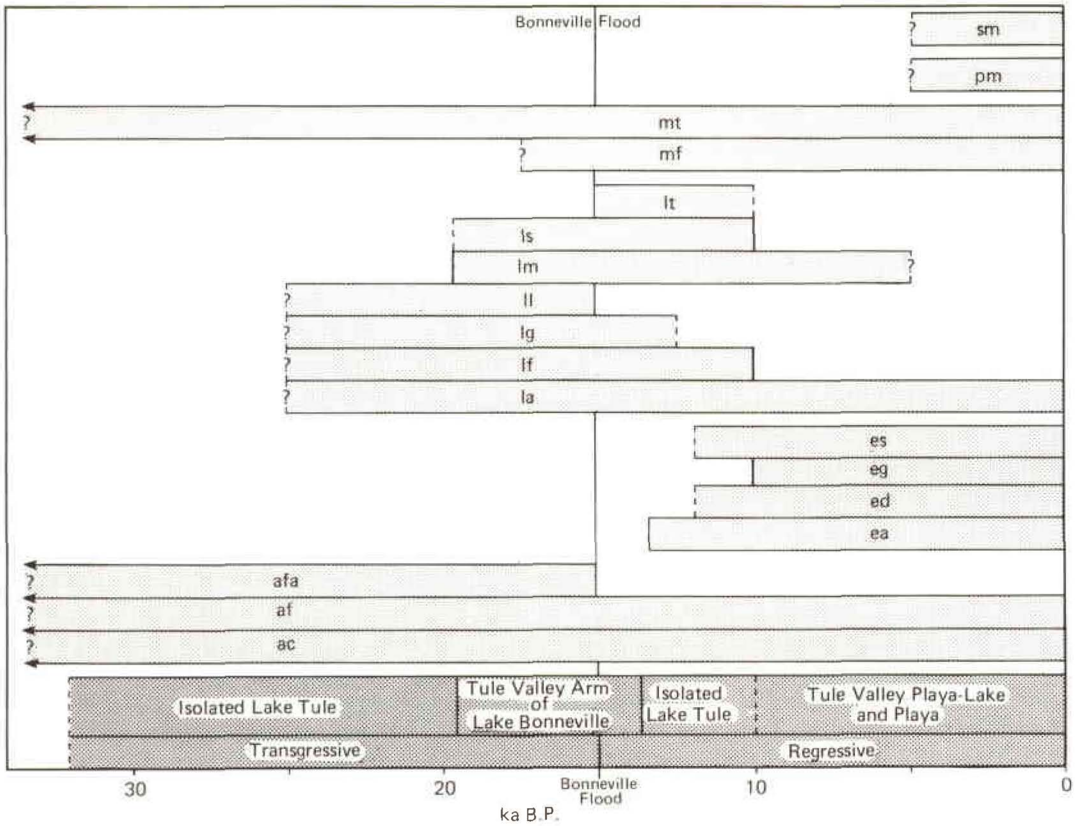


Figure 7. Approximate correlation of Quaternary map units.

Surficial material mapped as Qeg consists primarily of sand-sized gypsum deposited as sand sheets rather than in well-developed dunes. Qeg occurs in the central part of the valley and near the piedmont toe in the northeast and east-central portion of the study area. Gypsum sand sheets lie downwind from fine-grained, gypsum-bearing valley floor deposits and adjacent to gypsum dunes. As Eardley (1962) reported from the Great Salt Lake Desert, sand-sized gypsum crystals form on the surface of carbonate-rich Tule Valley basin-floor muds. The wind-deposited gypsum sand sheets were deposited during Holocene time.

Siliceous sand deposited as sand sheets rather than in well-developed dunes is mapped as Qes. This unit appears in the northeast and southeast parts of the study area near outcrops of quartzite and quartz monzonite bedrock. Stream channels crossing the lower piedmont sector in the northeastern part of Tule Valley carry considerable sand derived from the Prospect Mountain Quartzite. Most of these channels widen at their distal ends in the lower piedmont zone, where they deposit sandy alluvium. Eolian processes transport some of the sand a short distance to the northeast, depositing it as a sheet of siliceous sand. Some lower portions of the House Range piedmont in the northeastern part of Tule Valley consist of a complex mixture of siliceous and gypsiferous eolian sand. Siliceous eolian sand deposits may be of very late Pleistocene through Holocene age.

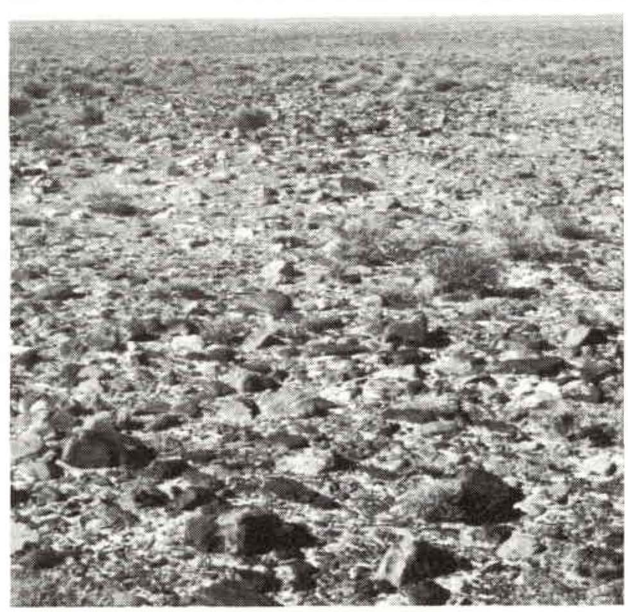


Figure 8. Alluvial-fan deposits (Qaf) of the House Range piedmont.

LACUSTRINE DEPOSITS

Under various circumstances coarse- to fine-grained sediments found in the piedmont zone below the Bonneville shoreline are mapped as Qla. In the middle and upper piedmont sectors this unit consists mainly of alluvial-fan deposits of pre-Bonneville lake-cycle age that were only moderately reworked by lacustrine processes. As a result, the mapped area contains alluvial-fan deposits overlain by a thin cover of lacustrine gravel. In these places the unit is commonly expressed geomorphically as pre-Bonneville alluvial fans etched by Lake Tule or Lake Bonneville shorelines (figure 9). In the lower piedmont sector Qla is generally more fine-grained than in the upper piedmont because the pre-lake fan material was finer near the distal end of the fan. Smaller areas of Qla occur where Lake Tule or 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 of late Pleistocene through latest Holocene age.

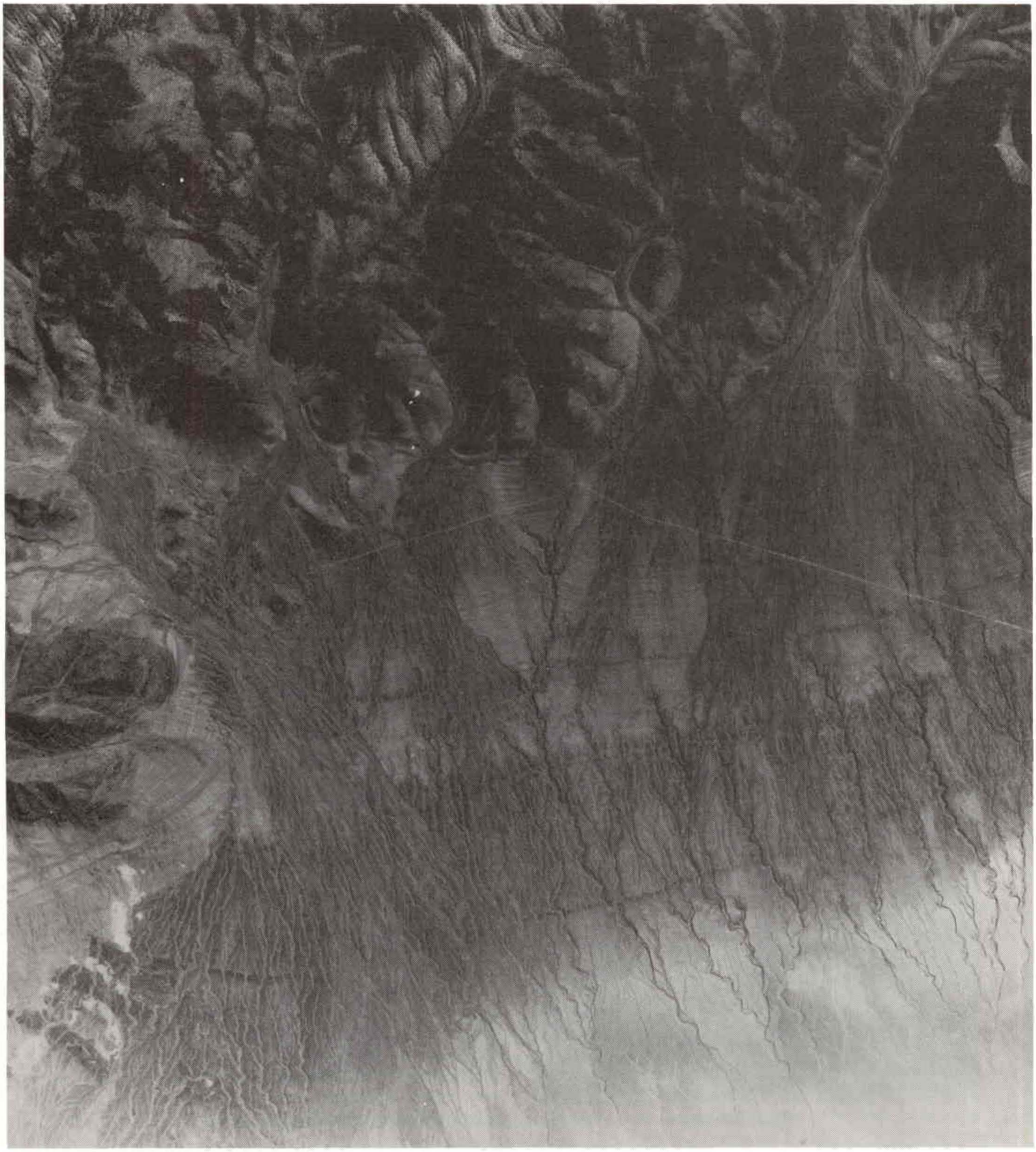
Qlf consists of varying combinations of lake-deposited sand, silt, clay, and marl found mainly on the margins of the valley floor. The sediments mapped in Tule Valley as lake fines are frequently sand-dominated, with the sand fraction locally occurring as gypsum. The lacustrine fines commonly contain efflorescing salts. In some places, this unit is reworked into shrub-coppice dunes. In other places eolian deflation has removed the fines down to the level of underlying water-saturated marly mud, leaving isolated remnant buttes of lake fines separated by marl flats (figure 10). Qlf locally includes alluvially reworked lacustrine deposits. Qlf is of late Pleistocene age.

Coastal gravel deposited by Lake Tule or the Tule Valley arm of Lake Bonneville is mapped as Qlg. Alluvial fans constitute the immediate source of material for most of Tule Valley's lacustrine gravel depositional features. Geomorphically, the gravel deposits occur as beaches, spits, tombolos, bayhead barriers, and cuspate barriers (V-bars). The elevation of the lowest Lake Bonneville shoreline found in Tule Valley (figure 9) ranges from about 4740 feet (1445 m) at the north end of the valley to about 4710 feet (1436 m) at the south end. Lake Bonneville deposited the lacustrine gravels found at or above this shoreline; Lake Tule gravels occur below this shoreline. Most Lake Tule coastal gravel and its largest depositional features were deposited during Lake Tule's transgressive phase. Regressive Lake Tule lacustrine gravel typically forms only small spits of reworked transgressive gravel. The highest transgressive Lake Tule shoreline (figure 9) occurs about elevation 4645 feet (1416 m) at the north end of the study area, decreasing to an elevation about 4613 feet (1406 m) at the south end. Below this shoreline both transgressive and regressive Lake Tule gravel deposits occur, but the majority are from the transgression, as supported by stratigraphic relationships with deep-water Lake Bonneville sediments (figure 11). Lacustrine gravel between the lowest Lake Bonneville and highest transgressive Lake Tule shorelines was deposited by regressive Lake Tule. Qlg deposits are late Pleistocene in age.

The Qll unit consists of sand, silt, clay, and marl deposited in lagoons behind Lake Tule and Lake Bonneville gravel barriers. A minor amount of post-lacustrine, Holocene sediment may have washed into the depressions by slopewash. Tule Valley lagoon deposits are late Pleistocene in age.

Figure 10. *Remnant butte of fine-grained lacustrine deposits (Qlf) overlying marl (Qlm).*

***Figure 9.** Aerial photograph of the House Range piedmont, northeast Tule Valley (north is to left). The photo shows pre-Bonneville alluvial fans etched by shorelines (Qla) and active alluvial fans (Qaf). The null zone is the dark band without shorelines that extends generally left to right across the lower portion of the photo. Well-developed transgressive Lake Tule shorelines build up to the bottom of the null zone shoreline in the lower left corner. (Photo from EROS Data Center.)*



Qlm includes Gilbert's (1890) pelagic Lake Bonneville white marl (figure 11) as well as sandy reworked white marl and marly sand. Above the Provo shoreline Qlm consists of unreworked marl, although it may contain sand and pebbles especially in relatively nearshore sites. Large accumulations of original and reworked marl occur just below Provo-level depocenters, and most of the broad basin floor is composed of lake-deposited marl and marly fines (figure 12). The surface of the valley-floor marl deposits commonly exhibits sand-sized gypsum grains. Other marl exposures often display efflorescing salts. Marl in Tule Valley typically contains abundant ostracodes and occasional gastropods. Tinl and Pierce (1984) noted diatoms in a 12-foot (3.7 m) core of marl from Tule Valley. The large amount of marl in Tule Valley may be due in part to the dominantly carbonate bedrock in the surrounding ranges, but probably is especially the result of limited circulation between the Tule Valley embayment and the main body of Lake Bonneville. Qlm is late Pleistocene to middle Holocene in age.

Qls occurs as sand, marly sand, or pebbly sand in association with the Provo shoreline. Qls lies about 10 to 60 feet (3-18 m) vertically below depositional segments of the Provo shoreline, usually overlying the white marl (Qlm). Lacustrine sand locally includes carbonate-coated gastropods and sand-sized ooids. It is of late Pleistocene age.

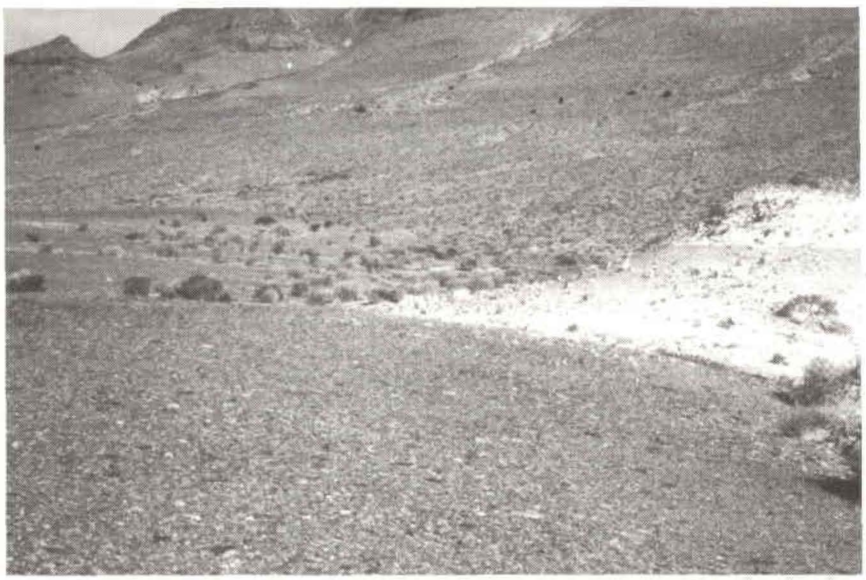


Figure 11. Pelagic Lake Bonneville white marl (Qlm) overlying transgressive Lake Tule coastal gravel (Qlg).

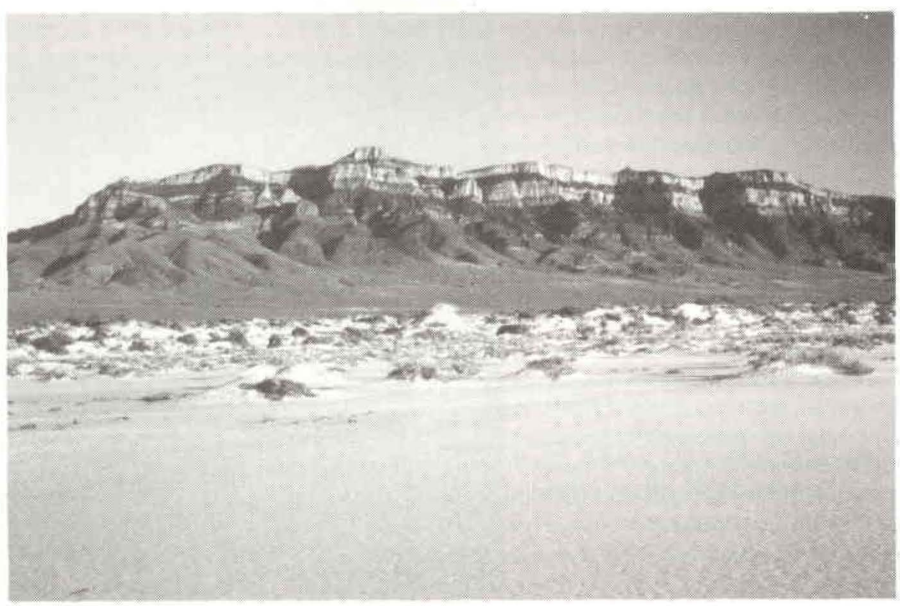


Figure 12. An area of marl flats (Qlm) on the floor of Tule Valley.

Qlt is calcium carbonate precipitated in nearshore environments during Provo shoreline time and during the subsequent regressive phase of Lakes Bonneville and Tule. Most of the tufa overlies marly lacustrine fines in a zone extending about 20 to 75 feet (6-23 m) below erosional segments of the Provo shoreline, where it forms a semicontinuous shelf around the basin. Dome-shaped accumulations of tufa overlie marl at very low elevations along the Smelter Hills. A radiocarbon date of 13,790 ± 130 yr B.P. (Beta-26794) (plate 1, locality A) on this material supports the hypothesis that it precipitated from the calcium bicarbonate-rich water of regressive Lake Tule. Tule Valley lacustrine tufa is late Pleistocene in age.

MASS MOVEMENT DEPOSITS

Debris-flow deposits (Qmf), generally coarse and lacking interstitial fines, occur in sites just below the House Range piedmont junction (figure 13). This unit is used instead of Qaf where the debris-flow deposit does not display a well-developed fan shape, or where the material appears to be solely of debris-flow origin rather than from a combination of streamfloods and debris flows, as is commonly the case for alluvial fans. The tendency for Qmf deposits to have only small amounts of interstitial fines may be due to 1) postdepositional washout of fine-grained sediments, or 2) a generally sparse production of fine-grained debris, especially in flow deposits derived from regions of quartzite bedrock. Tule Valley debris-flow deposits range from late Pleistocene to latest Holocene age.

Scree (Qmt) is coarse rockfall debris comprising talus. Qmt occurs at approximately the piedmont junction and is found at a mappable scale only along the southern portion of the front of the House Range. Scree is late Pleistocene to latest Holocene in age.

PLAYA DEPOSITS

Playa mud (Qpm) consists of poorly sorted clay, silt, marl, and small amounts of sand. In many places thin accumulations of gypsum, halite, and other salts form on the playa surface. The extensive Tule Valley basin floor has only relatively small areas of true playa deposits (figure 14), and instead is dominated by lake-deposited marl (figure 12). Tule Valley playa muds are Holocene deposits.

SPRING DEPOSITS

Small areas of fine-grained marsh deposits (Qsm) occur in areas with high water tables, typically near basin-floor springs. These deposits tend to be organic-rich, marly, and saline. They are Holocene-age deposits.

BEDROCK

Mappable, undifferentiated bedrock outcrops included within the study area perimeter are designated B on plate 1.

LATE QUATERNARY HISTORY

The general Quaternary geologic history of Tule Valley primarily reflects the regional Quaternary climatic history. Tule Valley was probably a closed basin throughout most of the late Quaternary (approximately the last 190,000 years), except perhaps during climatic minimum periods when it attained hydrologic integration with the Bonneville basin. Its deposits reflect oscillations between arid and more humid climatic periods. During periods of lower available moisture,

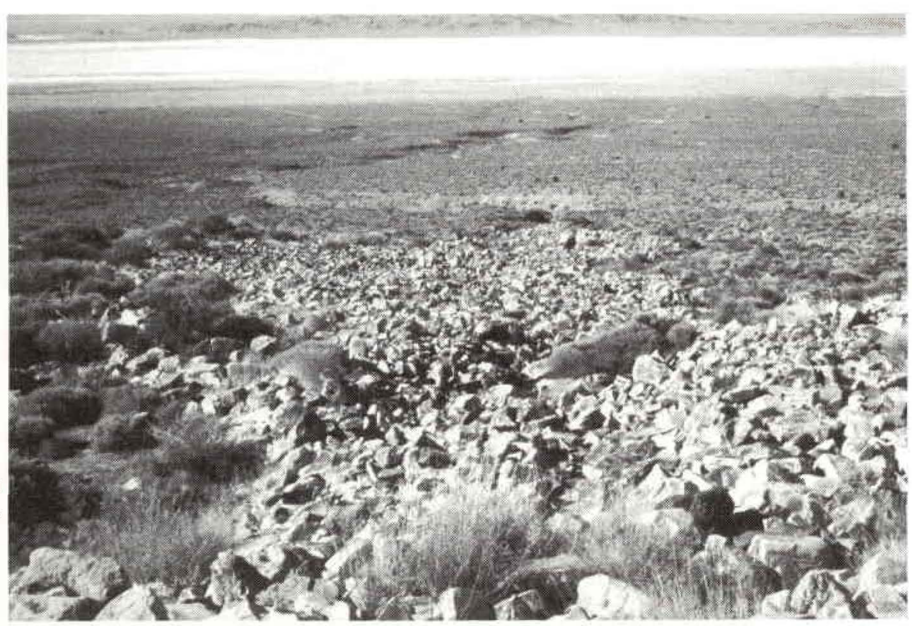


Figure 13. *Debris-flow deposits (Qmf) just below the House Range piedmont junction.*

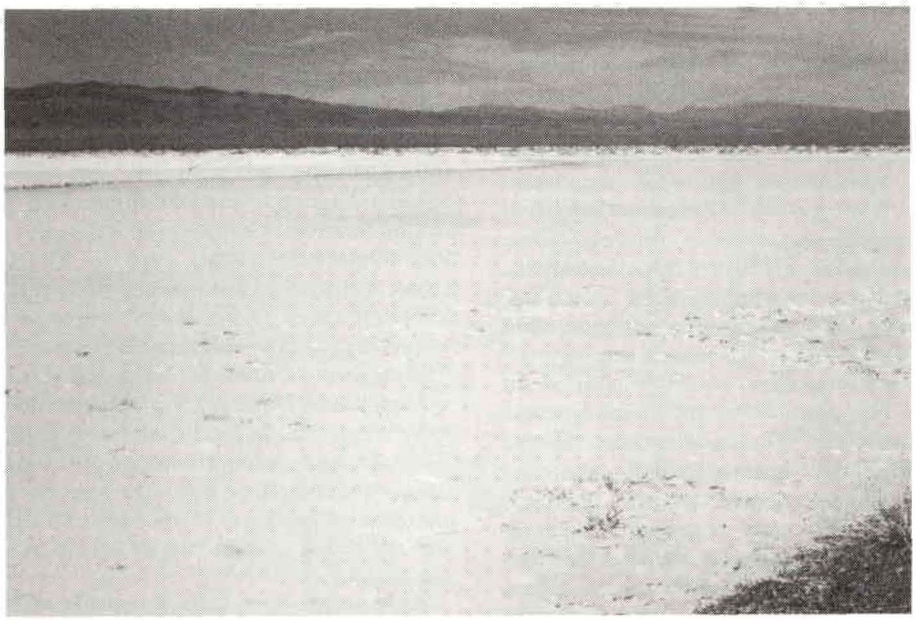


Figure 14. The surface of the modern Tule Valley playa. Note playa blisters and the surface accumulation of salts.

alluvial-fan and, to a lesser extent, eolian processes dominated the geomorphic system. During times of higher precipitation/evaporation ratios, basin playas expanded into perennial lakes in the lower portions of Tule Valley, but alluvial-fan processes may still have acted on the upper piedmont. By comparing the size and degree of preservation of Bonneville basin alluvial fans with its lacustrine features, Gilbert (1890, p. 93) concluded that the pre-Bonneville period of aridity lasted much longer than the lacustrine epoch. Compared with the main portion of the Bonneville basin, arid-phase processes probably have been even more dominant in Tule Valley because it 1) does not have the hydrologic advantage of an extremely high and large drainage basin, like the Great Salt Lake drainage basin does, and 2) was probably only integrated with Bonneville basin lakes during their higher stages. Nevertheless, relict lacustrine deposits and geomorphic features are common and relatively well preserved in Tule Valley (figure 9). They are emphasized in this investigation because, in addition to providing several potential opportunities to find datable material, they tie into well-established Bonneville basin lake chronologies (e.g., Scott and others, 1983; Currey and Oviatt, 1985; McCoy, 1987; Oviatt and others, 1987).

In late Pleistocene time, the Bonneville basin contained major lakes at least twice prior to the Bonneville lacustral cycle. Lake Bonneville existed within marine oxygen-isotope stage 2. When the water level reached an elevation around 5092 feet (1552 m) (Currey, 1982, p. 23), Lake Bonneville discharged into the Pacific Ocean drainage system. The penultimate lake cycle, the Cutler Dam cycle, probably occurred sometime between 40,000 and 80,000 yr B.P., perhaps toward the end of oxygen-isotope stage 4 (Oviatt and others, 1987, p. 257). According to Oviatt and others (1987, p. 253), the water level of this saline lake may not have exceeded an elevation of 4396 feet (1340 m). A lake also existed in the Bonneville basin near the end of oxygen-isotope stage 6, probably sometime between 150,000 and 90,000 yr B.P. (Scott and others, 1983, p. 280). During this Little Valley lake cycle (McCoy, 1981; Scott and others, 1982, 1983) the water rose higher than the lake did in the Cutler Dam cycle, but not as high as Lake Bonneville.

Firm evidence supports the interpretation that Tule Valley was integrated with Lake Bonneville. This evidence includes: 1) Lake Bonneville shorelines are traceable into Tule Valley on aerial photographs, 2) the Bonneville and Provo shorelines are identifiable in Tule Valley by their distinctive elevation, and by their morphologic, sedimentologic, and stratigraphic signatures, 3) the pelagic Lake Bonneville white marl is found in Tule Valley, and, 4) an inflow feature exists on the Tule Valley side of Sand Pass. The present elevation of Sand Pass is 4744 feet (1446 m). This is much lower than the maximum threshold elevation of Lake Bonneville at 5092 feet (1552 m). Sand Pass is, however, above 4396 feet (1340 m), which is the elevation suggested for the highest lake level of the Cutler Dam cycle (Oviatt and others, 1987). Apparently Tule Valley was not a subbasin of the Bonneville basin during that lake cycle. However, the highest unfaulted evidence of the Bonneville basin's Little Valley lake cycle occurs at an elevation of 4954 feet (1510 m) (Scott and others, 1983; McCoy, 1987). This sugggests that Tule Valley may have been integrated with the isotope-stage 6 lake.

BONNEVILLE LAKE CYCLE

Because closed-basin lakes have no outlet stabilizing the water level, they are constantly fluctuating in response to changing climatic and hydrologic variables. As a result of the oscillating water level, shoreline features potentially occur throughout the entire vertical span over which the closed-basin lake fluctuates. As soon as the lake regresses, subaerial processes begin to obliterate this evidence. In Tule Valley, however, obliteration of the shore features from the last lake cycle has not proceeded very far, and abundant coastal features remain. As a result, Tule Valley on aerial photographs exhibits an anomalous zone of no shorelines that approximately encircles the entire basin in the lower part of the piedmont (figure 9). This zone of no shorelines covers a vertical range of about 95 feet (29 m) and is called the null zone. The upper and lower boundaries of the null zone consist of shorelines that are traceable around the entire basin, the top and bottom of the null zone shorelines. Like the Bonneville and Provo shorelines, they are higher at the north than at the south end of Tule Valley. The deformation of these shorelines is primarily due to isostatic rebound (Gilbert, 1890; Crittenden, 1963; Currey, 1982).

Although the modern elevation of Sand Pass is 4744 feet (1446 m), it consists of an estimated 4 feet (1.2 m) of Lake Bonneville regressive and post-lake subaerial deposits. Therefore, 4740 feet (1445 m) is probably the approximate immediate post-inflow elevation of the pass. Near Sand Pass the top of the null zone shoreline also has an elevation of 4740 feet (1445 m). The top of the null zone shoreline is the lowest Lake Bonneville shoreline in Tule Valley. Thus far, the stratigraphic evidence is inadequate to determine whether it is a transgressive or regressive feature. If it is transgressive it is the first Lake Bonneville shoreline to have formed in Tule Valley, and it resulted from a stillstand that accompanied water-level equilibration just after Lake Bonneville spilled into Tule Valley. Alternatively, it may be the result of a brief regressive stillstand just before the two water bodies re-isolated.

Near Sand Pass the bottom of the null zone shoreline has an elevation of 4645 feet (1416 m), about 95 feet (29 m) below the immediate post-inflow elevation of the pass. At several places throughout the valley the bottom of the null zone shoreline lies at the top of a large stack of well-developed coastal features (figure 9). Because these features, as well as the bottom of the null zone shoreline, are clearly overlain by Lake Bonneville white marl, they are transgressive rather than regressive. As a result, the bottom of the null zone shoreline is interpreted to be the shoreline occupied by transgressive Lake Tule at the moment inflow began over Sand Pass from Lake Bonneville. When Lake Bonneville stood at the brink of Sand Pass ready to overflow into Tule Valley, it occupied the highest level it had yet attained in the lake cycle (Currey and Oviatt, 1985). By analogy, at this same time Lake Tule must also have occupied the highest level it had thus far reached in the lake cycle. Therefore, the bottom of the null zone shoreline is believed to be the highest transgressive shoreline of Lake Tule. At this level, Lake Tule had an area of about 255 square miles (660 km^2) and a maximum depth of about 250 feet (76 m). When Lake Bonneville spilled in at Sand Pass, the water level rose rapidly over the 95-foot-high (29 m) null zone, leaving little shoreline evidence.

Assuming that the immediate post-inflow elevation of Sand Pass is roughly equivalent to its pre-inflow elevation, an estimate of the age of Lake Bonneville spillover can be derived from the Currey and Oviatt (1987, unpublished diagram) time-altitude diagram of the lake (figure 15). Using an isostatic rebound-corrected elevation of 4675 feet (1425 m) for Sand Pass (Currey and Oviatt, 1985, p. 10) and the Currey and Oviatt hydrograph, Lake Bonneville would have reached the threshold about 19,500 yr B.P. Because inflow may have incised the pass, this age is considered an estimated maximum-limiting date. In addition, the estimated post-inflow elevation of Sand Pass is 77 feet (23.5 m) below the local elevation of the Provo shoreline. In North Salt Lake, Scott and others (1980, 1982) obtained a radiocarbon date on wood from transgressive deposits 66 feet (20 m) below the local elevation of the Provo shoreline. That date of 19,700 ± 200 yr B.P. (W-4421) suggests that the 19,500 yr B.P. estimate for inflow into Tule Valley is reasonable.

After integration, Lake Bonneville continued its general rising trend toward the Bonneville shoreline, although there were certainly oscillations and stillstands throughout the transgression (Currey and Oviatt, 1985). Eventually the lake reached the Bonneville shoreline, underwent the Keg Mountain oscillation, broke through the alluvial threshold, and fell to a lower threshold at which elevation it formed the Provo shoreline.

Some of Lake Bonneville's transgressive oscillations and stillstands have been identified (Currey and Oviatt, 1985) (figure 15). In parts of the Bonneville basin outside of Tule Valley, previous researchers have casually noted transgressive coastal gravel deposits occurring beneath regressive Provo-stage depositional features (Jones and Marsell, 1955; Goode and Eardley, 1960; Morrison and Goode, 1965; Scott and others, 1980, 1982, 1983; Currey, Oviatt, and Czarnomski, 1984). In their hydrograph of Lake Bonneville, Currey and Oviatt (1987, unpublished) (figure 15) portray the inflow into Tule Valley as being responsible for a brief basin-wide transgressive stillstand. These researchers (1985, p.11) hypothesized that this stillstand may have been responsible for the transgressive coastal gravel deposits typically found about 30 to 50 feet (9-15 m) below the Provo shoreline. However, stratigraphic work in Tule Valley reveals that every major Provo-level depositional feature in the study area also overlies well-developed transgressive coastal deposits. The elevations of four discrete sub-Provo depositional features were measured with an electronic total station at three localities in Tule Valley (figures 16-18). The tops of the sub-Provo features lie 19 feet (5.8 m) (plate 1, locality B; figure 16, upper barrier), 26 feet (7.9 m) (plate 1, locality C; figure 17), 34 feet (10.4 m) (plate 1, locality B; figure 16, lower barrier), and 55 feet (16.7 m) (plate 1, locality D; figure 18) below the local elevation of the Provo shoreline. Because the sub-Provo transgressive coastal gravel deposits that occur approximately 30 to 50 feet (9-15 m) below the Provo shoreline lie above the elevation of Sand Pass and are very well developed in Tule Valley, they cannot be attributed to a stillstand generated by the inflow of Lake Bonneville into Tule Valley.

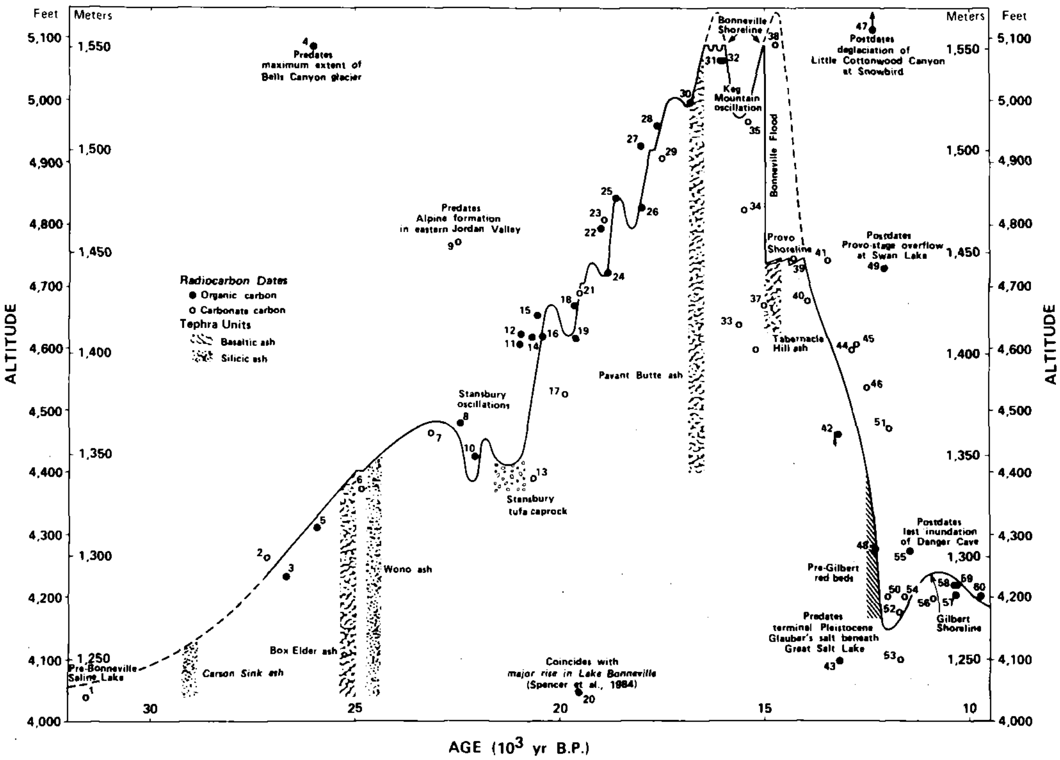


Figure 15. Time-altitude diagram of Lake Bonneville (Currey and Oviatt, 1987, unpublished).

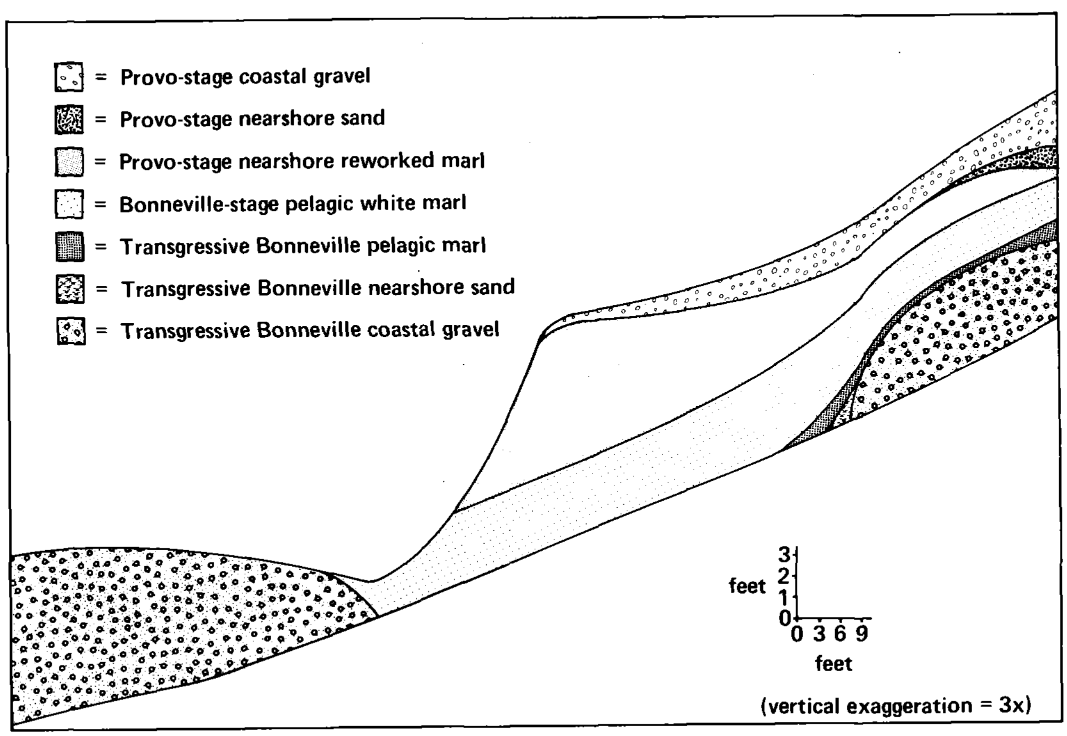


Figure 16. Cross-section through north Hell'n Maria Provo-level depocenter (plate 1, locality B).

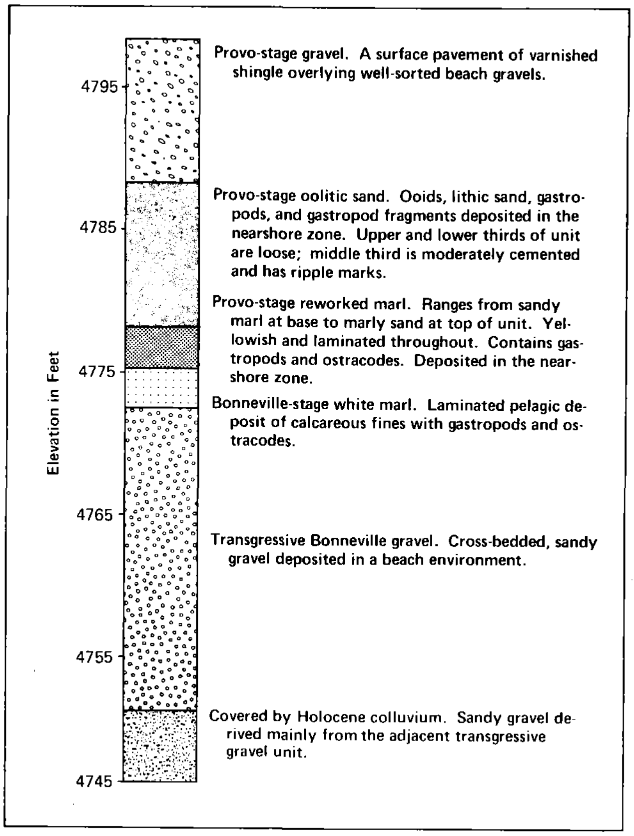


Figure 17. Columnar section at the Provo-level Millab tombolo (plate 1, locality C).

Moreover, geomorphic and elevation data suggest that the sub-Provo features postdate the Bonneville overflow. A radiocarbon date of 17,710 ± 320 yr B.P. (Beta-26795) on gastropod shells from the top of a Tule Valley sub-Provo gravel spit (plate 1, locality E) supports this reasoning, assuming that the 19,500 yr B.P. estimated date of overflow is reasonable. The shells were collected from an elevation of approximately 4760 feet (1451 m) which is about 40 feet (12 m) below the Provo shoreline. Sub-Provo coastal gravel features, therefore, apparently are a Bonneville basin-wide phenomena that were deposited as the result of one or more stillstands or oscillations during the post-Tule Valley inflow part of the Lake Bonneville transgression. It may be coincidental that this transgressive shoreline occurred very close to the elevation that the lake later would occupy during Provo shoreline time.

Previous researchers have attributed the large size of Provo shoreline features, as first noted by Gilbert (1890), to a long stillstand at the regressive Provo shoreline (Gilbert, 1890; Pack, 1939; Currey, 1980) and to Provo-level reworking of Bonneville shoreline deposits (Gilbert, 1890; Scott and others, 1983). Alternatively, the Tule Valley evidence indicates that the large size of Provo-level features may be due, at least partially, to the location of the regressive Provo shoreline just above the elevation of the transgressive sub-Provo stillstand or oscillation.

Lake Bonneville regressed from the Provo shoreline about 14,000 yr B.P. due to climatic change (Currey and Oviatt, 1985, p. 13). Currey (1987, personal communication) suggests that

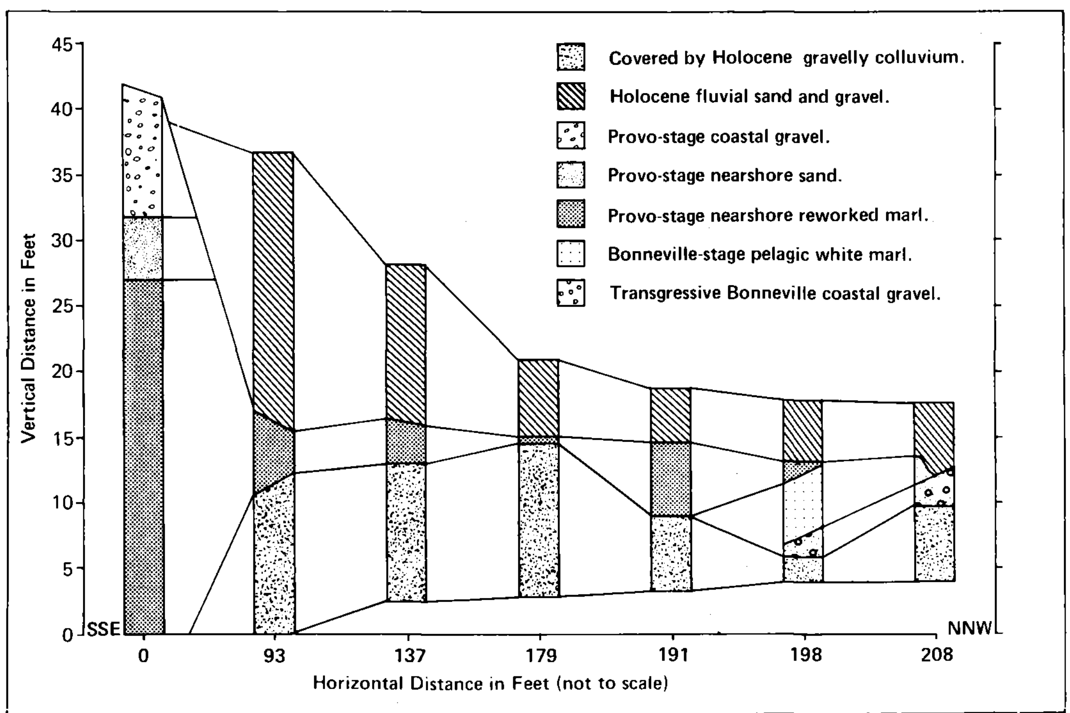


Figure 18. Correlated columnar sections, Roadside Reservoir Provo-level barrier (plate 1, locality D).

the main body of Lake Bonneville fell so rapidly that within about 2000 years it had dropped at least 600 feet (183 m), to a level lower than the present Great Salt Lake. This provides an estimated average long-term rate of regression of 0.3 ft/yr (9 cm/yr). At this rate, Lake Bonneville would have dropped the 77 feet (23.5 m) from the Provo shoreline to the level of re-isolation, Sand Pass, in 257 years.

If Lake Bonneville with its large influent streams regressed at the rate of 0.3 ft/yr (9 cm/yr), certainly the newly re-isolated and hydrologically inferior Lake Tule regressed at a faster rate. The Tule basin-floor tufa that yielded a radiocarbon date (Beta-26794) of 13,790 ± 130 yr B.P. was collected at an elevation of approximately 4460 feet (1359 m). However, because the deposit probably formed in a shallow subaqueous environment, the water level at the time of tufa formation may have been as high as 4490 feet (1369 m). If Lake Tule fell the 250 feet (76 m) from Sand Pass to an elevation of 4490 feet (1369 m) between 14,000 and 13,790 yr B.P., it had an average regression rate of about 1.2 ft/yr (37 cm/yr).

While at the Provo level and continuing into the early stages of Lake Bonneville regression in Tule Valley, calcium carbonate precipitated out of the lake as a ring of tufa fairly close to the Provo shoreline. As the size of the lake decreased further, calcium sulfate precipitated out of the regressing Lake Tule and Tule playa-lake and playa water. In Holocene time, eolian processes have transported gypsum from the valley floor northeast across the valley, depositing it in sand sheets and dunes. The very small modern playa is currently precipitating chlorides.

LITTLE VALLEY LAKE CYCLE

An incompletely resolved problem regarding the late Quaternary history of Tule Valley concerns the hypothesis that the Little Valley cycle lake also spilled into and integrated Tule Valley. Possible evidence for this consists of 1) Little Valley lake-cycle deposits found in the main Bonneville basin at elevations considerably above Sand Pass (Scott and others, 1983; McCoy, 1987), and 2) details of the Sand Pass inflow feature (figures 5 and 19).

The inflow deposit is cut longitudinally by an axial channel that heads near the pass. The axial channel may have formed largely by transgressive Lake Bonneville overflow. The highest point on the inflow feature lies near its proximal end, and has an approximate elevation of 4760 feet (1451 m). This is 20 feet (6 m) above the estimated post-inflow elevation of Sand Pass. Mass balance analyses demonstrate that the volume of water required to raise the water level in Tule Valley from the bottom to the top of the null zone shoreline is very small compared to the volume contained in 20 vertical feet (6 m) of Lake Bonneville water (B. Bills, 1988, personal communication). This indicates that the water level in the main body of Lake Bonneville would not have been able to fall 20 feet (6 m) to reach equilibration with the water level in the newly filled Tule Valley, thereby forming the top of the null zone shoreline on the transgression. Both the 20 feet (6 m) of threshold incision and the water-level equilibration invoked to explain the top of the null zone shoreline as transgressive feature could not have occurred during Lake Bonneville inflow. Either the top of the null zone shoreline is a regressive Lake Bonneville shoreline or the inflow feature is of pre- Bonneville age.

Additional geomorphic evidence derived from the inflow feature suggests that it might be compound, consisting of a steep, proximal bedload component and a low-gradient, distal component (figure 5). Transverse gullies tributary to the axial stream incise the steep portion. The walls of some of these gullies are lined with nearshore lacustrine tufa.

Figure 19. *Delta-like inflow feature on the Tule Valley side of Sand Pass.*

A possible explanation for these features involves two episodes of inflow. Water from the Little Valley cycle lake may have spilled over Sand Pass depositing the steep delta-like inflow component, shortly thereafter incising it to some extent. Climatically induced regression of the lake caused the basins to re-isolate. Transverse gullies formed under subaerial processes during isotope stages 5, 4, and 3. In isotope stage 2, Lake Bonneville spilled into Tule Valley, further incising the steep inflow feature and shifting the locus of deposition down valley. Finally, lacustrine tufa precipitated onto the gully

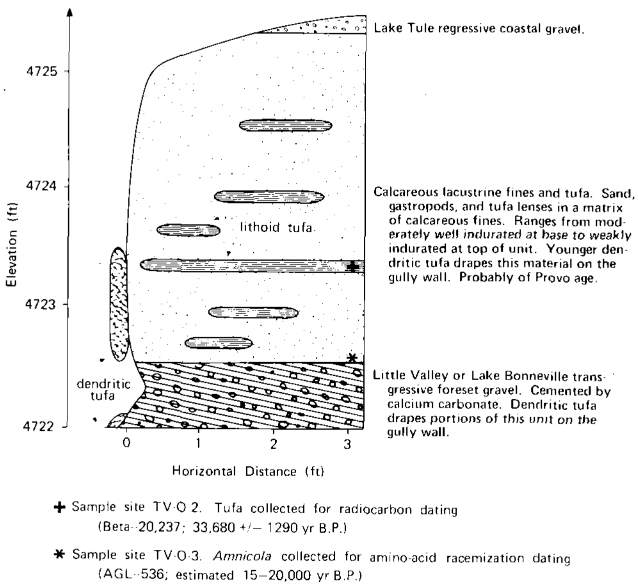


Figure 20. *Stratigraphic section of the Sand Pass delta-like inflow feature (plate 1, locality F).*

walls, perhaps on the transgression, but more likely during or after Provo shoreline time.

In order to test this hypothesis, two samples from a stratigraphic exposure on the steep inflow feature (plate 1, locality F) were collected for dating. The section (figure 20) consists of a basal unit of generally well-sorted foreset gravels, apparently deposited during high-energy inflow. Above the gravel unit lies a deposit of calcareous fines laced with lithoid tufa lenses. Similar calcareous fines are fairly typical of the Provo shoreline and post-Provo regressive nearshore environments. The natural gully wall cutting these lower two units is draped with dendritic tufa. The top of the section consists of a thin layer of coastal gravel, probably a regressive Lake Tule deposit.

Gastropods from the base of the calcareous fines yielded an amino-acid ratio of 0.155 (AGL-536), which is typical of *Amnicola* shells from the last cycle of Lake Bonneville (McCoy, 1981, p. 59; 1987, personal communication). This leads to the inference that the calcareous fines were deposited in the Provo nearshore zone. A corroborative radiocarbon analysis of lithoid tufa from higher up in the same unit, however, produced an age of 33,680 ± 1290 yr B.P. (Beta-20237). The amino-acid age is considered the more reliable age estimate of the carbonate fines for two reasons. First, any contamination of the gastropods would cause the determined amino-acid age to be older than the true age. Second, the tufa sample could easily have been contaminated with small clasts of Paleozoic carbonate bedrock from nearby outcrops.

Although this age determination leads to the inference that the steep inflow feature is of Bonneville cycle age, and therefore that the top of the null zone shoreline is a regressive Lake Bonneville feature, the dated *Amnicola* did come from the carbonate fines directly above the gravel foresets, rather than from the gravel unit itself. The possibility exists that the gravel unit is of isotope stage 6 age. If so, the absence of deposits from isotope stages 5, 4, and 3 must be explained. Subaerial deposits from this time span may have been stripped off during Lake Bonneville overflow or may never have been deposited.

ECONOMIC GEOLOGY

Several gravel pits, a marl pit, and a gypsum extraction site exist in Tule Valley (table 5). The gravel pits are in coarse-grained lacustrine depositional features (Qlg) (figure 21) and in undifferentiated lacustrine and alluvial deposits (Qla). It is likely that all the gravel removed from the pits has been used for local road surfacing. Although significant quantities of well-sorted gravel occur in Tule Valley, the long distance to present major construction centers probably precludes economically feasible, large-scale recovery, at least in the near future. Marl has been collected from one site along the southwest side of the Chalk Knolls, possibly for agricultural lime or diatomite (Tinl and Pierce, 1984). Loose gypsum sand occurs in moderate amounts in Tule Valley and has recently been removed from dunes near the center of the basin. Besides agricultural uses, gypsum is a component of cement, plaster, and sheetrock (Reeves, 1978).

Table 5.
Location of Tule Valley gravel, marl, and gypsum pits

Material	Location
Gravel	NW ¼, SW ¼, SW ¼, sec. 10, T14S, R14W
Gravel	NE ¼, NW ¼, SE ¼, sec. 16, T14S, R14W
Gravel	NW ¼, NW ¼, SE ¼, sec. 16, T14S, R14W
Gypsum	SW ¼, SE ¼, SW ¼, sec. 10, T16S, R15W
Gravel	NE ¼, SW ¼, SE ¼, sec. 11, T16S, R15W
Gravel	NE ¼, SE ¼, NW ¼, sec. 10, T17S, R14W
Gravel	SW ¼, SE ¼, NE ¼, sec. 29, T17S, R15W
Gravel	NW ¼, SE ¼, NE ¼, sec. 16, T18S, R14W
Gravel	NW ¼, NE ¼, SW ¼, sec. 18, T18S, R14W
Gravel	NW ¼, SE ¼, NE ¼, sec. 2, T18S, R15W
Marl	NW ¼, SW ¼, SE ¼, sec. 22, T18S, R15W
Gravel	NE ¼, NE ¼, SW ¼, sec. 13, T19S, R15W
Gravel	SW ¼, NE ¼, SE ¼, sec. 33, T19S, R15W
Gravel	NW ¼, SW ¼, NW ¼, sec. 34, T19S, R15W
Gravel	SW ¼, NE ¼, NE ¼, sec. 19, T20S, R14W
Gravel	SE ¼, NW ¼, NE ¼, sec. 19, T20S, R14W
Gravel	SE ¼, SE ¼, NE ¼, sec. 35, T20S, R14W
Gravel	NW ¼, SE ¼, NW ¼, sec. 8, T20S, R15W
Gravel	SE ¼, NW ¼, NW ¼, sec. 9, T20S, R15W
Gravel	NW ¼, NW ¼, SE ¼, sec. 9, T20S, R15W
Gravel	SW ¼, SW ¼, NW ¼, sec. 11, T20S, R15W

***Figure 21.** Gravel pit in a transgressive Lake Tule coastal depocenter.*

SPRINGS

Springs located within the study area are found near the center of Tule Valley on the basin floor (table 6 and plate 1). They lie along an approximately north-northeasterly trend and have water temperatures from about 67° to 82°F (19.4-27.8°C) (Stephens, 1977, p. 22). Because these values are at least 10°F (5.6°C) higher than the estimated mean annual temperature of Tule Valley, the springs are classified as thermal springs (Mundorff, 1970, p. 7; Stephens, 1977, p. 22). Both the alignment and the thermal character of the springs suggest that they are located along a subsurface fault zone (Stephens, 1977, p. 16).

Table 6.
Location and estimated flow of major Tule Valley springs

Name	Location	Flow (gal/min)	Year
Coyote Spg.	NW ¼, NE ¼, NW ¼, sec. 13, T16S, R15W	100	1986*
		380	1984+
		400	1984+
		320	1983+
		100	1976#
		10	1974#
N. Tule Spg.	NE ¼, NW ¼, SE ¼, sec. 3, T17S, R15W	10	1986*
		30	1984+
		20	1983+
Tule Spg.	NE ¼, NW ¼, NE ¼, sec. 10, T17S, R15W	200	1986*
S. Tule Spg.	SW ¼, NW ¼, NE ¼, sec. 15, T17S, R15W	40	1986*
		100	1984+
N. Willow Spg.	SW ¼, NE ¼, SE ¼, sec. 34, T16S, R15W	100	1984+
Willow Spg.	NE ¼, NW ¼, NE ¼, sec. 3, T17S, R15W	21	1984+
		11	1983+
S. Willow Spg.	SW ¼, NW ¼, NE ¼, sec. 3, T17S, R15W	2	1984+
		3	1983+

**Data were collected by the author for this report. +Data are from Wilberg and Stolp (1985). # Data are from Stephens (1977).*

GEOLOGIC HAZARDS

The geologic hazards in the study area include debris flows, flash floods, water accumulations on the valley bottom, earthquakes, and blowing sand and dust. The greatest danger from debris flows exists in the piedmont zone, especially that of the House Range. Recent debris-flow deposits are common on Tule Valley alluvial fans and near the House Range piedmont junction. The height, steepness, and relatively sparse vegetation of the western House Range render it especially susceptible to thunderstorm-induced mass-wasting events. The distribution of debris-flow deposits suggests that upper piedmont locations are more likely to experience this hazard.

Running water hazards in Tule Valley consist of streamfloods and sheetfloods. Streamfloods sometimes occur immediately after debris flows (Beaty, 1968), or they may originate independently. Both are associated with major, intense precipitation events. Because snowfall usually is modest in the neighboring ranges, most flood hazards probably arise from thunderstorms rather than rapid snowmelt. However, both precipitation sources can contribute to flooding if intense rain falls on soils previously saturated by melting snow. All of the streams in Tule Valley are ephemeral, and from the normally dry condition of the stream channels people may derive a false sense of security about streamflood hazards (figure 22). Channelized flow in Tule Valley is short-lived, occurring only during and just after major rainstorms, but it can be torrential. The piedmont zones are particularly hazardous because most of the valley's stream channels are located there. The House Range piedmont is especially prone to both types of flood hazard because the mountains can orographically enhance precipitation.

A different type of flood hazard occurs on the valley floor. For a few days after a heavy rainfall, larger than average playa areas may be flooded and water may be found on previously unflooded portions of the valley floor. Flooded conditions can persist on the valley bottom for a few years when greater than average annual precipitation falls for several years.

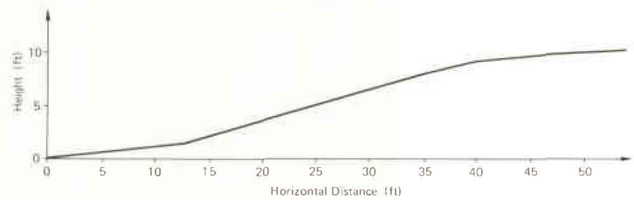
The size and extent of Tule Valley piedmont fault scarps attest to the study area's seismic hazard (Bucknam and Anderson, 1979; Piekarski, 1980). Approximately 4.75 miles (7.6 km) of fault scarps have been mapped for this report, including many previously unmapped traces. Figure 23 presents the topographic profile of a fault scarp on the north side of the Hell'n Maria Canyon fan (plate 1, locality G; figure 24). This scarp is 5.2 feet (1.6 m) high and has a slope angle of 15.5°. Because it offsets transgressive Lake Bonneville shorelines above the Provo shoreline, local evidence provides an estimated maximum-limiting age of approximately 19,000 yr B.P.

Wallace (1977) suggested age categories for fault scarps from other Basin and Range localities. According to his scheme, scarps that, like this one, have a single slope and a slope angle between 15° and 35° are younger than 12,000 yr B.P. Sufficient evidence to support a minimum-limiting age for this scarp is not available, but because the slope angle is close to the minimum for Wallace's youngest scarp category, 12,000 yr B.P. may be a reasonable estimate.

Bucknam and others (1980, p. 302) estimate that fault scarps of similar size located farther north along the central House Range's western piedmont resulted from earthquakes in the Richter magnitude range of 7.0 to 7.5. The hazards associated with an event of this magnitude would include scarp formation, liquefaction, ground cracking, and rockfall in range-front localities. If a large-magnitude earthquake occurs when soils are saturated, ground shaking may trigger slides, slumps, and debris flows that could affect the piedmont zone.

Blowing dust has been observed on many occasions during periods of strong southwesterly winds (figure 25). The potential severity of this hazard is not known. The amount of blowing dust and saltating sand is dependent on surface moisture conditions, wind velocity, and wind duration.

Figure 23. *Topographic profile of north Hell'n Maria Canyon fan fault scarp (plate 1, locality G).*



ACKNOWLEDGMENTS

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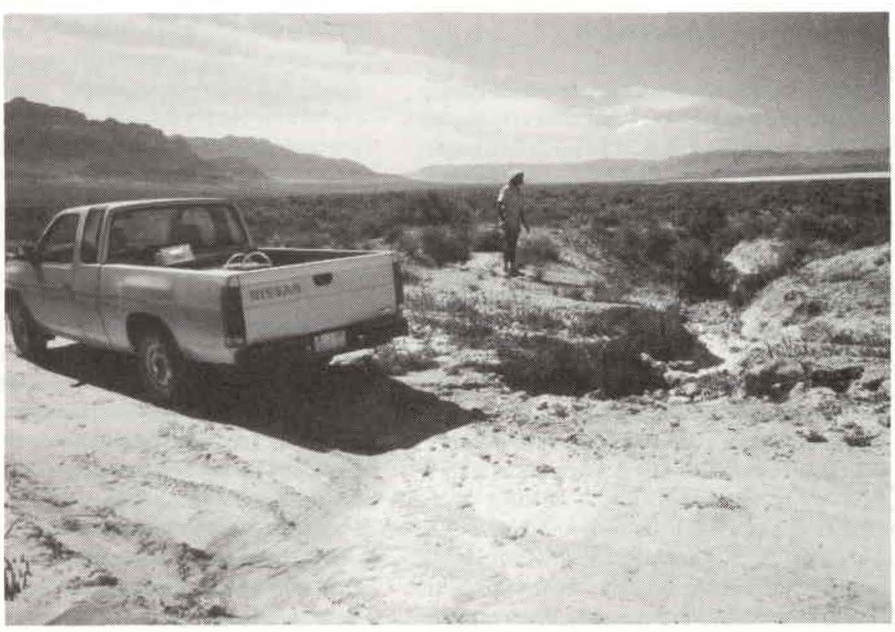
Figure 22. ***Stream channel cut across a road along the House Range piedmont.***



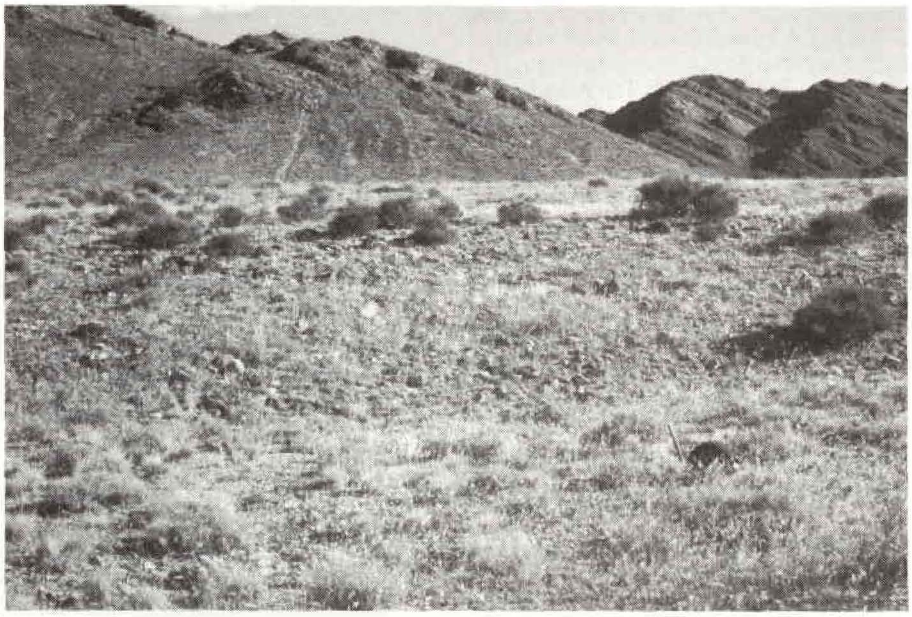


Figure 24. Ground view of the piedmont fault scarp on north Hell'n Maria Canyon fan. Photograph taken near the site of the topographic profile of figure 23 (plate 1, locality G).

Figure 25. Blowing dust approaching Highways 6 and 50 near the south end of the study area.

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