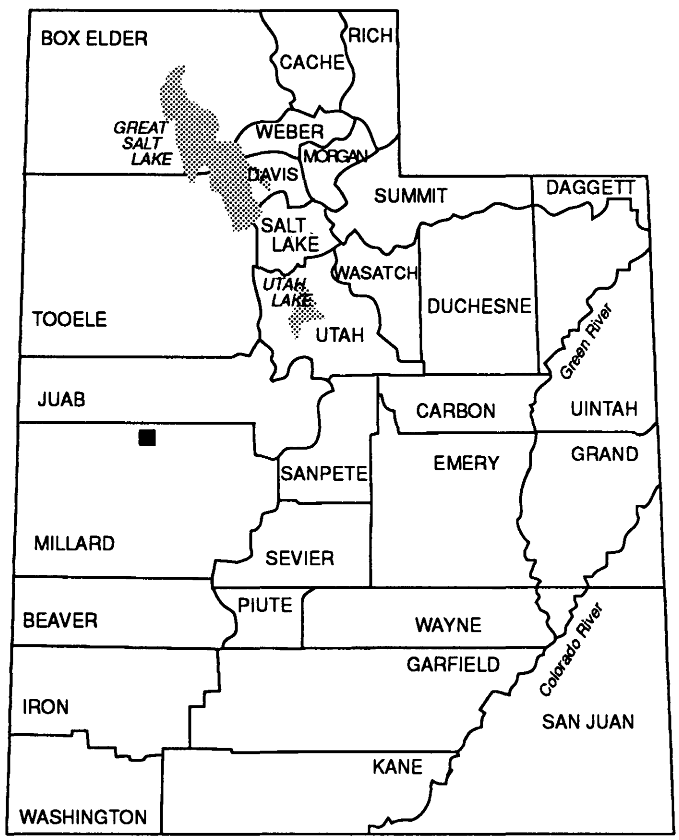
GEOLOGIC MAP OF THE SMELTER KNOLLS WEST QUADRANGLE, MILLARD COUNTY, UTAH

by
Lehi F. Hintze and Charles G. Oviatt
Utah Geological Survey



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GEOLOGIC MAP OF THE SMELTER KNOLLS WEST QUADRANGLE, MILLARD COUNTY, UTAH

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ABSTRACT

This quadrangle includes the southeastern tip of the Drum Mountains, the eastern part of the Little Drum Mountains, a portion of the Sevier Desert transected by a swarm of Quaternary fault scarps, and the western side of the Smelter Knolls rhyolite dome and lava flow complex. Oldest rocks are Middle Cambrian carbonates and shales of the Chisholm, Whirlwind, Swasey Limestone, Wheeler, and Pierson Cove formations. Regionally, these strata aggregate about 2,600 feet (790 m) in thickness but, because of faulting, less than half that amount is exposed in the map area. The east side of the Little Drum Mountains exposes a gentle homocline made up almost entirely of Eocene volcanogenic rocks that lie with angular unconformity over the structurally more complex Cambrian strata. The oldest volcanic rock is the Drum Mountains Rhyodacite, about 1,000 feet (305 m) thick and about 42 million years old. The rhyodacite is overlain by the Little Drum Formation (new name) which is about 39 million years old and 2,400 feet (730 m) thick, here divided into 12 map units. A series of andesitic ash-flow tuffs and tuffaceous deposits make up more than half of the Little Drum Formation. The remainder is composed of a series of coarse, poorly sorted conglomerates that are intercalated with the tuffs. These conglomerates include rounded to subangular quartzite and andesite boulders up to several feet in diameter that were most likely derived from the Drum Mountains area to the northwest.

The east edge of the map includes about a third of the Smelter Knolls rhyolite dome and lava flow complex, which was extruded 3.4 million years ago on the alluvial floor of the Sevier Desert. The locally glassy rhyolite bears tiny topaz crystals that were formed in lithophysal cavities by vapors from the rhyolite magma. The base of the rhyolite is not exposed, but the rhyolite edifice rises some 500 feet (150 m) above the desert floor in the adjacent quadrangle to the east.

Lake Bonneville covered this part of the Sevier Desert between 18,000 and 13,000 years ago. Two of its shorelines are shown on the map. The Bonneville shoreline, at an elevation of about 5,190 feet, (1,582 m) marks the highest lake level. The Provo shoreline, at an elevation of about 4,785 feet (1,458 m), is marked by the largest gravel deposits that were formed by the lake.

Probably the most unusual feature in the quadrangle is a swarm of Quaternary fault scarps that trend northward through the middle of the map area. The scarps range up to 24 feet (7 m) high, cut Lake Bonneville deposits and post-Bonneville alluvium, and are presumed to have been formed during a single earthquake event a few thousand years ago.

Geologically related economic resources in the quadrangle include gravel and marl deposits and ground water. Likelihood for development of metal and petroleum resources is not high. The only resource currently being produced is ground water, which is pumped from wells less than 200 feet (61 m) deep. The water is used for range cattle, and for cyanide leaching at the Drum gold mine located 3 miles (5 km) north of the quadrangle boundary.

Flash flooding is the most frequent natural hazard, commonly occurring during the August cloudburst season. Earthquakes may occur here but their frequency of repeat occurrence is measured in thousands of years. Likelihood for significant losses from earthquake damage is small.

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INTRODUCTION

This quadrangle shows several features of geologic interest. Low hills along its eastern edge are part of the Smelter Knolls topaz rhyolite flow-dome complex, extruded about 3.4 million years ago in late Pliocene time. The western third of the quadrangle includes the east face of the Little Drum Mountains where gently dipping andesitic ash-flow tuffs and related conglomerates of the late Eocene - early Oligocene (37-40 million years) Little Drum Formation (new name) are well exposed. In the central part of the quadrangle Quaternary alluvial and lacustrine deposits are cut by a spectacular group of north-trending Holocene fault scarps that show scarp heights as large as 24 feet (7 m). Several paired scarps define grabens, one of which can be traced continuously for 3 miles (5 km). The northwestern corner of the quadrangle includes part of the southeastern edge of the Drum Mountains, which are here made up of fossiliferous Middle Cambrian limestone and shale.

The quadrangle lies about 20 miles (32 km) west of Delta, Utah and is easily accessible via good graded roads as shown on figure 1. Geology of the quadrangle has heretofore been shown only on regional maps at small scale (Hintze, 1963, 1980). Turley and Nash (1980) published a geologic sketch map showing igneous rocks in the vicinity of Smelter Knolls. Pierce (1974) described the geology of the southern Little Drum Mountains; we have elaborated on his basic work by obtaining isotopic ages for the ash-flow tuffs, and by subdividing the sedimentary deposits between the tuffs into a greater number of map units. Crone (1983) summarized findings from a backhoe trench investigation across one of the Holocene fault scarps. Rees and Robison (1989) reviewed Middle Cambrian stratigraphy of the southern Drum Mountains. Oviatt (1989) mapped Quaternary deposits of a large part of the Sevier Desert, including this quadrangle, at a 1:100,000 scale; he was responsible for mapping the Quaternary units on the present map and for their description in our text. Hintze was responsible for mapping the bedrock units and for their description.

STRATIGRAPHY

Three groups of formally named, pre-Quaternary rocks are found in this quadrangle. The oldest are Cambrian formations that extend half a mile (0.8 km) into the northwest corner of the map from the Drum Mountains where they are more extensively exposed. South of the Cambrian outcrops, the east side of the Little Drum Mountains consists of gently westward-dipping andesitic ash-flow tuffs and interbedded conglomerates of latest Eocene and Oligocene age. Along the east edge of the quadrangle, the Smelter Knolls are Pliocene lava flow domes of topaz rhyolite about 3.4 million years old. Formal names have not been given to Quaternary units on the map. Rather, they are identified as to their process of origin such as alluvial, lacustrine, or mass movement, and by kind of material such as gravel, sand, or marl. The central part of the quadrangle is covered by an irregular veneer of lacustrine and alluvial deposits that thicken eastward in the Sevier Desert basin. The surficial lacustrine deposits were formed in Lake Bonneville or along its shores between 18,000 and 13,000 years ago and have suffered some subsequent erosion.

Cambrian Strata of the Drum Mountains

Complete sections of all Cambrian strata are extensively exposed in the Drum Mountains just north of this quadrangle where they were mapped and described by Dommer (1980). Dommer documented a complete Cambrian rock succession but only its middle portion extends into this quadrangle, where it is represented by the Chisholm, Whirlwind, Swasey Limestone,

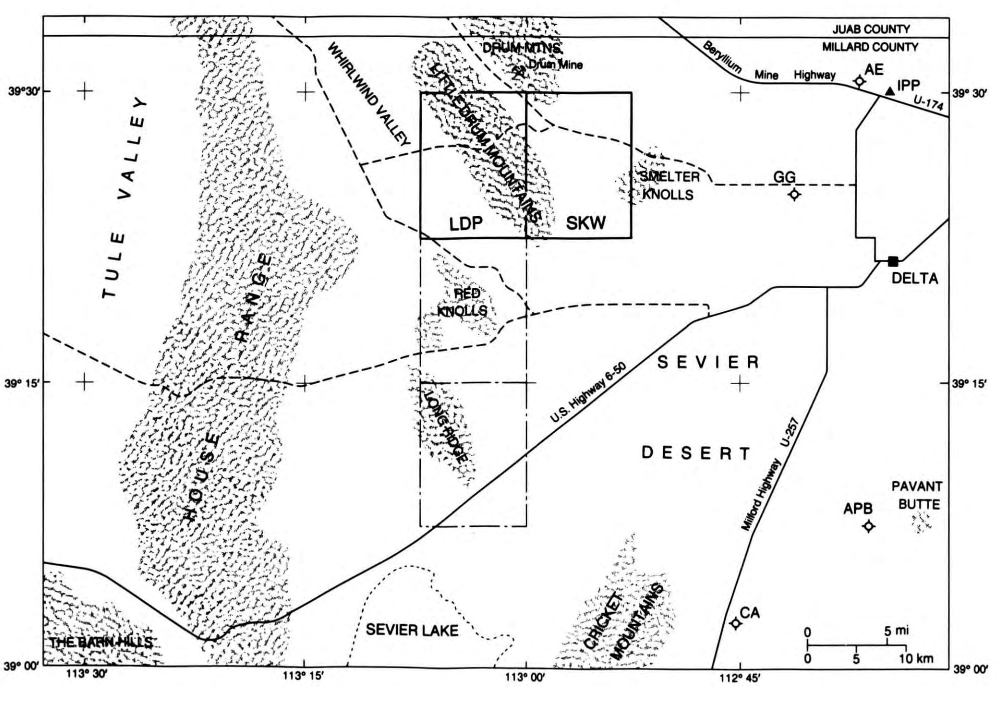

Figure 1. Map of north-central Millard County showing the location of the Smelter Knolls West (SKW) and Little Drum Pass (LDP) quadrangles (solid lines) and the previously mapped Red Knolls (Hintze and Davis, 1992b) and Long Ridge (Hintze and Davis, 1992a) quadrangles (dot-dash lines) with respect to nearby mountains and valleys. Paved highways are solid lines; selected graded roads are dashed lines. AE, Argonaut Energy well; GG, Gulf-Groning well; CA, Cominco-American well; APB, Arco Pavant Butte well; IPP, Intermountain Power Plant.

Wheeler, and Pierson Cove formations, all of Middle Cambrian age. The Dome Limestone, which lies between the Chisholm and Whirlwind Formations, is completely faulted out in this quadrangle, and the other formations are only incompletely represented.

Chisholm Formation (€c)

In western Utah the Chisholm Formation commonly consists of a recessive lower shaly interval, a ledge-forming middle oncolitic limestone, and a recessive upper shale. Only the middle part of the formation is found in this quadrangle, but a well-exposed complete section is present just north of the edge of the quadrangle in NW¼, section 22, T. 15 S., R. 10 W. At that location the Chisholm Formation consists of the following:

1. Upper shale unit: Fissile, olive-gray or maroon, forms slope beneath Dome Limestone.
   Thickness . . . . 25 feet (7.6 m).
2. Middle limestone unit: Medium to dark-gray, abundant oncolites, forms ledges. Thickness . . .75 feet (22.9 m).
3. Lower shaly unit: Lower 35 feet (10.7 m) is thin-bedded, oncolitic and oolitic, medium-dark-gray limestone that forms low ledges. Upper 70 feet (21.8 m) is slope-forming olive-gray shale that contains thin interbeds of nodular limestone that is a coquina of disarticulated parts of the trilobite *Glossopleura.*
   Thickness . . . . 105 feet (32 m).

Total thickness of Chisholm Formation 205 feet (62.5 m).

Dome Limestone

The Dome Limestone is not exposed in this quadrangle, having been faulted out. It is present just north of the quadrangle where Dommer (1980) reported that it is a thick-bedded to massive, cliff-forming limestone about 300 feet (90 m) thick.

Whirlwind Formation (€ww)

Like the Chisholm Formation, the Whirlwind consists of three parts: upper and lower recessive shaly units, and a middle ledge-forming limestone unit. This quadrangle includes only a small exposure of the upper part of the Whirlwind Formation. A complete section is well exposed just north of the quadrangle boundary in the west part of section 22, T. 15 S., R. 10 W. where the following was measured:

1. Upper shaly unit: Light-olive-gray, fissile shale with thin interbeds of intraformational conglomerate and limestone coquina of the trilobite *Ehmaniella.* Unit forms recessive slope beneath Swasey Limestone cliff. Thickness . . . . 55 feet (17 m).
2. Middle limestone: Medium- to light-gray, thin-bedded, silty limestone that forms a persistent ledge between recessive units 1 and 3. Thickness . . . . . 27 feet (8 m).
3. Lower shaly unit: Upper part is red-weathering, fissile shale; lower part is thin-bedded, slope-forming, silty limestone. *Ehmaniella* coquinas are present in a few beds but not nearly so commonly as in the upper shaly unit. Thickness . . . . 55 feet (17 m).

Total thickness of Whirlwind Formation 137 feet (42 m).

The paleontology and depositional environment of the Whirlwind Formation were studied by Kopaska-Merkel (1983) who concluded that Whirlwind sediments were deposited in a shallow shelf basin which was protected from the open ocean to the west by carbonate banks. Deposition of more carbonate in the middle Whirlwind represents a moderate eastward encroachment of carbonate, perhaps caused by slight change in rate of basin subsidence. Water depth may have ranged between 20 and 100 feet (6-30 m). The depauperate fauna of the Whirlwind, consisting almost entirely of the trilobite *Ehmaniella*, was most likely caused by the high salinity and temperature, and possibly low oxygen concentration in nearshore marine waters during deposition of the Whirlwind Formation.

Swasey Limestone (€sw)

This limestone forms dark-gray ledges and cliffs between the less-resistant formations above and below. The lower half of the Swasey is more massive and cliff-forming than adjacent formations; the upper half is medium to thin bedded and forms ledges and flagstone outcrops. The formation is incompletely represented in the Smelter Knolls West quadrangle, but Dommer (1980) measured the Swasey Limestone just north of the quadrangle boundary and reported it to be 180 feet (55 m) thick there. Randolph (1973) described a *Glyphaspis* trilobite fauna from the upper part of the Swasey Limestone in the Drum Mountains.

Wheeler Formation overview

Dommer (1980) mapped the Wheeler Formation with lower, middle, and upper members and we have followed the same practice. The Wheeler Formation in the Drum Mountains was described by White (1973); Dommer's (1980) subdivisions are approximately the same as those of White. Dommer's total thickness for the Wheeler Formation is 780 feet (238 m), about 200 feet (61 m) less than that recorded by White. Most of the difference is in the thickness assigned to the middle member and we believe that White's figure is more accurate. Dommer measured his section about a mile (1.6 km) northwest of where White's section was measured, and we believe that the middle member in Dommer's location has been subjected to brittle attenuation faulting (structural thinning).

The Wheeler Formation in the Drum Mountains differs considerably in appearance from that in its type area in the House Range, where it is almost entirely a light-greenish-gray-weathering, platy, calcareous shale. But in the Drum Mountains it is mostly limestone, with shaly horizons only in the upper and lower members.

Lower member of Wheeler Formation (€whl): The lower Wheeler member is fairly well exposed along the north edge of this quadrangle, but it is cut by minor faults. It consists of interbedded limy shale and thin-bedded, clayey limestone. Small, inarticulate brachiopods and agnostid trilobites are common in several horizons within the lower member. Professor Richard A. Robison of the University of Kansas examined three collections of fossils from the localities shown on our map as F1, F2, and F3. He reported:

Collection F1 - *Modocia brevispina*
Peronopsis interstricta
Peronopsis segmenta
Ptychagnostus atavus
hexactinellid sponge spicules

Collection F2 - *Peronopsis interstricta*
Ptychagnostus atavus
hexactinellid sponge spicules

Collections F1 and F2 are representative of the *Ptychagnostus atavus* Interval-zone which occurs between 230 and 280 feet (70 and 85 m) above the base of the Wheeler Formation in the Drum Mountains.

Collection F3 - *Elrathia* n. sp.
Peronopsis interstricta
Ptychagnostus gibbus
hexactinellid sponge spicules

Collection F3 is from White's (1973) "silver shale" which occurs from 175 to 198 feet (53-60 m) above the base of the Wheeler Formation in the Drum Mountains.

Depositional environments of the lower member of the Wheeler Formation in the Drum Mountains were studied by McGee (1974) who used White's (1973) measured section, 280 feet (85 m) thick, for his study. McGee concluded that the shaly lithologies of the Wheeler Formation represent deeper water environments of deposition than do the carbonate-rich lithologies.

Middle member of Wheeler Formation (€whm): This quadrangle contains a good exposure of the lower half of this member, and a fault-truncated portion of beds in its upper part. The rocks are mostly dark-gray, fine-grained limestone in beds 1 to 3 inches (2.5-7.5 cm) thick. Oolitic limestone is common on the southern dipslope of hill 5239. Fossils are scarce. Only a few inarticulate brachiopods and some fragments of non-agnostoid trilobites were found during a careful search. Some horizons a few tens of feet thick have been dolomitized on hill 5239. White (1973) reported that the middle Wheeler limestone is 505 feet (154 m) thick.

Upper member of Wheeler Formation (€whu): Vorwald (1983) studied this member in the Drum Mountains. One of his sections was located in this quadrangle on hill 5497 in W½ NW¼ SE¼, section 21, T. 15 S., R. 10 W. where he measured 125 feet (38 m) of upper Wheeler strata. Vorwald collected fossils at several horizons within this interval at the above location and listed the following fossils:

Trilobites	
Brachyaspidion microps	very rare
Elrathia kingii	common
Baltagnostus eurypyx	very rare
Modocia sp.	rare
Peronopsis interstricta	common
Bolaspidella housensis	rare
Olenoides nevadensis	rare
Alokistocare harrisi	very rare
Kootenia n.sp.	rare
Elrathia? sp.	rare
3 new species, each a new genus	rare
Brachiopods	
Micrometra modesta	rare
Lingulella sp.	rare
Nisusia sp.	rare
Curticia? sp.	rare

Rees and Robison (1989) summarized their interpretation of depositional environments in the Swasey and Wheeler formations and gave special attention to the upper Wheeler interval. They noted that marked changes of facies occur between the section on hill 5497 and sections less than 2 miles (3.2 km) to the northwest. Upper Wheeler platy limestone and shale (figure 2) in hill 5497 were interpreted to represent subtidal and peritidal environments. Here, at the base of the upper Wheeler member, there is a prominent ledge-forming limestone, 10 feet (3.3 m) thick, largely algal in origin, and including individual stromatolites up to 6 feet (1.8 m) high and 4 feet (1.2 m) across (figure 3). This limestone represents deposition in a low-energy, shallow-marine lagoon with abundant algal growth.

Pierson Cove Formation (€pc)

Only the lower third of this formation is included in this quadrangle, and these beds are partly dolomitized and cut by attenuation faults. Better sections of the Pierson Cove Formation are present to the northwest in the Drum Mountains, as described by Dommer (1980). The unaltered Pierson Cove Formation is mostly dark-gray, thick-bedded limestone; many beds are mottled with dolomitic limestone that fills burrowings. In the mineralized areas in the Drum Mountains, the Pierson Cove Formation has been secondarily and extensively dolomitized. Where this has occurred the formation is light to dark brown. Contact of the Pierson Cove Formation with the Wheeler Formation is transitional and transgressive; the formations have an intertonguing relationship locally. Vorwald (1979) recommended moving the contact higher in the section than previous workers, based on fossil occurrences in intercalated shaly horizons in the lower ledges of the Pierson Cove. We have chosen to not follow his suggestion and place the mapping contact at the position where slope-forming, yellowish-gray-weathering, shaly limestones of the Wheeler Formation are

***Figure 2.** Platy limestone and calcareous shale in the upper member of the Wheeler Formation in section 21, T. 15 S., R. 10 W. These outcrops show no apparent hydrothermal alteration, in contrast to similar rocks near the Drum gold mine 3 miles (4.8 km) northwest of these outcrops.*

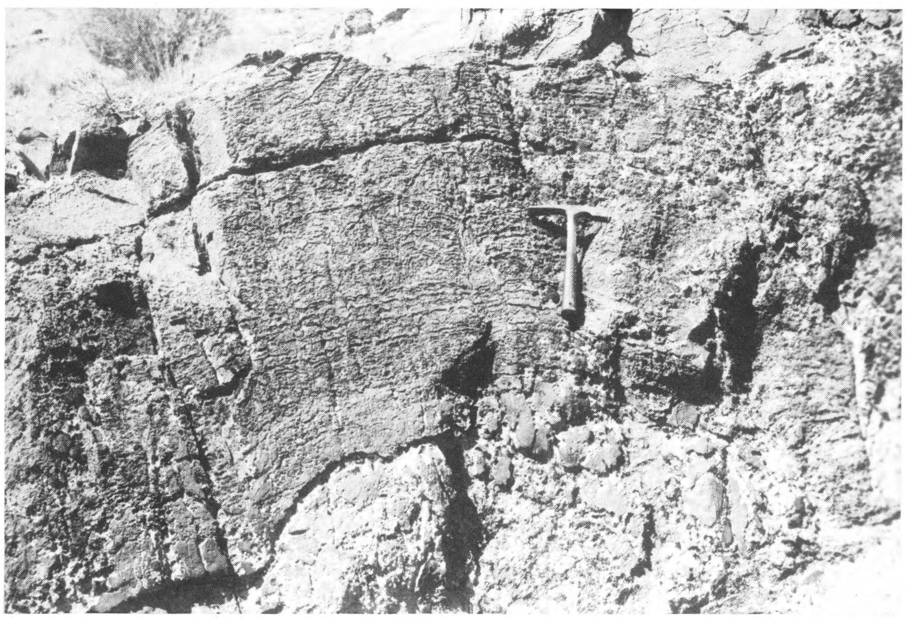

***Figure 3.** Large algal stromatolite at the base of the upper member of the Wheeler Formation near the same location as figure 2. Hammer handle is 12 inches (30 cm) long.*

overlain by predominantly dark-gray, ledge- and cliff-forming limestones of the Pierson Cove Formation. Dommer (1980) measured 803 feet (245 m) of Pierson Cove limestone and dolomite in the Drum Mountains just north of this quadrangle.

Eocene-Oligocene Volcanic Rocks and Conglomerates of the Little Drum Mountains

The Little Drum Mountains are made up entirely of a sequence of volcanic rocks and intercalated conglomerates that are known principally from this range. These rocks are crudely layered to form a stack aggregating nearly 7,000 feet (2,135 m) thick and are mostly westward dipping between 6 and 10 degrees. The lower half of the sequence is exposed in this quadrangle; the upper half is present in the adjacent Little Drum Pass quadrangle (Hintze, in preparation) to the west. The lowest unit in this sequence is the Eocene Drum Mountains Rhyodacite. It is overlain by a series of ash-flow tuffs of intermediate composition that are interlayered with poorly sorted conglomerates containing quartzite boulders and well-rounded volcanic clasts. This series of intercalated Eocene tuffs and conglomerates is herein named the Little Drum Formation and is described below. The Little Drum Formation is unconformably overlain by the Oligocene volcanic sequence of Dennison Canyon which is more widely exposed in the adjacent Little Drum Pass quadrangle where it was mapped by Hintze (in preparation). The overlying Red Knolls Tuff, the age of which is about 31.5 million years, is exposed only in one small outcrop in this quadrangle but it is more widely distributed on the Red Knolls and Little Drum Pass quadrangles (figure 1).

Age and regional correlation of volcanic units

Isotopic dating of igneous rocks in western Utah has clarified our understanding of the history of volcanism in the area. Several isotopic ages have been obtained for some rock units, whereas ages for other rock units are based on only one sample using one isotopic technique; thus their actual age is poorly constrained. Correlation between units that have minimal isotopic age control is often problematic.

Often the relative age of igneous units can be established on the basis of the principles of superposition (oldest on the bottom of the stack) and cross-cutting (younger cuts older) relationships. Thus, although it does not crop out in the immediate area of this quadrangle, the well-dated Cottonwood Wash Tuff of the Needles Range Group (Best and Grant, 1987) places an upper limit on the age that can be reasonably inferred for the volcanogenic rocks in this quadrangle. The Cottonwood Wash Tuff has an average age of 30.6 Ma based on four potassium-argon determinations (Best and Grant, 1987). It overlies the Skull Rock Pass Conglomerate (Hintze, 1974), which in turn overlies the Red Knolls Tuff, which has five zircon fission track ages averaging 31.5 ± 2.5 Ma (Hintze and Kowallis, 1989). The Red Knolls Tuff overlies the volcanic sequence of Dennison Canyon which has a zircon fission-track age of 31.3 ± 2.3 Ma and a potassium-argon age on plagioclase of 28.5 ± 1.9 Ma (table 1). The 31.3 Ma age of the volcanic sequence of Dennison Canyon is about the same as the average age of the Dell Tuff, 32.0 Ma, reported by Lindsey (1982, table 2).

Zircon fission track ages of single samples from the basal (Tl_2) and uppermost (Tl_{11}) tuffs of the Little Drum Formation are 39.5 ± 3.5 Ma and 38.6 ± 3.1 Ma respectively. Those ages are within the age range of nine samples from the Joy Tuff reported by Lindsey (1982, table 2) which average 38.0 Ma. However, using the argon 39-argon 40 technique, Shubat and Snee (1990) obtained an age of 34.88 ± 0.06 Ma for the Joy Tuff in the Keg Mountains. The age of the oldest igneous rock in the quadrangle, the Drum Mountains Rhyodacite, is poorly constrained. Lindsey (1982) reported a zircon fission track age of 41.8 ± 2.3 Ma from one sample.

Drum Mountains Rhyodacite (Tdr)

This formation was named by Lindsey (1979), and its type locality was rather broadly identified as being in sections 32, 33, and 34, T. 14 S., R. 11 W., some 5 miles (8 km) northwest of the nearest exposures in the Smelter Knolls West quadrangle. Lindsey characterized the rock as including rusty-weathering, black rhyodacite flows and breccias with phenocrysts of intermediate-composition to calcic plagioclase and pyroxene in an aphanitic to glassy matrix. According to Lindsey, the rock is modally a hypersthene andesite, but chemical analyses show the rock to range from rhyodacite to quartz latite. Lindsey (1982) reported a single fission track age of 41.8 ± 2.3 Ma, indicating a late Eocene age.

Within this quadrangle, rocks mapped as Drum Mountains Rhyodacite include not only the black flows described by Lindsey, but also maroon to dark-red-weathering rocks in the northwest corner of the quadrangle. The more limited exposures in the south-central part of the quadrangle are mostly dark-green, vesicular, and amygdaloidal lavas that Pierce (1974) described as pyroxene shoshonite. The Drum Mountains Rhyodacite is about 1,000 feet (305 m) thick in the northwest corner of this quadrangle, based on dip of flow layering and map distance measurements. The unit rests directly and with angular unconformity on Cambrian formations along the southern margin of the Drum Mountains.

Little Drum Formation (new name)

The andesitic ash-flow tuffs and intercalated conglomerates exposed on the east side of the Little Drum Mountains (figure 4) are unique to this part of Utah and we here propose that they be called the Little Drum Formation. We place the base of its type section near the corner common to sections 22, 23, 26, and 27, T. 16 S., R. 10 W., in this quadrangle. The type section ascends westward to the corner common to sections 19, 20, 29, and 30 in the adjacent Little Drum Pass quadrangle. The description of the individual members that follows was made at the type section, except for members 9 and 10, which only occur 2 miles (3.2 km) to the north. The deposits dip 6 to 8 degrees westward along this line of section. These rocks were first studied by Pierce (1974) who gave special attention to the tuffs. We rely on his petrographic and modal analyses in our descriptions of these rocks as well as on his measurement of their magnetic polarity. Pierce called the conglomerates "lahars." But volcanologists (Smith and Fritz, 1989) have recommended the following definition of lahar: "A general term for a rapidly flowing mixture of rock debris and water (other than normal stream flow) from a volcano. A lahar is an event; it can refer to one or more discrete processes, but it does not refer to a deposit."

We have subdivided the unit that Pierce (1974) called "laharic breccia, Tlb_1" into seven informal members, and have found that it is more than twice as thick as the 500 feet (152 m) reported by Pierce. In addition, we have recognized a basal conglomerate, not mapped by Pierce, that underlies his oldest tuff; we call this conglomerate "member 1" as described below.

Member 1 of the Little Drum Formation (Tl_1): Both exposures of this unit lie on the valley floor east of the foot of the Little Drum Mountains and are separated from the rest of the units in the type section by a normal fault of some 200 feet (61 m) displacement. The basal beds in the small northern exposure consist of angular clasts of dark andesite ranging from 2 to 6 inches (5-15 cm) across in a comminuted volcanic matrix of lighter color. No direct contact with the Drum Mountains Rhyodacite is well exposed. About 35 feet (11 m) above these basal exposures, quartzite clasts appear and increase upsection both in size and numbers until quartzite makes up about half of the clasts, whose average size is about one inch (2.5 cm), with

Table 1. *Selected isotopic dates from Smelter Knolls West (SKW) and Little Drum Pass (LDP) quadrangles.*

Sample	Unit	Latitude	Longitude	Quadrangle	Mineral	Method	Age (Ma)
Tt3	Td_1	39°24'15"N	113°00'10"W	LDP	zircon	fission track[1]	31.3 ± 2.3
Tt3X	Td_1	39°24'08"N	113°00'06"W	LDP	plagio-clase	K-Ar[2]	28.5 ± 1.9
Tt2	Tl_{11}	39°24'02"N	112°59'59"W	SKW	zircon	fission track[1]	38.6 ± 3.1
Tt1	Tl_2	39°23'28"N	112°57'42"W	SKW	zircon	fission track[1]	39.5 ± 3.5

1. Analysis by Bart J. Kowallis (Hintze and Kowallis, 1989)

2. Analysis by Krueger Enterprises, 22 December 1989, unpublished.

Table 2. *Fault scarp measurements (R.C. Bucknam, unpublished data, 1979).*

* Refer to figure 15 for explanation of the parameters listed below.

Map location	Scarp height (feet)	Scarp slope angle (degrees)	Surface slope angle (degrees)	Surface offset (feet)
A	17.2	24.0	1.0	15.6
B	10.2	16.5	3.0	8.7
C	9.6	17.5	3.0	7.7
D	10.4	17.0	2.0	8.6
E	4.1	8.5	2.0	3.2
F	2.4	6.0	2.0	1.6
G	3.0	5.0	1.0	2.2
H	2.5	6.5	2.0	1.7
J	9.6	19.5	2.0	7.8
K	6.8	18.0	4.0	5.1
L	7.8	16.0	4.5	5.6
M	11.5	19.5	2.0	9.6
N	10.6	20.5	3.5	8.5
O	20.5	25.0	2.5	18.9
P	16.6	24.5	1.5	14.9
Q	16.1	20.5	0.5	14.7
R	15.9	25.0	1.0	14.7
S	20.5	21.5	1.5	19.2
T	24.0	25.0	2.5	21.9
U	6.9	14.0	2.0	6.0

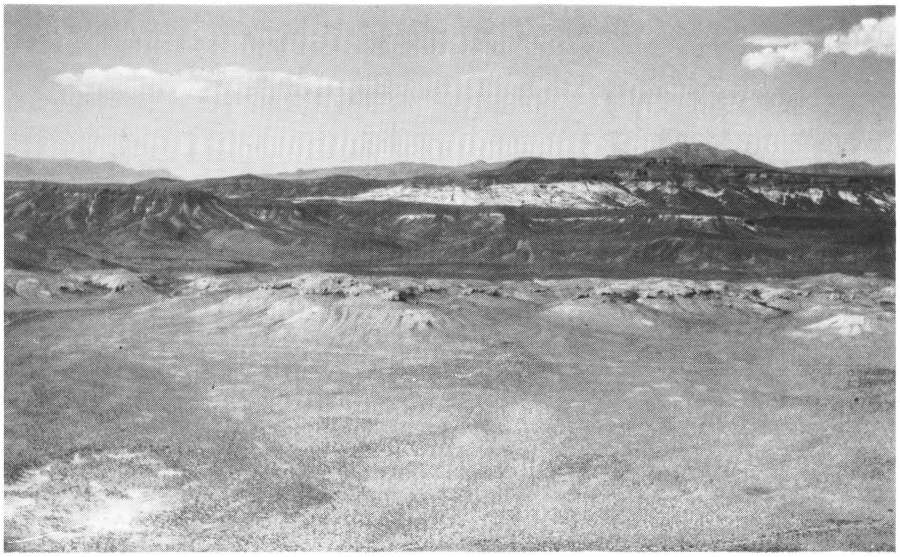

Figure 4. Aerial view of the east face of the Little Drum Mountains. The low hills that extend across the middle of the photograph are made up of the oldest tuff member (member 2) of the Little Drum Formation. The prominent light outcrops in the upper third of the photograph are exposures of the basal ash-flow tuff of the volcanic sequence of Dennison Canyon.

larger clasts up to 4 inches (10 cm) across. The top of the northern exposure is covered with alluvium. Tl_1 is 100 feet (30 m) thick in the northern exposure.

The larger exposure mapped as Tl_1 is at the east end of a spit of Lake Bonneville gravel. The entire exposure bears evidence of reworking by the lakeshore processes, which have winnowed away the matrix leaving a boulder armor on the surface of the deposit. This armor is composed largely of quartzite boulders similar to those exposed on the east face of the Drum Mountains some 10 miles (16 km) to the north. The quartzite boulders, which make up 70 percent of the clasts, range from white to tan to maroon and were mostly derived from the Cambrian Prospect Mountain Quartzite and the Precambrian Mutual Formation, the lithologies of which are described by Dommer (1980). Clasts range up to 2 feet (61 cm) in diameter and are well rounded. Average clast size is about 6 inches (15 cm). Dark clasts of dense andesite are also present; these could have been derived from the Drum Mountains Rhyodacite or other pre-Little Drum volcanic rocks as exposed in the Drum Mountains. Matrix is pebbles, cobbles, grit, and comminuted volcanic sandy silt. No bedding can be seen in these deposits; hence there is no indication of their source direction other than the observation that the clasts could have been derived from bedrock units found in the Drum Mountains to the north. However, they also could have come from areas to the south or east from sources now concealed beneath the Sevier Desert since the present topography is the result of Miocene and later block faulting. The topography of this area during late Eocene time is relatively unknown. Baer and Hintze (1987) suggested that the relief was subdued at this time and that regional drainage was probably eastward with streams heading toward the Uinta Basin.

Member 2 of the Little Drum Formation (Tl_2): This member is the oldest ash-flow tuff in the sequence. Fission track age of zircon from this tuff is 39.5 ± 3.5 Ma (table 1). Member 2 is the same as Pierce's (1974) Tt_1. This partially welded, orange-pink tuff is well exposed for 4 miles (6.4 km) along the east foot of the Little Drum Mountains and is also present just east of the range front in low knobs that have been down-faulted to the east. Pierce described it as a crystal-vitric andesitic tuff that contains the following constituent percentages in thin section: plagioclase, 34; biotite, 3; amphibole, 2; pyroxene, 1; oxides, 3; lithic fragments, 3; matrix, 54. At outcrop scale, lithic fragments (figure 5) make up as much as 20 percent of the rock. Angular, brownish-red, felsitic lithic fragments up to 3 inches (7.5 cm) in diameter are common, as are white pumice fragments up to 2 inches (5 cm) long. The matrix consists of glass shards and small pumice fragments that show some molding around the phenocrysts. Tuff Tl_2 is rather soft and weathers to rounded ledges and cliffs that are cavernous in some places. Pierce stated that this tuff shows normal magnetic polarity. As measured along the type section traverse, it is 225 feet (69 m) thick. The upper third is generally softer and more poorly exposed than the lower part; the upper part is also a lighter pink color and contains fewer lithic fragments.

Member 3 of the Little Drum Formation (Tl_3): The lower 130 feet (40 m) of this member is a green tuff that includes rounded cobbles and boulders of dark andesitic rocks and quartzites. These clasts increase in abundance upward to comprise 70 percent of the rock 90 to 130 (27-40 m) feet above the base. This boulder-bearing tuff is overlain by a resistant conglomerate mostly made of angular to subrounded cobbles of andesitic rocks but including some boulders as much as 3 feet (1 m) across. This conglomerate is 210 feet (64 m) thick and forms the caprock and backslope of a low cuesta along the range front. The conglomerate matrix includes many small clasts of medium-gray, glassy, andesitic rock that is rich in very small hornblende phenocrysts. Thickness of member 3 is 340 feet (104 m) at the type section. It pinches out to the north.

Member 4 of the Little Drum Formation (Tl_4): This member is a resistant, cuesta-capping, dark-brown to dark-greenish-gray basaltic andesite. Some layers are amygdaloidal. The upper few

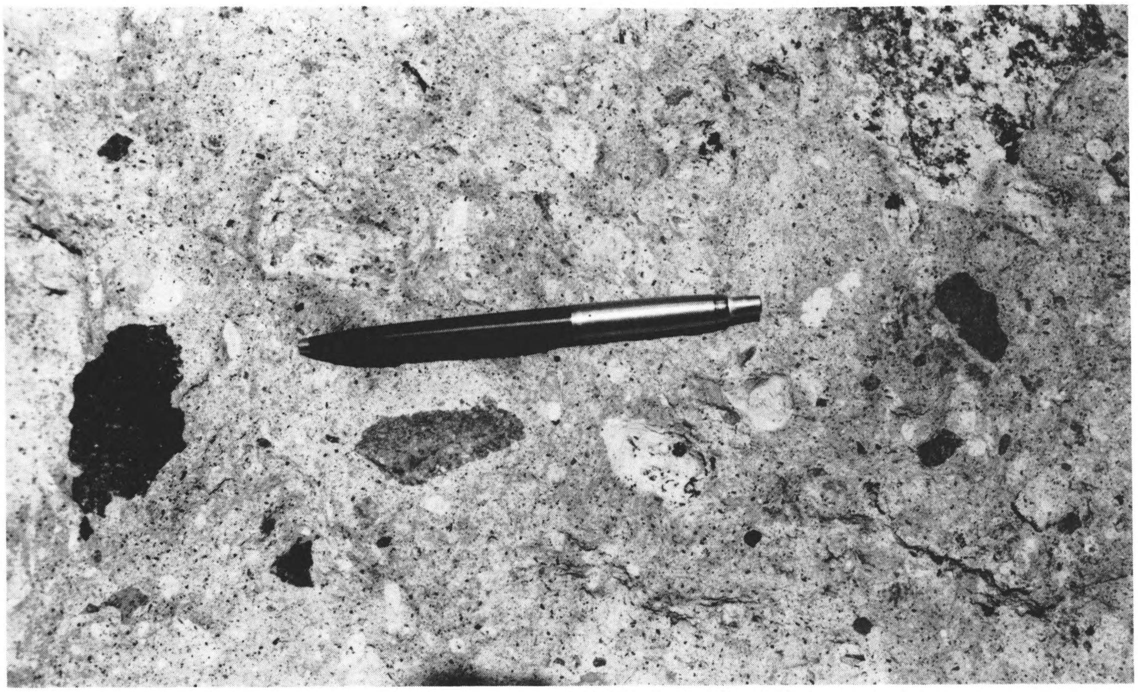

Figure 5. *Member 2 of the Little Drum Formation includes a large number of lithic fragments. Pen is 5 inches (12.5 cm) long.*

feet are a boulder conglomerate of the same rocks in a sandy matrix of similar composition. This member is 150 feet (46 m) thick.

Member 5 of the Little Drum Formation (Tl$_5$): This member is a light-brownish-gray, slightly bentonitic, tuffaceous mudstone that forms slopes and swales and is commonly covered with talus and colluvium. It does not contain large clasts, in contrast to all other members of the Little Drum Formation. Along the traverse line of the type section it is 290 feet (88 m) thick.

Member 6 of the Little Drum Formation (Tl$_6$): This member is a conglomerate that includes boulders up to 5 feet (1.5 m) in diameter in a tuffaceous matrix. About half of the boulders and cobbles are derived from Cambrian and Precambrian quartzites; the remainder are volcanic rock clasts including some from Little Drum Formation members Tl$_2$ and Tl$_4$. Member 6 is 220 feet (67 m) thick as measured along the type section traverse. It pinches out about a mile (1.6 km) south of there and also a short distance north of the traverse, but picks up again to continue northward for 2 more miles (3.2 km).

Member 7 of the Little Drum Formation (Tl$_7$): This is a pink tuff very similar to member 2, with small biotite and hornblende phenocrysts, and felsitic, lithic, and small pumice fragments in about the same proportion as member 2. This tuff is poorly welded throughout most of its exposure, but a welded zone as much as 100 feet (30 m) thick forms cliffs near the top of this member from its southernmost exposure to the northwest corner of section 17. This member is 250 feet (76 m) thick along the traverse of the type section between sections 21 and 28. It wedges out in both north and south directions suggesting that it may have filled an east-west paleovalley.

Member 8 of the Little Drum Formation (Tl$_8$): This conglomerate caps the cuesta in the southwest corner of this quadrangle. As much as half of the large clasts are rounded cobbles and boulders of quartzite (figure 6); the remainder are subrounded to subangular clasts of volcanic rocks, mostly dark-brownish or greenish-gray andesite. Boulders range up to 3 feet (1 m) across but most are 6 to 8 inches (15 - 20 cm). Matrix is mostly comminuted volcanic rock but also includes small, rounded quartzite pebbles. A few of the igneous clasts look like Mt. Laird Tuff, suggesting that this material may have been derived from the Drum Mountains to the north. This conglomerate is not consolidated, and no bedding or other means of determining its direction of transport are evident. It is about 250 feet (76 m) thick along the type section traverse.

Member 9 of the Little Drum Formation (Tl$_9$): This is a thin, poorly welded, ash-flow tuff found only along the west edge of the quadrangle. It ranges up to 50 feet (15 m) thick and is generally recessive and covered by talus or colluvium. It is light gray to white and includes as much as 25 percent lithic fragments, mostly of pumice and felsitic volcanic rocks. One of the most common and distinctive lithic types is a light-gray, crystal-rich rock with the following phenocrysts in decreasing order of abundance: plagioclase, augite, hornblende, and biotite. Angular lithic fragments of this composition range up to 10 inches (25 cm) across. The tuff also includes some dark andesitic lithic fragments. The type section for this member and member 10 is just west of hill 5306 in the southern part of section 5, T. 16 S., R. 10 W.

Member 10 of the Little Drum Formation (Tl$_{10}$): This conglomerate resembles member 8, except that it lacks quartzite cobbles and boulders, being made up almost entirely of reddish-brown-weathering basaltic andesite clasts as much as 3 feet (1

Figure 6. Unconsolidated conglomerate of member 8 of the Little Drum Formation, exposed along the road in section 17, T. 16 S., R. 10 W. Quartzite boulders in this unit glisten in the sunshine, making this unit easy to distinguish from member 10 which lacks quartzite clasts.

m) in diameter in a poorly cemented sandy grit matrix. Two-thirds of the clasts are vesicular; most are subrounded to subangular, and a few are angular. No bedding or sorting is evident. Thickness is up to 220 feet (67 m).

Member 11 of the Little Drum Formation (Tl_{11}): This partially welded, white, ash-flow tuff is Pierce's (1974) "vitric-lithic tuff Tt_2" which he characterized by the near absence of megascopic phenocrysts and an abundance of white, chalky pumice fragments up to 2 inches (5 cm) long. Pierce gave the modal composition percentages determined from thin sections as follows: plagioclase, 2; quartz, trace; pyroxene, 1; oxides, 1; lithic fragments, 21; matrix, 75. The lithic fragments include pyroxene and hornblende andesite, and more rarely, quartzite pebbles. Magnetic polarity of this member is normal. The member ranges from 0 to 200 feet (0 - 61 m) thick, pinching out towards the north. Age of member 11 as determined by fission tracks in zircon crystals (table 1) is 38.6 ± 3.1 Ma.

Member 12 of the Little Drum Formation (Tl_{12}): This thin conglomerate, which separates the prominent ash-flow tuff members Tl_{11} and Td_1, ranges up to 30 feet (9 m) thick and is composed almost entirely of subrounded cobbles and small boulders of dark-brownish-gray basaltic andesite, many of which are vesicular. This conglomerate is caprock for a low cuesta at the top of member Tl_{11}. Contact with the underlying member is gradational, with dark igneous cobbles being mixed with reworked tuff in the lower 5 feet (1.5 m) of the conglomerate. Except in this lower tuff-rich zone the conglomerate is unconsolidated and loose where exposed at the surface. It represents an erosional interval, with minor deposition, between two tuff units whose fission track ages are several million years apart.

Volcanic sequence of Dennison Canyon

This formation consists mostly of andesitic conglomerates and flows which cover the east half of the adjacent Little Drum Pass quadrangle (Hintze, in preparation). Only its basal tuff member (Td_1) is present in the Smelter Knolls West quadrangle.

Basal tuff member of the volcanic sequence of Dennison Canyon (Td_1): This ash-flow tuff is Pierce's "latite tuff Tt_3." It forms prominent pink cliffs that extend northward for more than 5 miles (8 km) along the upper east face of the Little Drum Mountains. The fission track age of zircons from this tuff (table 1) is 31.3 ± 2.3 Ma. A potassium-argon age of 28.5 ± 1.9 Ma was obtained on plagioclase from this tuff.

Pierce (1974) noted the following composition percentages from thin sections of this tuff: plagioclase, 24; quartz, 2; biotite, 5; amphibole, 2; pyroxene, 1; oxides, 1; lithic fragments, trace; matrix, 65. Megascopically this tuff has abundant pumice and felsitic lithic fragments (figure 7). The most common rock fragments are light-gray and of intermediate composition, and contain abundant biotite books up to 0.1 inch (3 mm) in diameter. Biotite is also scattered throughout the matrix of the tuff as noted

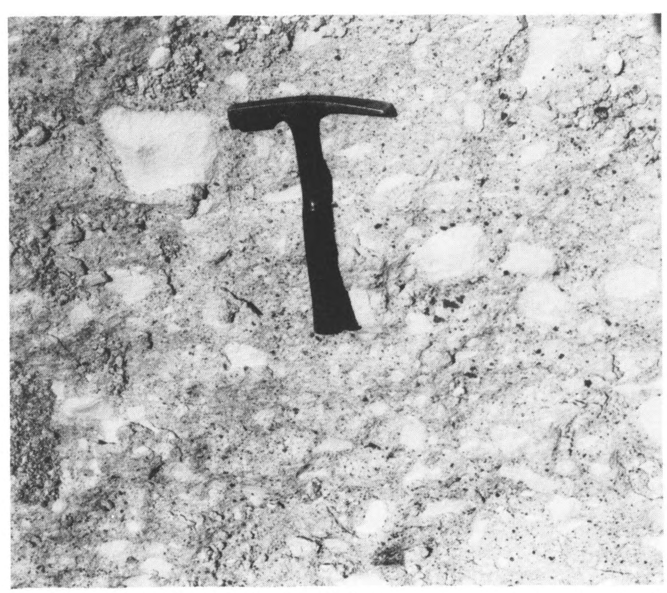

Figure 7. Pumice and felsic lithic fragments are abundant in the basal tuff member of the volanic sequence of Dennison Canyon. The hammer is 12 inches (30 cm) long.

Figure 8. *The basal tuff member of the volcanic sequence of Dennison Canyon is a poorly welded tuff that weathers into small caves called tafoni, with open lace-work texture. Photograph taken in section 20, T. 16 S., R. 10 W.*

in the modal analysis above. This member is poorly welded and rather soft. It weathers into honeycomb and small cavern forms (tafoni) on cliff faces (figure 8). The tuff attains its maximum thickness of 500 feet (152 m) in section 20 on the west edge of the quadrangle and thins northward to less than 100 feet (30 m) in the north part of the adjacent Little Drum Pass quadrangle. The vent source for this tuff is not known. However, lithic clasts in the tuff are largest in the southern exposures, suggesting that the source of the tuff may lie buried beneath the Sevier Desert somewhere south of the Little Drum Mountains.

Red Knolls Tuff (Trk)

This tuff was named by Hintze and Davis (1992b) for its occurrence in the nearby Red Knolls quadrangle. It is a light-gray to grayish-orange-pink, moderately resistant, dacite tuff which contains 10 to 30 percent lithic fragments, mostly of volcanic rocks of similar composition. Phenocrysts make up about half of the matrix and are, in decreasing order of abundance: plagioclase, biotite, quartz, hornblende, and a trace of bright-green augite. Pierce (1974) incorrectly correlated this tuff with the Needles Range Formation which is slightly younger. The natural remnant magnetization direction (written communication to M.G. Best, February 27, 1990, from C.S. Gromme) is neither Cottonwood Wash Formation nor Wah Wah Springs Formation of the Needles Range Group. Hintze and Kowallis (1989) reported that zircon fission track ages from four different sample localities range between 29.8 and 32.6 Ma giving an average age of 31.5 million years. Lindsey (1982, table 3) reported an additional zircon fission track age from this same formation (which he listed as Needles Range (?) Formation) as 30.6 ± 1.2 Ma. This tuff is exposed in only one outcrop near the center of the quadrangle. The exposed thickness there is about 20 feet (6 m), but more may lie buried beneath the surface. In its type locality this tuff is about 200 feet (61 m) thick.

Pliocene Rhyolite of Smelter Knolls (Tr)

Turley and Nash (1980) studied the topaz-bearing rhyolites at Smelter Knolls as part of an examination of late Tertiary and Quaternary volcanism in west-central Utah and part of the following is summarized from their report. The Smelter Knolls are a single rhyolite dome and flow complex about 3 miles (4.8 km) in diameter that rises as much as 500 feet (152 m) above the valley floor and retains some of its original eruptive form. Only the western edge of the complex is included within this quadrangle (figure 9). The rhyolite is flow layered, medium to light gray, and contains 10 to 20 percent phenocrysts of quartz, alkali feldspar, plagioclase, biotite, and Fe-Ti oxides. Topaz and hematite occur as vapor-phase products in lithophysal cavities and as a groundmass mineral. The potassium-argon (K-Ar) age of sanidine is 3.4± 0.1Ma. Magnetic polarity is reversed indicating eruption near the end of the Gilbert magnetic epoch. Glassy parts within the unit are indicated on the map by the symbol Trg.

QUATERNARY DEPOSITS

Surficial deposits in the map area consist of fine-grained material laid down in Lake Bonneville and pre-Bonneville lakes, and coarse-grained lacustrine and alluvial material in piedmont areas. Quaternary faults cut the alluvial and lacustrine deposits.

Previous work on the surficial deposits and geomorphology of the Smelter Knolls area includes Gilbert (1890), Bucknam and Anderson (1979a; 1979b), Crone (1983), Colman and Wat-

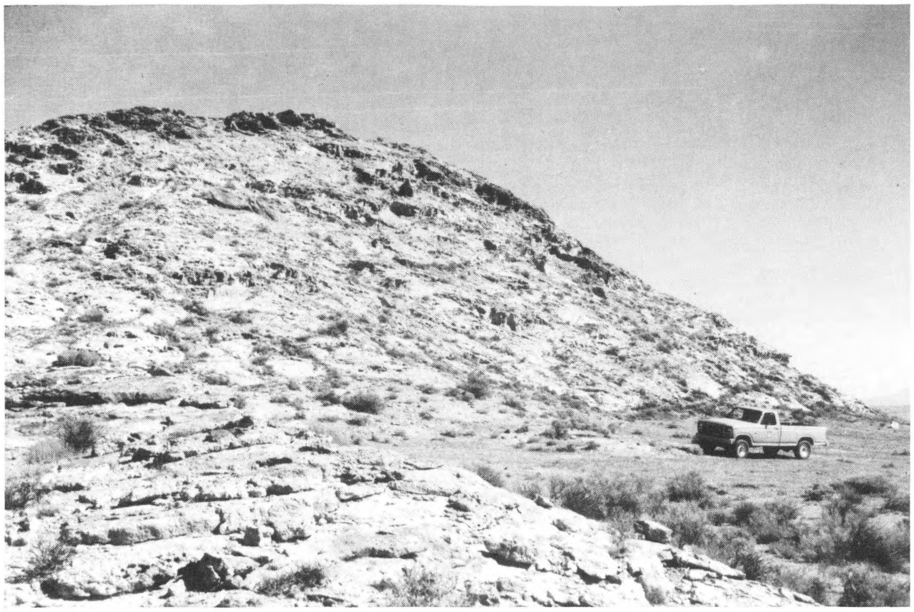

Figure 9. *Topaz-bearing rhyolite of the Smelter Knolls weathers to form small caves in most outcrops. Photograph is of the southeast side of hill 4907 in section 17, T. 16 S., R. 9 W. Platy flow layering shows along the bottom of the picture.*

son (1983), Crone and Harding (1984), Hanks and others (1984), Sterr (1985), Pierce and Colman (1986), and Oviatt (1989).

Quaternary deposits in the quadrangle are classified primarily on the basis of their environments of deposition, which in this case are lacustrine, alluvial, and mass movement as indicated by the first lower-case letter in the map-unit symbols. Other distinguishing characteristics, such as texture, lithology, or geomorphic expression, are used to subdivide the deposits into mappable units, and are indicated by the second lower-case letter in the symbol. In the case where two lithologically similar map units have distinctly different relative ages, number subscripts are used, such as in the map units Qaf_1 and Qaf_2. The subscript 1 indicates a younger relative age than the subscript 2.

Lacustrine Deposits

Pliocene and Pleistocene fine-grained lacustrine deposits (QTlf)

Fine-grained lacustrine deposits (QTlf) of a pre-Bonneville lake or lakes are exposed in a few small badland areas in the central part of the quadrangle. The unit includes brown (7.5 YR 5/4 on the Geological Society of America Rock-Color Chart) to light-olive-gray (5 Y 6/2), calcareous silty clay, silt, and minor amounts of sand. QTlf probably overlies bedrock surfaces, alluvial-fan deposits, and possibly other upper Tertiary lake beds, but the base is not exposed in the quadrangle; the maximum exposed thickness is about 30 feet (10 m). QTlf contains ostracodes but other fossils have not been found in this unit in the quadrangle. QTlf is mapped in a few small areas where it is exposed in badlands and along fault scarps. It is typically overlain by lacustrine and alluvial gravel.

The age of the Plio-Pleistocene lake beds is constrained by dated volcanic ashes that are interbedded with equivalent fine-grained deposits outside the map area (Oviatt, 1989). These ashes are the Bishop ash (758,000 years old), the Huckleberry Ridge ash (2.02 million years old), and the Cudahy Mine ash (about 2.5 million years old) (Oviatt, 1989, 1991). Thus QTlf ranges in age from at least late Pliocene to middle Pleistocene.

Lacustrine carbonate sand (Qlk)

Lacustrine sand or pebbly sand composed of carbonate pellets, carbonate-coated gastropods, and ooids is mapped as Qlk. Qlk is mapped in two areas below the Provo shoreline, where it overlies the white marl (Qlm). Similar deposits have been mapped at a number of localities in the Sevier Desert (Oviatt, 1989). The carbonate-rich sediments are inferred to have been deposited during the long stillstand of Lake Bonneville at the Provo shoreline when the lake was overflowing into the Great Salt Lake basin and the water was fresh but rich in calcium carbonate.

White marl (Qlm)

Open-water or deep-water deposits (Qlm) of Lake Bonneville are preserved at a few localities in the quadrangle. The map unit Qlm is the same as the stratigraphic unit named the "white marl" (Gilbert, 1890; Oviatt, 1987). The white marl consists of fine-grained white to gray marl, and sandy marl or marly sand, which were deposited in open-water environments of Lake Bonneville. It is finely bedded to indistinctly laminated, and contains abundant ostracodes throughout. Gastropods are locally abundant near the base and the top of the unit. Diatoms are abundant in some exposures, especially below the Provo shoreline. Thickness ranges from 6 to 30 ft (2 - 10 m). Qlm also includes transgressive- and regressive-phase calcareous sand at the base and top of the unit. Some of the best exposures of the white marl are in the Chalk Knolls adjacent to the southern boundary of the quadrangle.

In the map area, the white marl ranges in age from about 18,000 years to 13,000 years (Oviatt, 1989), and represents deposition in Lake Bonneville during part of its transgressive phase, its high stand at the Bonneville shoreline, and its overflowing stage at the Provo shoreline.

Lacustrine gravel (Qlg)

Beach or spit gravel deposited in Lake Bonneville is mapped as Qlg. The most extensive and thickest deposits are in the double tombolo at the Provo shoreline in the eastern part of the map area. Gravel in the tombolos was transported by longshore currents from the piedmont slopes toward the Smelter Knolls, which blocked incoming waves from the east and northeast. Other accumulations of lacustrine gravel include a cuspate barrier (V-bar) north of the double tombolo, which formed either in the transgressive phase of Lake Bonneville or in a pre-Bonneville lake cycle, and smaller barriers and spits close to the Bonneville shoreline. The Qlg deposited in Lake Bonneville ranges in age from about 18,000 to 13,000 years (Oviatt, 1989).

Gravel of lacustrine and/or alluvial origin (Qla)

Thin lacustrine gravel deposits that overlie either QTlf or pre-Bonneville alluvial fans on the piedmont of the Drum Mountains and Little Drum Mountains are mapped as Qla. The lacustrine gravel was reworked from coarse-grained alluvium by waves during the transgressive and regressive phases of Lake Bonneville. The gravel is moderately well rounded and sorted, and locally contains gastropods. In some areas the lacustrine-gravel component of Qla is so thin it cannot be easily distinguished from the pre-Bonneville alluvial-fan gravel on which it lies. But Lake Bonneville shorelines, which are visible on aerial photographs, are etched across the pre-Bonneville alluvial fans indicating that waves in Lake Bonneville modified the alluvial-fan surfaces, and that post-Bonneville fluvial activity has been negligible in these areas. The white marl (Qlm) is locally preserved on Qla, but was stripped from most of the area by waves during the regressive phase of Lake Bonneville and by post-Bonneville stream erosion, sheet wash, or wind deflation.

Lagoon fill (Qll)

Poorly bedded deposits of silt, sand, and clay that filled lagoons behind Lake Bonneville barrier beaches are mapped as Qll. Some of the fine-grained sediment in these settings was probably deposited by waves that washed over the crests of the barrier beaches during storms, and some was deposited in post-Bonneville time as slope wash from the surrounding hill slopes. Qll therefore is both Bonneville and post-Bonneville in age. The largest barrier-beach lagoon in the map area is preserved between two long barrier beaches that form a double tombolo at the Provo shoreline on the west side of Smelter Knolls.

Alluvial Deposits

Pre-Bonneville alluvial-fan deposits (Qaf_2)

Pre-Bonneville alluvial fans are mapped as Qaf_2. These deposits are composed mostly of coarse-grained debris, and form dissected remnants overlying Tertiary volcanic rocks above the Bonneville shoreline. Deposits mapped as Qla below the Bonneville shoreline are composed of pre-Bonneville alluvial-fan deposits below the thin surficial cover of Qla.

Post-Bonneville alluvial-fan deposits (Qaf_1)

Post-Bonneville alluvial fans are mapped as Qaf_1. Qaf_1 consists of poorly sorted, coarse- to fine-grained alluvium of ephemeral washes in channels and in fans on piedmont slopes. In the distal parts of fans Qaf_1 is composed of fine-grained sediments reworked from lacustrine deposits of Lake Bonneville or from QTlf. Small areas of Qaf_1 are lumped with Qla if they cannot be shown at a scale of 1:24,000.

Mass-Movement Deposits

Pliocene or Pleistocene landslide deposit (QTms)

This unit is composed of chaotic, angular, blocky debris of all sizes up to very large blocks. It is made up almost entirely of Cambrian carbonate rocks from the Wheeler and Pierson Cove Formations, and occurs only in the northwest corner of the map area. The landslide deposit is older than pre-Bonneville alluvial-fan deposits (Qaf_2) and, lacking definitive age data, is tentatively assigned a Pliocene or Pleistocene age. It is no more than 50 feet (15 m) thick, and was obviously derived from the hillsides immediately to the north and/or west of the deposit.

Colluvium (Qmc)

Two small areas along the north and west margins of the quadrangle were mapped as colluvium. The northern deposit is made up entirely of debris from the Pierson Cove Formation. The western deposit consists entirely of debris from the Dennison Formation. The deposits range up to 30 feet (10 m) thick.

STRUCTURAL GEOLOGY

Structural features exposed in the quadrangle include: 1) brittle attentuation of Cambrian rocks, this deformation related to their eastward transport during the Sevier orogeny, 2) angular unconformity of Eocene volcanic rocks on Cambrian strata, 3) gentle westward tilting of the Eocene-Oligocene volcanogenic sequence produced during Miocene-Pliocene basin-and-range uplift and extensional normal faulting, 4) Pliocene rhyolite lava flows and domes along the east edge of the quadrangle, and 5) Holocene basin-and-range extensional normal faults manifest by numerous north-trending scarps that cut Quaternary deposits in the east half of the map area.

Sevier Attenuation Faulting

Cambrian rocks exposed along the northwest edge of the quadrangle extend northwestward into the Drum Mountains where they have been mapped by Dommer (1980) and Nutt and others (1990, 1991). Cambrian strata in the Drum Mountains are cut by bedding-parallel, brittle attenuation faults associated with Sevier orogenic compression (Hintze, 1978), and by later high-angle faults and pebble dikes. Within this quadrangle, brittle attenuation faulting is evident in bedding-parallel disturbance (figure 10) of the Pierson Cove Formation in the northwest corner of the map area.

Before the Sevier orogeny, more than 40,000 feet (12,200 m) of late Precambrian and Paleozoic shallow-water marine strata had accumulated in western Utah and eastern Nevada (Hintze, 1988). These rocks were thrust eastward and upward during Late Cretaceous time to form part of the Sevier orogenic highlands. Erosion concurrent with Sevier uplift removed all Paleozoic strata above the Cambrian over a broad arch centered over the present Sevier Desert area (Harris, 1959).

Angular Unconformity Beneath Eocene Volcanic Rocks

Erosion of the Sevier orogenic highlands continued until volcanic activity commenced in the Tintic-Keg-Drum Mountains area in latest Eocene time about 40 million years ago. Volcanogenic deposits of the Drum Mountains Rhyodacite lie with angular unconformity on the older rocks in this quadrangle. Dommer's (1980) mapping of the adjacent part of the Drum Mountains shows that volcanic rocks there filled valleys cut into the Cambrian strata. Lindsey (1982) summarized the sequence of volcanic events that followed deposition of the Drum Mountains Rhyodacite in the northern Drum Mountains.

Basin-and-Range Uplift and Westward Tilting of the Little Drum Mountains

The geologic cross-section on plate 2 shows the regular, gentle, westward dip of the Little Drum Formation and the volcanic sequence of Dennison Canyon in the western part of the quadrangle. Lindsey (1982) concluded that most basin-and-range faulting in this area occurred between 21 and 7 million years ago, and that the faulting in the west half of the Smelter Knolls West quadrangle probably occurred then, prior to extrusion of the Smelter Knolls rhyolite domes.

Smelter Knolls Rhyolite Extrusion

Rhyolite exposures along the east side of the quadrangle are part of a rhyolite dome and lava flow complex (figure 11) with an age of 3.4 Ma (Turley and Nash, 1980). This volcanic activity apparently postdates the normal faulting that caused tilting in the older volcanic rocks, because the rhyolites do not appear to be significantly faulted or tilted.

Quaternary Basin-and-Range Normal Faults

This quadrangle includes the greatest concentration of fault scarps that belong to a zone of Quaternary scarps which is 25 miles (40 km) long and up to 7 miles (11 km) wide and trends northerly along the east side of the Little Drum and Drum Mountains. These East Drum Mountains fault scarps (figure 12) were initially documented by Bucknam and Anderson (1979a; 1979b). Bucknam measured numerous scarp profiles and kindly furnished us with some of his data as given on table 2. Scarp heights range from 2.4 to 24 feet (0.7 - 7.0 m). Crone (1983) mapped fault exposures, both natural (figure 13) and as exposed in a trench (figure 14) along the south wall of the unnamed wash at locality B in table 2 and on the geologic map (plate 1). Crone concluded that this scarp was the result of a single faulting event. The East Drum Mountains scarp zone has been used by several investigators to estimate the age of faulting by a technique called slope-morphometric dating (Machette, 1989). This technique is based on the principle that the erosional modification of the scarp is a continuous function of time. Using this technique, Hanks and others (1984) estimated the age of the East Drum Mountains scarps to be between 3,600-5,700 years old; Pierce and Colman (1986) estimated an age of about 9,000 years; and Machette (1989) estimated 5,600 to 2,300 years. Machette (1989) summarized the age range, precision, and accuracy of the slope-morphometric technique. Unfortunately, no material suitable for isotopic age determination has been found in association with the scarps.

The trench studied by Crone (1983) was only 9 feet (3 m) deep, probably not deep enough to definitively assess the possibility of earlier movement on the East Drum Mountains faults. Because the scarps extend over such a large area they are unusual within the Great Basin; scarp zones formed elsewhere by single historic earthquakes are nowhere nearly so extensive. The East Drum Mountains scarps mainly cut gravel of lacustrine and/or alluvial origin (Qla), which is shown on our correlation table (plate 2) as being generally older than the post-Bonneville alluvial-fan deposits (Qaf_1). But in some localities, Lake Bonneville gravel (Qlg) and post-Bonneville fan deposits (Qaf_1) are also cut. Additional deep trenching will probably be required to unequivocally demonstrate if the East Drum fault scarps are, indeed, the result of a single event.

The locations of all fault scarps shown on the geologic map, plate 1, were plotted from 1:25,000 color aerial photographs taken in 1978. The scarp showing the greatest height (location T on plate 1) also brings QTlf to the surface at several locations.

Some grabens can be traced for several miles in the East Drum fault zone. In almost all such structures, the down-to-the-

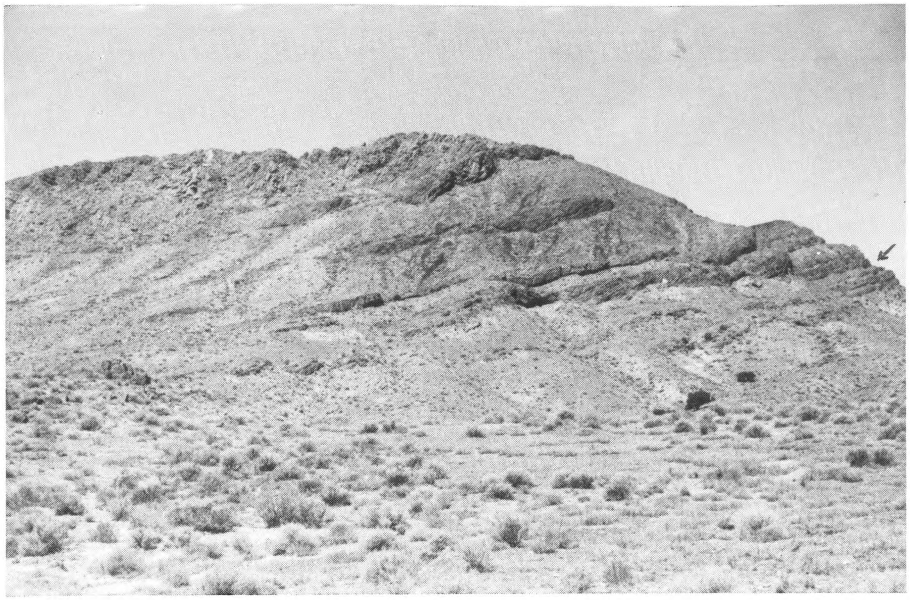

Figure 10. *Lower Pierson Cove and upper Wheeler Formations exposed in section 21, T. 15 S., R. 10 W. Top of the Wheeler Formation is marked by light shale outcrops below the dark ledges in the middle of the photograph. Contact indicated by arrow at right side. Attenuation faulting is evident near the top of the hill in the chaotic bedding of the Pierson Cove Formation in carbonate units that ordinarily show as sharply defined ledges in undeformed areas.*

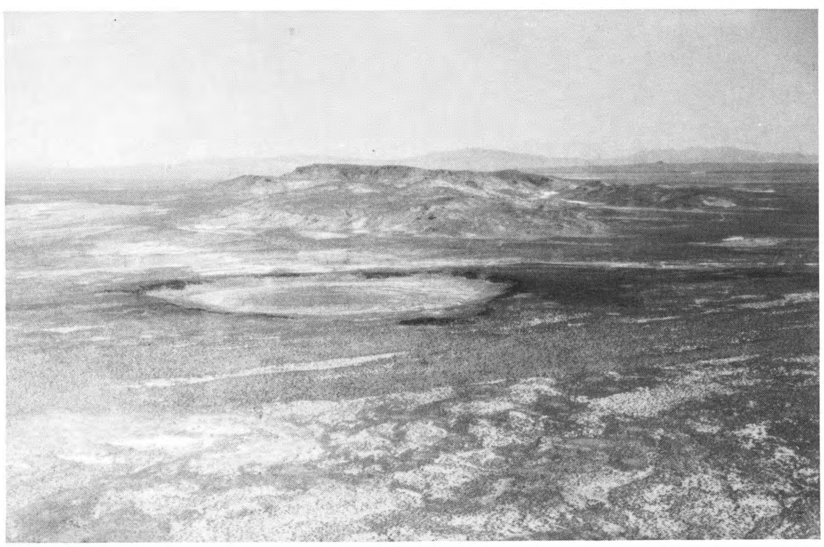

Figure 11. *Smelter Knolls are the hills that lie just beyond the explosion crater in the middle of the picture. Smelter Knolls are composed of topaz-bearing rhyolite domes and flows dated by Turley and Nash at 3.4 Ma. The phreatic explosion crater disrupted basalt flows that have an age of 310,000 years. The crater is 0.2 miles (320 m) in diameter and lies about a mile (1.6 km) east of the edge of the Smelter Knolls West quadrangle.*

east scarps are much higher than the down-to-the-west scarps, making the net displacement down-to-the-east.

Regional Structural Relationships

Features within this quadrangle are shown in their relationship to some major regional structures on figure 12. Cenozoic structural basins outlined on this map were derived from the regional gravity map of Bankey and Cook (1989). Additional subsurface information has been gained from the four deep exploration wells shown on the map, as well as a deep seismic reflection line (COCORP) that traversed the map area from west to east (Von Tish and others, 1985). This line passed through the Red Knolls quadrangle, described by Hintze and Davis (1992b) who presented a more extensive discussion of regional deep subsurface relationships than is given here.

The East Drum Mountains fault scarps lie in the northern extension of the Chalk Knolls graben, which shows on Bankey and Cook's (1989) map as a gravity low of 4-6 milligals. Its

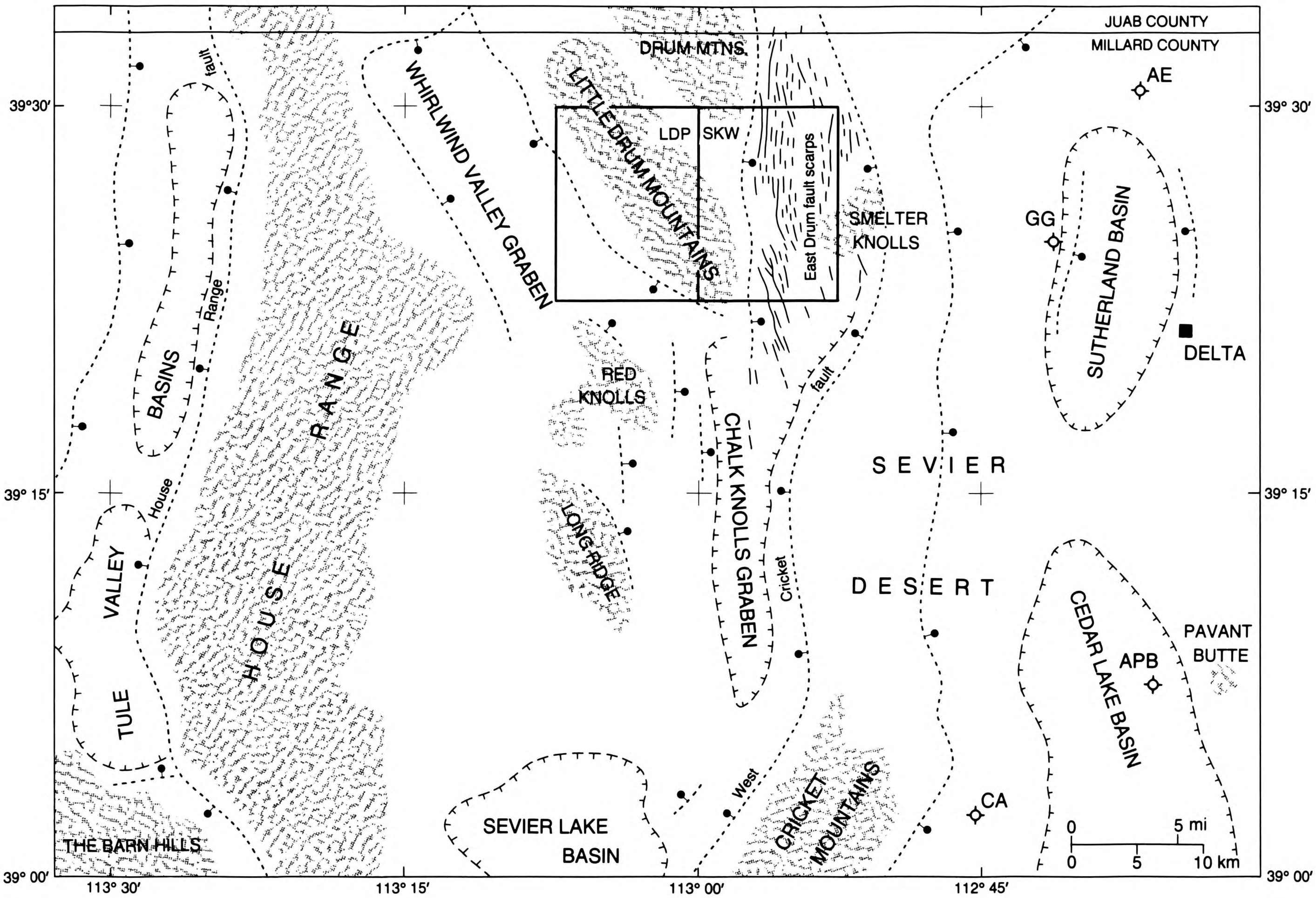

Figure 12. *Regional structural map of the same area as figure 1 showing bedrock exposures, major basins filled with low-gravity Tertiary deposits (hachure bounded), position of major basin-and-range faults as inferred from high gravity-gradient trends (dotted fault lines), and Holocene fault scarps east of the Little Drum and Drum Mountains. Rectangles show the position of the Little Drum Pass (LDP) and Smelter Knolls West (SKW) quadrangles. Gravity data are from Bankey and Cook (1989).*

Figure 13. *Holocene fault scarp in section 35, T. 15 S., R. 10 W. Position of graded road as shown on Smelter Knolls West topographic base map is incorrect; the road now follows the graben all the way north from the main road to Greener Reservoir. The down-to-the-east scarp is left of the vehicle. The down-to-the-west scarp does not show in the picture but is 2 to 4 feet (0.6 - 1.3 m) high along the graben.*

***Figure 14.** Fault scarp and trench at locality B (plate 1) in section 2, T. 16 S., R. 10 W. looking south. Crone (1983) logged this trench and concluded that the scarp was formed by one surface-faulting event. Doug Ekart is pointing his pick toward the main fault which dips eastward 80 degrees. The ground surface just above Doug's head corresponds to profile B shown on table 2.*

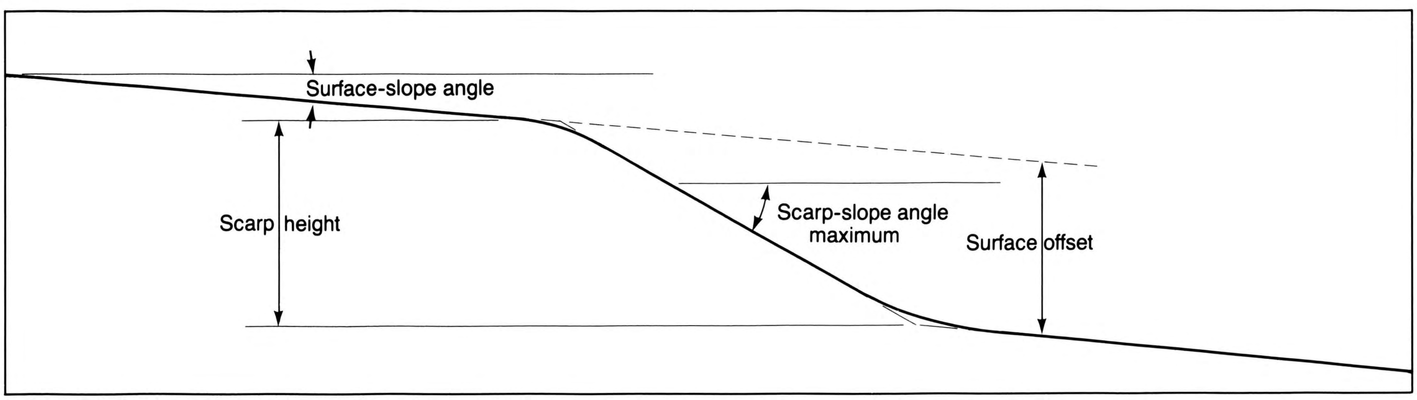

***Figure 15.** Heavy line represents a typical slope profile across a fault scarp. This diagram shows the surface-slope, scarp-slope, and scarp height parameters measured in the field for table 2. The surface offset is calculated from those values.*

boundaries are rather poorly defined because gravity stations in the vicinity are widely spaced. The gravity high that extends northward from the Cricket Mountains is a much better defined feature that separates the Chalk Knolls graben from the much deeper Clear Lake and Sutherland basins. The West Cricket fault shows as a prominent gravity feature as far north as 39°15′ where it becomes less sharply defined. It picks up definition again around 39°30′, just off the northeast corner of the Smelter Knolls West quadrangle.

The concealed major fault along the east base of the Drum Mountains is well defined on Bankey and Cook's (1989) map. Its maximum gravity gradient expression lies in the northwest quarter of the Smelter Knolls West quadrangle in section 34, T. 15 S., R. 10 W., about a mile (1.6 km) west of the East Drum Mountains fault scarp zone.

An unpublished aeromagnetic map of the Delta 1° x 2° quadrangle, furnished to the authors by David Campbell of the U.S. Geological Survey, shows no magnetic highs in the Smelter Knolls West quadrangle. A magnetic low is centered over the northwest corner of the quadrangle at the south end of the Drum Mountains in the area covered by Drum Mountains Rhyodacite flows.

ECONOMIC GEOLOGY

Gravel Deposits

Lake Bonneville gravel deposits (Qlg) are present in many places in the map area. Numerous small deposits are found in the northwest quarter of the map at the highest lake level, the Bonneville shoreline, at an elevation of about 5,190 feet (1,582 m). The largest deposits are just west of Smelter Knolls at the Provo level of the lake, between 4,860 and 4,880 feet (1,481 - 1,487 m). In general, lacustrine gravel (Qlg) deposits are the thickest and most uniform of the Quaternary gravel sources. However, gravel of lacustrine and/or alluvial origin (Qla) is very widespread and locally contains much gravel suitable for road construction.

Diatomaceous Earth

Lake Bonneville white marl (Qlm) is present along the eastern side of the quadrangle in the flats below the Provo shoreline. It is also well exposed in the Chalk Knolls along the south edge of the map area. The marl ranges up to 30 feet (10 m) thick and is mostly composed of calcareous mud. Most beds contain ostracodes; gastropods are locally abundant, and some beds contain diatoms, usually as broken siliceous debris. The marl is probably not suitable for use as a filter material, but it may have potential for cement manufacture.

Petroleum Possibilities

Neither the surface geology or what is known of the subsurface geology suggests that commercial accumulations of oil or gas underlie the quadrangle. Quaternary lake deposits are thin and lack dark organic material. Beneath the Quaternary deposits, the Oligocene-Eocene conglomerates and tuffs are improbable source rocks, but they might form reservoir rocks if a suitable caprock were present. Cambrian rocks probably underlie the volcanogenic Tertiary deposits. Although the Cambrian strata are of marine origin, and contain some organic matter in the gray carbonate and shale units, they have not been shown to produce oil or gas anywhere nearby. Figure 1 shows the location of four deep wildcat wells to the east of this quadrangle. None of these showed commercial promise.

Ore Deposits

No prospects or mines have been developed within the map area, but the Drum gold mine lies only about 2 miles (3.2 km) northwest of the northwest corner of this quadrangle. This mine produced some 120,000 ounces (3,400 kg) of gold during the 1980s (Nutt and others, 1990). The gold occurs in altered and faulted Cambrian carbonates and shales. Mineralization was apparently related to a small Tertiary intrusion located north of the mine. Mineralized rock does not appear to extend as far south as the Smelter Knolls West quadrangle.

Water Resources

There are no perennial streams within the quadrangle. Ground-water studies of the Sevier Desert area were made by Enright and Holmes (1982), Holmes (1984), and Mason and others (1985). The ground-water reservoir in this area is unconsolidated basin fill. Mason and others (1985) reported the following information on water depths in three test wells shown on plate 1:

Location	Well depth	Depth to water
Sec. 29, T. 15 S., R. 9 W.	200 feet (61 m)	107 feet (33 m)
Sec. 19, T. 16 S., R. 9 W.	180 feet (55 m)	176 feet (54 m)
Sec. 31, T. 16 S., R. 9 W.	202 feet (62 m)	121 feet (37 m)

Of the two wells shown on the topographic map, the Little Drum Well in section 33, T. 15 S., R. 10 W. is not currently used. The Old Smelter Well in section 29, T. 16 S., R. 9 W. has a windmill pump and furnishes water for cattle. The Smelter Knolls Reservoir in section 18, T. 16 S., R. 9 W. is dry except after exceptional surface runoff. A well located just south of Greener Reservoir (dry) in section 26, T. 15 S., R. 10 W. furnishes sufficient water to be pumped 6 miles (10 km) to the Drum gold mine via a six-inch (15-cm) surface pipeline.

GEOLOGIC HAZARDS

The map area is uninhabited. The county road that runs between Delta and the Drum gold mine currently carries daily traffic. The area is used for stock grazing, but the cattle are generally untended. Flash floods and the debris flows and erosion that accompany them are the most common geologic hazards in this quadrangle. The unnamed wash that leads westward from the northwest corner of the map has the largest catchment basin and would probably be capable of the largest floods, but each wash that drains the east face of the Little Drum Mountains is capable of major flooding if a cloudburst were to occur in its headwaters. Such flooding is capable of washing out roads. Travelers should not attempt to cross flooded roadways and washes, but flood waters usually subside within a few minutes to an hour.

Although geotechnical studies of local lacustrine marl (Qlm) have not been done, it probably is not a good foundation material because of the potential for workability problems and expansive behavior. Therefore, geotechnical studies should be done prior to construction of large facilities on Qlm deposits.

Earthquakes are a possible, but infrequent hazard. If Crone's (1983) evaluation that the East Drum Mountains fault scarps were produced by a single seismic event is correct, we have no basis for estimating the interval between earthquakes in the area. In addition, there may be some question as to whether the faults are seismogenic (earthquake-generating) or not. The quadrangle lies on the west side of the Intermountain seismic belt, and more specifically is in zone 2b on the 1988 Uniform Building Code Seismic Zone Map published by the International Conference of Building Officials, Whittier, California.

Because of the lack of people or significant structures within the area, there is little probability of significant loss of life or property damage from geologic hazards, however infrequent they may be.

ACKNOWLEDGMENTS

We are grateful to Robert C. Bucknam of the U.S. Geological Survey (USGS) for providing us with the fault scarp measurements shown in table 2, to David L. Campbell, also of the USGS, who gave us advance copies of gravity and aeromagnetic maps of the Delta 1° x 2° quadrangle, and to Myron G. Best of Brigham Young University, who helped with our igneous rock descriptions. The manuscript was improved as a result of helpful reviews by Myron Best, Brigitte Hucka, David Lindsey, Susan Olig, and Grant Willis to whom the authors are indebted.

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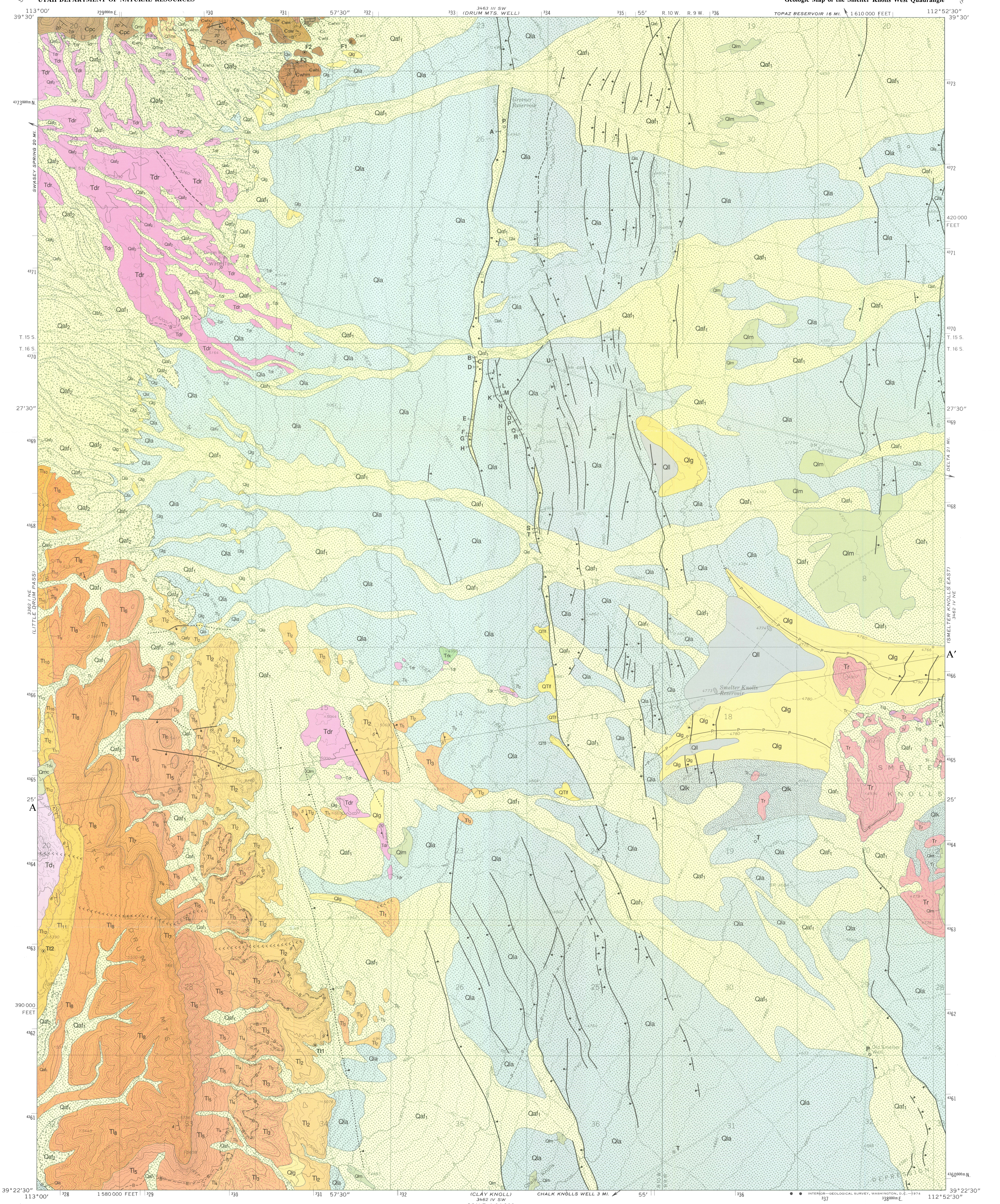
Plate 1
Utah Geological Survey Map 148
Geologic Map of the Smelter Knolls West Quadrangle



Base map from U.S. Geological Survey,
Smelter Knolls West 7.5′ quadrangle, 1971

SCALE 1:24 000

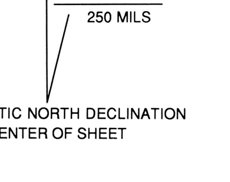
1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

Bedrock mapping by Hintze, 1989-1990
Quaternary mapping by Oviatt, 1986-1987
Cartography by J. Parker



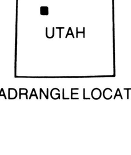
1993 MAGNETIC NORTH DECLINATION
AT CENTER OF SHEET

GEOLOGIC MAP OF THE SMELTER KNOLLS WEST QUADRANGLE, MILLARD COUNTY, UTAH

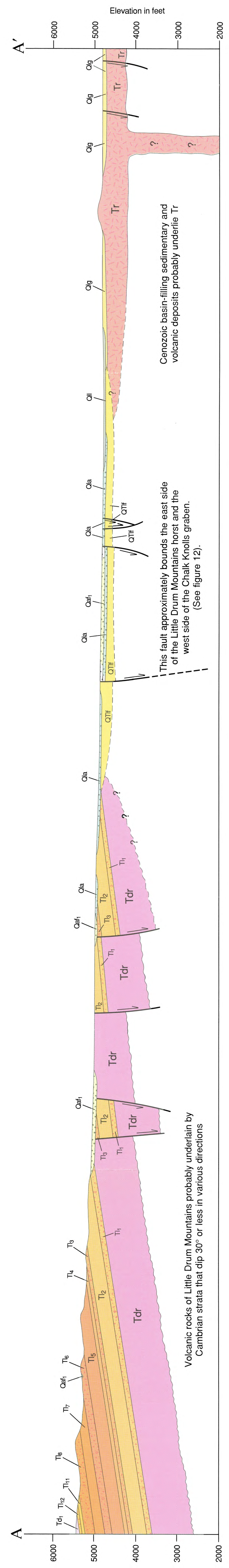
by

Lehi F. Hintze and Charles G. Oviatt

1993



QUADRANGLE LOCATION



DESCRIPTION OF MAP UNITS

Qaf₁ Post-Bonneville alluvial-fan deposits--*Coarse- to fine-grained alluvium on piedmont slopes. Deposition of this unit began before Holocene faulting and has continued to the present time.*

Qaf₂ Pre-Bonneville alluvial-fan deposits--*Coarse-grained alluvium in piedmont areas above the Bonneville shoreline.*

Qla Gravel of lacustrine and/or alluvial origin--*Mapped in piedmont areas where pre-Bonneville alluvial gravel was reworked by Lake Bonneville, but where the lacustrine gravel component is thin; includes pre-Bonneville alluvial fans etched by waves in Lake Bonneville and thin lacustrine gravel capping QTlf.*

Qll Lagoon fill--*Silt, sand, and clay that filled lagoons behind barrier beaches; Bonneville and post-Bonneville in age.*

Qlk Lacustrine carbonate sand--*Sand or pebbly sand composed dominantly of calcium carbonate, including sand- to pebble-size clasts of calcium carbonate, carbonate-coated gastropods, and oolitic sand below the Provo shoreline; stratigraphically overlies the white marl.*

Qlm White marl--*The white marl as defined by Gilbert, 1890, and Oviatt, 1987; fine-grained, white to gray marl and sandy marl deposited in Lake Bonneville; finely bedded to indistinctly laminated; contains abundant ostracodes throughout, and locally contains gastropods near the base and top; thickness 6 to 30 ft (2 to 10 m); also includes calcareous sand at the base and top.*

Qlg Lacustrine gravel--*Sandy gravel composed of locally derived rock fragments; beach or spit gravel deposited in Lake Bonneville.*

QTlf Pliocene and Pleistocene fine-grained lacustrine deposits--*Red, green, and light-gray calcareous silty clay, silt, and sand, which underlie Quaternary alluvial and lacustrine deposits. Outside the map area this unit contains the Bishop ash (0.74 Ma.), and the Cudahy Mine ash (about 2.5 Ma.).*

Qmc Colluvium--*Unconsolidated angular debris that has accumulated at the base of some steep slopes.*

QTms Landslide deposit--*Coarse, angular, unconsolidated, unsorted, blocky debris derived from nearby Cambrian cliffs and deposited at their base.*

Tr Rhyolite of Smelter Knolls--*Medium to light-gray, flow-banded rhyolite that contains 10 to 20 percent phenocrysts of quartz, alkali feldspar, plagioclase, biotite, and Fe-Ti oxides. Topaz and hematite occur in lithophysal cavities. Occurs as flows and domes over 500 feet (150 m) thick. Reverse polarity. K-Ar age of sanidine is 3.4 ± 0.1 Ma.*

Trg Glassy flows within rhyolite of Smelter Knolls--*Local glassy zones within rhyolite flows. Glassy zones are neither common nor large; most are less than 20 feet (6 m) thick.*

Trk Red Knolls Tuff--*Pink, crystal-rich, welded, ash-flow tuff; lithic fragments abundant. More than 200 feet (61 m) thick in nearby Red Knolls quadrangle (Hintze and Davis, 1992b).*

Td₁ Basal tuff member of the volcanic sequence of Dennison Canyon--*Light-pink, partly welded, ash-flow tuff. Forms rounded cliffs honeycombed with small caverns. Contains conspicuous biotite and abundant pumice and lithic fragments. Maximum thickness of 500 feet (150 m) along west edge of quadrangle.*

Tl₁₂ Member 12 of the Little Drum Formation--*Conglomerate composed of subrounded cobbles and small boulders of dark basaltic andesite. These dark clasts commonly float in a matrix of white tuff reworked from member 11. Contact with member 11 is gradational. Conglomerate ranges to 30 feet (9m) thick and forms caprock for a low cuesta.*

Tl₁₁ Member 11 of the Little Drum Formation--*White ash-flow tuff that lacks conspicuous phenocrysts and biotite but contains abundant chalky pumice fragments. Ranges to 200 feet (61 m) thick, pinching out to the north. Fission track age on zircon crystals is 38.6 ± 3.1 Ma.*

Tl₁₀ Member 10 of the Little Drum Formation--*Conglomerate that resembles member 8 except that it lacks cobbles and boulders of quartzite. Reddish-brown-weathering, subrounded, basaltic andesite clasts are up to 3 feet (1m) in diameter, and are in a poorly cemented sandy matrix. No bedding or sorting. Maximum thickness 220 feet (67 m).*

Tl₉ Member 9 of the Little Drum Formation--*Light-gray to white, poorly welded, ash-flow tuff. Includes abundant lithic fragments of pumice and felsitic volcanic rocks. Member 9 is recessive and generally poorly exposed. Ranges up to 50 feet (15 m) thick.*

Tl₈ Member 8 of the Little Drum Formation--*Conglomerate composed of rounded cobbles and boulders of quartzite, and subrounded to subangular dark andesite. Unbedded and unconsolidated. Thickness ranges up to 250 feet (76 m).*

Tl₇ Member 7 of the Little Drum Formation--*Pink tuff, similar to member 2, with biotite and hornblende phenocrysts and felsitic, lithic, and pumice fragments. Mostly poorly welded and non-resistant, except for a welded zone as much as 100 feet (30 m) thick near top of the unit that forms cliffs locally. Maximum thickness 250 feet (76 m).*

Tl₆ Member 6 of the Little Drum Formation--*Conglomerate of quartzite and volcanic clasts up to 5 feet (1.5 m) in diameter in a tuffaceous matrix. Ranges up to 220 feet (67 m) thick.*

Tl₅ Member 5 of the Little Drum Formation--*Light-brownish-gray, tuffaceous mudstone; non-resistant. Thickness about 290 feet (88 m).*

Tl₄ Member 4 of the Little Drum Formation--*Dark-brown to dark-greenish-gray basaltic andesite with amygdaloidal zones; conglomeratic near top. Thickness 150 feet (46 m).*

Tl₃ Member 3 of the Little Drum Formation--*Basal third is green tuff that includes rounded cobbles and boulders of andesite and quartzite. Tuff grades upward into resistant conglomerate composed mostly of clasts of volcanic rock. Thickness ranges up to 340 feet (105 m).*

Tl₂ Member 2 of the Little Drum Formation--*Orange-pink, andesitic, ash-flow tuff containing abundant felsitic and pumice lithic fragments in a matrix of glass shards and small pumice fragments. Fission track zircon age is 39.5 ± 3.5 Ma. As much as 225 feet (69 m) thick.*

Tl₁ Member 1 of the Little Drum Formation--*Conglomerate with andesite and quartzite clasts, the percentage of quartzite increasing up section to nearly 50 percent. Unconsolidated, unbedded; ranges to 100 feet (30 m) thick.*

Tdr Drum Mountains Rhyodacite--*Dark-red-weathering flows and breccias in the northwest corner of the quadrangle where it is about 1,000 feet (305 m) thick. Dark-green, vesicular and amygdaloidal flows in the south central part of the map area are at least 150 feet (46 m) thick but their base is not exposed.*

Ꞓpc Pierson Cove Formation--*Dark-gray, thin- to thick-bedded limestone and dolomitic limestone. Forms ledges and cliffs. Cut by bedding-parallel attenuation faults locally. Only the basal third of a total thickness of about 800 feet (245 m) is present in this quadrangle.*

Ꞓwhu Upper member of the Wheeler Formation--*Mostly yellowish-gray, fossiliferous, platy limestone and calcareous shale. Basal unit is algal stromatolite limestone bed 10 feet (3 m) thick. Total thickness 125 feet (39 m).*

Ꞓwhm Middle member of the Wheeler Formation--*Dark-gray, fine-grained, thin-bedded unfossiliferous limestone. Oolitic beds common. Some beds have been dolomitized. Only part of the 500 foot (152 m) thickness of this member is exposed in this quadrangle.*

Ꞓwhl Lower member of the Wheeler Formation--*Interbedded limy shale and thin-bedded clayey limestone that commonly contains trilobites and inarticulate brachiopods. Non-resistant; 280 feet (85 m) thick.*

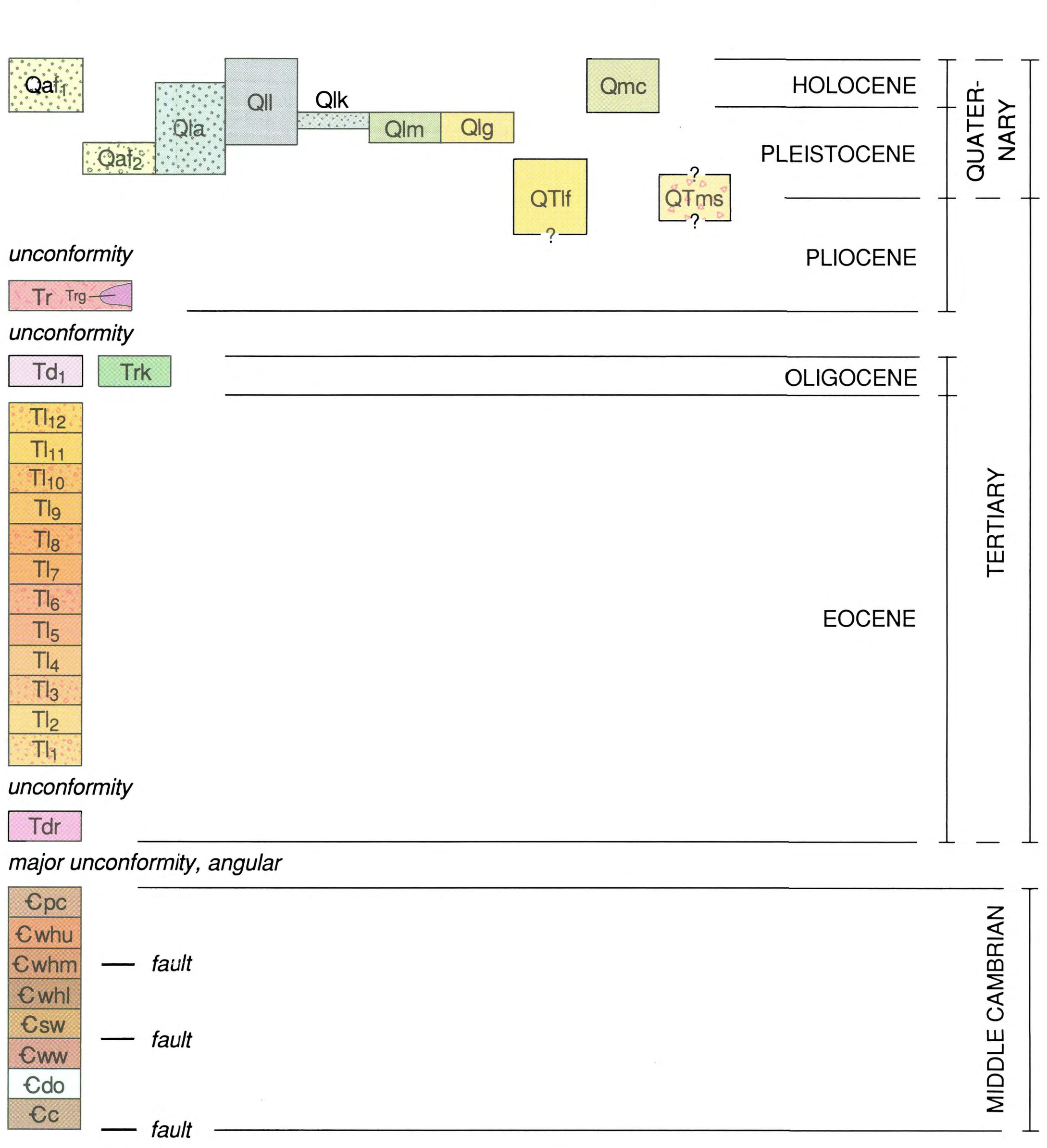
Ꞓsw Swasey Limestone--*Dark-gray, massive limestone that forms ledges and cliffs. Thickness 180 feet (55m).*

Ꞓww Whirlwind Formation--*This formation is about 150 feet (46 m) thick just north of the quadrangle boundary where it consists of lower and upper shale units separated by a middle limestone. Only the upper olive-gray shale is present in this map area. It is about 50 feet (15 m) thick and commonly contains conquinas of the trilobite Ehmaniella.*

Ꞓdo Dome Limestone--*Faults have cut out the Dome Limestone in this quadrangle. Nearby it is a cliff-forming unit about 300 feet (90 m) thick.*

Ꞓc Chisholm Formation--*This formation is about 200 feet (61 m) thick just north of the quadrangle boundary where it consists of lower and upper shale units separated by a middle limestone. Only the middle limestone is present here. It is dark gray, oncolitic, and contains the trilobite Glossopleura. Thickness about 75 feet (25 m).*

CORRELATION OF MAP UNITS



MAP SYMBOLS

- Contact--*Dashed where approximately located.*
- Normal fault--*Bar and ball on downthrown side; dashed where inferred, dotted where concealed. Where no bar and ball is shown, displacement was too small to determine.*
- Attenuation fault--*Nearly bedding-parallel, cuts out some beds in younger-on-older displacement.*
- P — — P — — Provo shoreline--*Dashed where poorly preserved; locally serves as a geologic contact; elevation about 4,785 feet (1,458 m).*
- B — — B — — Bonneville shoreline--*Dashed where poorly preserved; locally serves as a geologic contact; elevation about 5,190 feet (1,582 m).*
- 17 Strike and dip of stratified units
- 6 Strike and dip of volcanic foliation
- T Water test well
- P Water pump well
- A Location of scarp profiles of table 2
- Tt1 Fission track sample localities of table 1
- F1 Fossil localities mentioned in text
- < < < < < < < < < < < < Location of type section of the Little Drum Formation

LITHOLOGIC COLUMN

AGE	UNIT NAME		SYMBOL	FEET (METERS)	LITHOLOGY
QUAT.	Surficial units		see text	0-500 (0-152)	*Unconformity*
PLIOCENE	Fine-grained lacustrine deposits		QTlf	30 (10) *200? (*61?)	
PLIOCENE	Rhyolite of Smelter Knolls		Trg	0-30 (0-10)	Few glassy zones (Trg)
PLIOCENE	Rhyolite of Smelter Knolls		Tr	500+ (152+)	K-Ar sanidine age 3.4 ± 0.1 Ma; *Unconformity*
OLIGOCENE	Red Knolls Tuff		Trk	20 (6) *200 (*61)	Dark-red ash-flow tuff; Five fission-track zircon ages average 31.5 ± 2.5 Ma; ?; *Not in direct contact*
OLIGOCENE	Basal tuff member of the volcanic sequence of Dennison Canyon		Td₁	500 (152)	Honeycombed cliffs; Light pink tuff; Fission-track zircon age 31.3 ± 2.3 Ma
EOCENE	Little Drum Formation	Member 12	Tl₁₂	0-30 (0-9)	
EOCENE	Little Drum Formation	Member 11	Tl₁₁	0-200 (0-61)	White tuff; Fission-track zircon age 38.6 ± 3.1 Ma
EOCENE	Little Drum Formation	Member 10	Tl₁₀	0-220 (0-67)	Andesite clasts
EOCENE	Little Drum Formation	Member 9	Tl₉	0-50 (0-15)	Light-gray tuff
EOCENE	Little Drum Formation	Member 8	Tl₈	250 (76)	Quartzite and andesite cobbles and boulders
EOCENE	Little Drum Formation	Member 7	Tl₇	250 (76)	Welded zone; Pink tuff
EOCENE	Little Drum Formation	Member 6	Tl₆	220 (67)	Andesite and quartzite clasts
EOCENE	Little Drum Formation	Member 5	Tl₅	290 (88)	Tuffaceous mudstone
EOCENE	Little Drum Formation	Member 4	Tl₄	150 (46)	Amygdaloidal basaltic andesite
EOCENE	Little Drum Formation	Member 3	Tl₃	0-340 (0-104)	Andesite and quartzite clasts; Green tuff
EOCENE	Little Drum Formation	Member 2	Tl₂	225+ (69+)	Orange-pink tuff; Fission-track zircon age 39.5 ±3.5 Ma
EOCENE	Little Drum Formation	Member 1	Tl₁	100 (30)	Quartzite and andesite clasts; *Unconformity*
EOCENE	Drum Mountains Rhyodacite		Tdr	1000 (305)	Fission-track age 41.8 ± 2.3 Ma (Lindsey, 1979, 1982); *Angular unconformity*
MIDDLE CAMBRIAN	Pierson Cove Formation		Ꞓpc	300 (91) *803 (*245)	
MIDDLE CAMBRIAN	Wheeler Formation	Upper member	Ꞓwhu	125 (38)	Trilobites; Stromatolite heads
MIDDLE CAMBRIAN	Wheeler Formation	Middle member	Ꞓwhm	300 (91) *505 (*154)	*Fault*
MIDDLE CAMBRIAN	Wheeler Formation	Lower member	Ꞓwhl	280 (85)	Trilobites and inarticulate brachiopods
MIDDLE CAMBRIAN	Swasey Limestone		Ꞓsw	100 (30) *180 (*55)	*Fault*
MIDDLE CAMBRIAN	Whirlwind Formation		Ꞓww	55 (17) *137 (*42)	*Ehmaniella* coquinas
MIDDLE CAMBRIAN	Dome Limestone		Ꞓdo	*300 (*90)	*Fault (unit not exposed)*
MIDDLE CAMBRIAN	Chisholm Formation		Ꞓc	75 (23) *205 (*62.5)	*Glossopleura*; *Fault*

*Regional thickness