Mudflow deposit -
Lacustrine and alluvial deposits undifferentiated -
Volcanic conglomerate of Little Drum -
Alluvial deposits in washes and on fans -
Lacustrine marl -
Red Knolls Tuff -
Fine-grained lacustrine deposits -
Skull Rock Pass Conglomerate -
pre-Lake Bonneville alluvium has been reworked but where the lacustrine component is thin. Pre-Bonneville fan deposits may be several hundred feet thick locally.

...less than 20 feet (6 m) thick.

... action of Lake Bonneville has reworked this conglomerate leaving boulder-strewn gravel bars and smaller clasts of the same composition. Unit is poorly cemented and wave less than 10 feet (3 m) thick.

...lagoons behind gravel bars of Lake Bonneville (Qlg) at many levels. Most deposits deposited in Lake Bonneville. As much as 12 feet (3.6 m) thick locally.

...outcrops without matrix. A thickness of about 180 feet (55 m) is exposed of the quadrangle.

...of cobbles and boulders almost all of which were derived from Cambrian, Ordovician, and Silurian strata west of the quadrangle. Conglomerate is at least 150 feet (45 m)
in the quadrangle but it could be thicker in the subsurface on the east side.

...of slope after regression of Lake Bonneville. Locally a few tens of feet thick.

...rounded basaltic andesite boulders; interstices between rounded boulders are cobble horizons; lithic fragments widespread except near top. About 210 feet (64 m) thick.

...thick and may be as much as 200 feet (61 m) thick.

...of exposed section.

...significant thickness on the scale of this cross section.

...Quaternary units are too thin to show a significant thickness on the scale of this cross section.
GEOLOGIC MAP OF THE RED KNOLLS QUADRANGLE, MILLARD COUNTY, UTAH

by

Lehi F. Hintze and Fitzhugh D. Davis
Utah Geological Survey

MAP 142  1992
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
GEOLOGIC MAP OF THE RED KNOLLS QUADRANGLE, MILLARD COUNTY, UTAH

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ABSTRACT

Bedrock exposed in this quadrangle consists of 700 feet (213 m) of nearly flat-lying Oligocene volcanic and sedimentary deposits divided into three units. Oldest is the volcanic conglomerate of Little Drum, a cobble and boulder deposit 180+ feet (55+ m) thick (base not exposed) of dark andesitic rock derived from the Little Drum Mountains which lie northeast of the map area. Above this conglomerate is the Red Knolls Tuff (new name), a pink dacite ash-flow deposit 210 feet (64 m) thick which may have been derived from the Drum Mountains to the north. The youngest bedrock unit is the Skull Rock Pass Conglomerate, 200 feet (60 m) thick, an unconsolidated, unstratified, mud-flow diamictite consisting mostly of carbonate and quartzite boulders, as much as 15 feet (4.6 m) in diameter but mostly less than a foot in diameter, derived from lower Paleozoic formations exposed in the House and Confusion Ranges to the west. The matrix of the conglomerate is, in part, clayey, comminuted volcanic rock.

Late Quaternary Lake Bonneville covered the entire quadrangle except for a small part of Red Knolls that is above the highest lake level at 5,170 feet (1,576 m). Wave action during temporary transgressive and regressive stillstands of the lake created many gravel beaches and bars and substantially modified the surface exposures of the unconsolidated Oligocene conglomerates. Several small gravel pits have been developed in the Bonneville deposits; this material is used by Millard County road crews for surfacing the graded county roads. A white marl deposit that accumulated on the Lake Bonneville floor below the Provo level (4,787 feet [1,459 m]) has been prospected but not significantly produced in the quadrangle. The marl is mostly limy mud that included some fine-grained siliceous diatomaceous debris. Travertine deposits along a fault zone near Red Knolls have also been prospected but without significant production.

INTRODUCTION

The Red Knolls are low hills that rise about 400 feet (122 m) above the floor of the Sevier Desert some 25 miles (40 km) west of Delta, Utah (figure 1). The Sevier Desert is a broad Basin and Range valley surfaced with Quaternary deposits of alluvial, lacustrine, and eolian origin that conceal relationships of Tertiary and Paleozoic rocks beneath. Interest has been focused on subsurface structures of the Sevier Desert basin as a result of the Consortium for Continental Reflection Profiling (COCORP) deep seismic-reflection survey (Allmendinger and others, 1983) which crosses the Red Knolls quadrangle as shown on figure 1. Oligocene bedrock exposed in Red Knolls constrains COCORP subsurface interpretations by showing that the western edge of the Sevier Desert is not underlain by any great thickness of late Tertiary or Quaternary valley fill; instead it has more than 1,000 feet (305 m) of Oligocene conglomerate and tuff that rests directly on lower Paleozoic, probably entirely Cambrian, strata as shown on regional geologic maps (Hintze, 1963, 1980).

No previous geologic map of this quadrangle has been published except for reconnaissance mapping done in connection with regional map compilation (Hintze, 1963). Adjacent quadrangles to the west and northwest have been mapped (Hintze, 1981), and the Little Drum Mountains to the north have been described (Leedom, 1974, and Pierce, 1974). Oviatt (1989) mapped and described Quaternary deposits of the Sevier Desert in quadrangles immediately east and south of the Red Knolls and Long Ridge quadrangles. One of us (Davis) mapped Quaternary deposits in the quadrangle during the 1987 field season; Hintze mapped bedrock units of these quadrangles in the summer of 1988. Field work was facilitated by the availability of excellent 1:25,000 color aerial photographs of the CSR series taken for the Department of Defense mobile missile project reconnaissance in 1978.
STRATIGRAPHY

Pre-Quaternary rocks exposed in this quadrangle are entirely Oligocene in age and divided into three units (figure 2). Oldest is the volcanic conglomerate of Little Drum followed by the Red Knolls Tuff and the Skull Rock Pass Conglomerate. Oligocene volcanic rocks and related sedimentary deposits are generally less than 1,000 feet (305 m) thick where exposed in western Millard County (Hintze, 1988), and everywhere rest with angular discordance on tilted Paleozoic marine strata. Oligocene rocks in this quadrangle likely conform to this regional pattern although the Tertiary/Paleozoic contact is not exposed here. Oligocene rocks thicken northeastward toward their main source in the Little Drum-Drum Mountains area. The volcanic conglomerate of Little Drum is probably a distal tongue of laharric debris spread from a volcanic center in the northern Little Drum and Drum Mountains. The Red Knolls Tuff is an ash-flow tuff likely derived from the Drum Mountains area. The Skull Rock Pass Conglomerate contains almost no cobbles and boulders of igneous rock, and its clasts are derived from lower Paleozoic formations now exposed in the House and Confusion Ranges to the west; its matrix includes comminuted volcanic debris. Skull Rock Pass Conglomerate and Red Knolls Tuff are new names formally proposed in the UGS report on the Long Ridge quadrangle (Hintze and Davis, 1992), and in this report to replace similar informal previously used designations.

Formal names have not been given to Quaternary units on the map. Rather, they are described according to process of origin such as alluvial, lacustrine, or mass-movement, and by type of material such as gravel or marl. Most of the quadrangle is covered by an irregular veneer of lacustrine and alluvial deposits less than 100 feet (30 m) thick. The lacustrine deposits were formed in Lake Bonneville or along its shores between 30,000 and 10,000 years ago. These deposits have incurred some subsequent erosion.

<table>
<thead>
<tr>
<th>Formation</th>
<th>Map Symbol</th>
<th>Thickness (feet)</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skull Rock Pass</td>
<td>Tsr</td>
<td>200 (60)</td>
<td>bentonitic matrix locally</td>
</tr>
<tr>
<td>Conglomerate</td>
<td></td>
<td></td>
<td>boulders up to 15 ft. (4.6 m) across</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>occur rarely</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>top massive, structureless</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>local fiammu layers</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>30-32 m.y.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>local basal vitrophere</td>
</tr>
<tr>
<td>Red Knolls Tuff</td>
<td>Trk</td>
<td>210 (64)</td>
<td>reddish clayey matrix in</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>middle of exposed section</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>39 m.y., base not exposed</td>
</tr>
<tr>
<td>Volcanic</td>
<td>Tld</td>
<td>180+ (55+)</td>
<td></td>
</tr>
<tr>
<td>conglomerate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>of Little Drum</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Stratigraphic column of bedrock units exposed in the Red Knolls quadrangle.
Where wave action in Lake Bonneville modified the bedrock units to the extent that they are largely reworked, both the bedrock and Quaternary designations are shown with a combination symbol. For example, Qlg/Tsr indicates that Tsr has been significantly reworked by lake processes, and the present clast distribution is Quaternary in age.

**TERTIARY DEPOSITS**

**Volcanic Conglomerate of Little Drum (Tld)**

The oldest rock exposed in the quadrangle is a conglomerate made entirely of cobbles and boulders of dark volcanic rocks derived from the Little Drum Mountains area. The unit is best exposed in the southwest part of section 10, T. 17 S., R. 11 W., where three subdivisions can be seen. The lowermost 80 feet (24 m) is a boulder conglomerate with boulders 3 feet (0.9 m) in diameter common and boulders about 1 foot (0.3 m) in diameter very abundant. The boulders are well rounded to subrounded and there is little fine matrix; the space between boulders is filled with cobble- and pebble-size volcanic clasts. The middle 50 feet (15 m) of the map unit shows as bright-reddish brown on color aerial photos and is conglomerate with a reddish, clayey matrix that may make up to 40 percent of the rock volume. Its reddish color has attracted a little prospecting in the form of bulldozer pits. The upper 50 feet (15 m) is a boulder conglomerate similar to the lower portion. Leedom (1974) and Pierce (1974) called this unit a "laharic breccia," but in the Red Knolls quadrangle it is not a breccia. All the components are rounded volcanic pebbles, cobbles, or boulders, locally in a finer matrix. Some of the clasts are hornblende-pyroxene latite, but most are clasts of pyroxene andesite that show a few vesicles. The igneous petrology of these rocks was described by Leedom (1974) and Pierce (1974). Internal makeup of this conglomerate is exposed in only one place in the quadrangle. A travertine quarry along a fault zone in NW, SE, section 10, T. 17 S., R. 11 W. has exposed a few square feet of the conglomerate in a vertical wall; the boulders are densely packed and very little fine matrix is visible (figure 3). The upper contact with the Red Knolls Tuff is not clearly exposed anywhere in the quadrangle, being covered by colluvium or lake deposits. It is most nearly exposed along the east side of a small Quaternary lake deposit in section 15, T. 17 S., R. 11 W. where the two map units are separated by only a few feet of cover. In the northwest corner of the quadrangle, a low ridge was mapped as "Qa/Tld." All materials on this ridge have been reworked by Lake Bonneville wave action. But the boulders that remain on the ridge crest are entirely of volcanic materials, none are sedimentary clasts that make up the Skull Rock Pass Conglomerate.

It is not known how much of the section of volcanic rocks described by Leedom (1974) and Pierce (1974) in the Little Drum Mountains extends beneath this quadrangle. In the Red Knolls quadrangle there may be several hundred feet of unexposed Oligocene volcanic and sedimentary rocks beneath the base of those exposed, and they likely thin rapidly to the southwest. The age of the volcanic sequence in the Little Drum Mountains is about 39 million years, latest Eocene. The conglomerate of Little Drum has not been dated in the Red Knolls quadrangle but is probably of about this same age.

**Red Knolls Tuff (new name) (Trk)**

This is 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 (figure 4). Some beds of the tuff show abundant fiamme (figure 5). This is the same unit shown on the map of the adjacent Whirlwind Valley SW quadrangle as "dacite ash-flow tuff" which yielded a K-Ar age of 36 Ma on biotite (Hintze, 1981). It is probably the unit that Leedom (1974) and Pierce (1974) incorrectly identified as Needles Range Formation in the Little Drum Mountains. It is proposed to give this unit a new name, Red Knolls Tuff, and designate a type section for the formation in section 10, T. 17 S., R. 11 W. on the north end of hill 5224 (figure 6). There the formation is 210 feet (64 m) thick and its base and top are exposed. The Red Knolls Tuff ranges from a massive and resistant welded tuff to partially welded, relatively non-resistant rock with a honey-combed weathered surface. Samples of oriented tuff have been collected at the type section for the purpose of measuring magnetic polarity. Fission-track ages of zircon samples obtained from the tuff at its type section and nearby were determined by B.J. Kowallis at Brigham Young University as follows:

<table>
<thead>
<tr>
<th>Sample designation</th>
<th>Age ± 2σ yrs B.P.</th>
<th>Township</th>
<th>Latitude-Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>TW</td>
<td>32.5 ± 2.7</td>
<td>SW, NE, SE, 6-8S-11W</td>
<td>39°16'25&quot;-113°9'27&quot;50&quot;</td>
</tr>
<tr>
<td>RKM</td>
<td>33.0 ± 2.9</td>
<td>SW, NE, NW, 10-7S-11W</td>
<td>39°20'25&quot;-113°0'47&quot;22&quot;</td>
</tr>
<tr>
<td>RKB</td>
<td>29.8 ± 2.3</td>
<td>SW, NE, NW, 10-7S-11W</td>
<td>39°20'25&quot;-113°0'47&quot;22&quot;</td>
</tr>
<tr>
<td>&quot;Trk&quot;</td>
<td>31.4 ± 3.2</td>
<td>NW, SE, 11-16S-11W</td>
<td>39°26'06&quot;-113°0'34&quot;5&quot;</td>
</tr>
</tbody>
</table>

31.5 ± 2.8 a average age of these four samples.

The location of the source caldera of the Red Knolls Tuff is not known, but it may lie in the Drum Mountain-Keg Mountain volcanic complex to the north of Red Knolls. Known distribution of the tuff is limited to the Long Ridge-Red Knolls-Whirlwind Valley-Little Drum Mountains area. This formation should not be confused with the "Red Knolls Flows" described by Clark (1977) in central Utah. The name is different and the two units are in no way related.
This is an unsorted, uncedemented boulder conglomerate with a slightly bentonitic, silty to fine-sandy matrix which weathers light yellowish to reddish gray. Type locality for this formation is in the adjacent Long Ridge quadrangle (Hintze and Davis, 1992) where the conglomerate is extensively exposed above the highest reach of Lake Bonneville. In the Red Knolls quadrangle only two tiny areas near the center of the map were above the highest lake level; exposures of the formation in the rest of the quadrangle have been extensively reworked by wave action so that it is uncertain what amount of matrix was originally present and what its characteristics were. However, it appears that the matrix is clayey and silty and makes up about 20 percent of the rock. Clast composition is somewhat different from that on Long Ridge. In the Red Knolls quadrangle the conglomerate contains more basaltic andesite boulders (up to 5 percent of the clasts) derived from the Little Drum Mountains area, and less Eureka Quartzite, Ely Springs Dolomite, and Laketown Dolomite clasts. The predominant clasts are dolomite and limestone cobbles and boulders derived from Middle and Upper Cambrian strata in the House Range or the Drum Mountains. The thickest deposit of Skull Rock Pass Conglomerate in the quadrangle is on the unnamed hills in the central part of the map. The basal contact is exposed only in section 14 but has been inferred in sections 24 and 25 on the basis of topographic expression (the Red Knolls Tuff is less resistant than the conglomerate), and on the occurrence of quartz crystals in the lake sediments in the areas mapped as Qla/Trk. The stratigraphic top of the formation is not exposed in the quadrangle. Although no bedding surfaces have ever been identified within the Skull Rock Pass Conglomerate; the map relationships indicate that the formation is at least 150 feet (46 m) thick and may reach a maximum thickness of about 200 feet (60 m).

In section 10, T. 17 S., R. 11 W., two small patches of material mapped as Skull Rock Pass Conglomerate merit special attention because they are different than most of the exposures of the formation. They consist mostly of boulders of basaltic andesite similar to volcanic rocks in the Little Drum Mountains, or to material mapped in the adjacent Whirlwind Valley SW quadrangle as Oligocene andesite (Hintze, 1981). These exposures lie above the highest level of Lake Bonneville, so have not been subjected to wave action; nonetheless, they are devoid of matrix, which must have been removed by wind or rain. Winter ice pile-up on Lake Bonneville may also have been a factor in modifying these deposits.

**QUATERNARY DEPOSITS**

In coining the symbol for each type of Quaternary deposit, the first letter after the Q designates the general process responsible: a, alluvial; l, lacustrine; m, mass movement. The last letter represents a more specific description of the deposit.

**Lacustrine and alluvial deposits undifferentiated (Qla)** — These are deposits in piedmont areas where pre-Lake Bonneville alluvial sediments were reworked by waves and currents in Lake Bonneville, but the lacustrine sediment component is usually thin; the unit includes pre-Lake Bonneville alluvial fans etched by wave action in Lake Bonneville. The pre-Bonneville fan deposits may be several hundred feet thick locally and generally consist of interlayered coarse debris flows and finer grained mudflows. The surficial lacustrine sediments and the fan deposits contain rock types derived from nearby sources.
Lacustrine gravel (Qlg) — This unit includes sandy gravel deposited as barrier beaches, spits, bars, and embankments in Lake Bonneville. The gravel consists of subangular to rounded quartzite, limestone, dolomite, and volcanic rocks that are mostly pebble to cobble sized. In Qlg deposits above an elevation of 4,950 feet (1,509 m) and below the Bonneville shoreline (e.g., Olg/Tsr), the clasts range to boulders in size. Individual Qlg deposits are no more than about 20 feet (6 m) thick.

At the south-central edge of the quadrangle a barrier beach with a crestal elevation of 4,787 feet (1,459 m) denotes the Provo shoreline. This is about the average elevation of that shoreline across the quadrangle. Due to later erosion the shoreline is poorly preserved. A modified sea cliff about 10 feet (3 m) high marks the shoreline near the eastern edge of the quadrangle. Oviatt (1991) reported a radiocarbon date of 14,320 ± 90 yr B.P. for the shoreline which existed for about 300 years around that date.

A notable series of 8 semicircular barrier beaches and 5 intervening lagoon deposits are present in the southwest part of the quadrangle. These transgressive shoreline features were deposited at intermediate "stillstands" in a small embayment of Lake Bonneville.

Deposits associated with the Bonneville shoreline, at an elevation of 5,170 feet (1,576 m), are thin or absent. For the most part, the shoreline is a notch in the Red Knolls Tuff around hill 5224 in section 10, T. 17 S., R. 11 W. Lake Bonneville attained this level about 15,350 years ago, and the shoreline persisted about 850 years (Barr and Currey, 1988).

Lacustrine marl (Qlm) — This is a fine-grained, thinly bedded to indistinctly laminated, white to light-gray marl deposited in Lake Bonneville. It includes Gilbert's (1890) "white marl" as well as reworked silty and sandy marl that contains abundant ostracodes and locally has gastropods near the base and top of the unit. In this quadrangle most of the marl was deposited 5 to 100 feet (1.5-30 m) below the Provo shoreline of Lake Bonneville. Deposits may be as much as 12 feet (3.6 m) thick where protected. The Qlm is relatively soft and easily eroded. Most of the original deposit has probably been eroded from the quadrangle.

Lacustrine lagoon deposits (Qll) — This is white, tan, or light-gray clay, silt, and sand deposited in lagoons behind gravel (Qlg) barrier beaches and bars of Lake Bonneville; includes local, thin, surficial influxes of later alluvium. Most of the fine-grained sediment in these lagoons was deposited by waves that washed over the barrier beaches during storms. Lagoonal deposits are mostly less than 10 feet (3 m) thick.

Fine-grained lacustrine deposits (Qlf) — This unit includes varying percentages of clay, silt, and sand deposited in ephemeral lakes (except during Lake Bonneville time); locally may include a low percentage of salts; also includes local, thin, interfingerling influxes of alluvium. Thickness was not determined but is likely less than 15 feet (4.5 m).

Mudflow deposit (Qmf) — This is a mudflow deposit of clay, silt, and gravel that appears on color aerial photos as red shades that contrast with the gray tones of surrounding deposits. On the ground the mudflow has only a subtle topographic expression, but it obviously cuts across and drapes over transgressive Lake Bonneville shoreline features (SE section 34, T. 17 S., R. 11 W.). It is no more than 15 feet (4.6 m) thick and seems likely to have been a low-gradient subaqueous flow. The mudflow must have occurred just before the lake reached the Bonneville shoreline or during the rapid regression of the lake from the Bonneville shoreline to the Provo shoreline.

Alluvial deposits in washes and on fans (Qaf) — This is coarse to fine-grained alluvium deposited mostly on piedmont slopes and in washes after regression of Lake Bonneville. The deposits are predominately silt, sand, and gravel that reflect bedrock lithologies in the highlands nearby. Soap Wash and Swasey Wash contain the greatest expanses and thicknesses of alluvium which may be as much as a few tens of feet in thickness.

Lake Bonneville Shorelines

Bonneville shoreline — The highest shoreline of Lake Bonneville, at an elevation of 5,170 feet (1,576 m), is preserved around hill 5224 in section 10, T. 17 S., R. 11 W. The lake attained this level about 15,350 years ago; it cut through its outlet threshold in southern Idaho about 14,500 years ago and dropped quickly to the Provo level (Oviatt 1988, 1989; Oviatt and Nash, 1989).

Provo shoreline — The Provo shoreline lies at an average elevation of 4,787 feet (1,459 m) in this quadrangle. It is poorly preserved over most of its extent here, having suffered later erosion. It shows a modified sea cliff about 10 feet (3 m) high near the eastern edge of the quadrangle. Lake Bonneville stood at the Provo level between 14,500 and 14,200 years ago.

STRUCTURAL GEOLOGY

Although the quadrangle lies in the Sevier orogenic hinterland where major thrust transport occurred during Mesozoic time, and it is in the middle of Utah's portion of the basin-and-range extensional terrane, the relationships shown by exposed bedrock are deceptively simple. Layered Oligocene rocks tilt gently westward over most of the quadrangle; these rocks are downdropped to the east along two north-trending normal faults, each with vertical displacement of about 400 feet (122 m). See cross section A-A' on plate 2.

NORMAL FAULTS WITHIN THIS QUADRANGLE

All of the faults are shown on the geologic map (plate 1) by dotted lines indicating that the fault traces are concealed beneath unfaulted Quaternary deposits. Only at one locality in this quadrangle is a fault surface actually exposed. At the quarry shown on the map at the west edge of section 11, T. 17 S., R. 11 W., a vertical fault zone filled with travertine has been opened for a few tens of feet exposing Td in the fault face. See figures 6 and 7 for distant and close-up views of this quarry. Elsewhere the position of the fault trace has been drawn to separate blocks of differing structural levels. In some places the fault trace is closely constrained by nearby bedrock outcrops; in other places the position of the fault trace is very loosely constrained and its position has been drawn somewhat arbitrarily. For example, the position of the Swasey Wash Reservoir fault is poorly controlled; it was drawn to the east along the large hill mass in the east-central part of the quadrangle simply because the outcrops, such as they are, do not extend farther eastward, and because there is a small outcrop of Trk in the northeast corner of the map that places an easternmost limit on the fault trace. The Long Ridge fault is extended into the south edge of the quadrangle from the adjacent Long Ridge quadrangle (Hintze and Davis, 1992) where it is better constrained. There are probably additional concealed faults in the quadrangle that have not been drawn on the map, and some of those fault traces that are shown...
Figure 6. Type section of Red Knolls Tuff at Red Knolls in section 10, T. 17 S., R. 11 W. Small quarry in right foreground exposes white travertine that formed along a normal fault. Bush-covered slope in lower half of photo is formed on the conglomerate of Little Drum which lies beneath the ledge forming Red Knolls Tuff. Lake Bonneville shorelines indent the lower slopes.

may not be in quite the right place because there has been no shallow geophysical data available to help in positioning the faults. Nonetheless, it can be stated with some confidence that none of the faults, known or inferred, have a displacement of more than a few hundred feet. The geologic cross section that accompanies this report (plate 2) shows that the Red Knolls fault and the Swasey Wash Reservoir fault each have a down-to-the-east vertical offset of about 400 feet (122 m). The attitude of Cambrian strata that are presumed to underlie the Oligocene rocks is not known, but it is believed that they are gently to moderately tilted but not much folded, based upon structure of the nearest outcrops of Cambrian strata in the House, Drum, and Cricket Ranges and on regional attitudes shown in COCORP deep seismic-reflection data.

REGIONAL STRUCTURAL RELATIONSHIPS

Structure within this quadrangle is better understood when viewed from a larger perspective. Figures 8 and 9 show major structural features of central Millard County as deduced from gravity maps, shallow and deep seismic-reflection data, and drilling data from four deep wells. Gravity data show that the House Range-Long Ridge-Red Knolls platform is flanked by elongate basins; the Tule Valley basin on the west is narrow; the Chalk Knolls half-graben and the Sutherland basin on the east are broad and complex. The Sutherland basin is partially penetrated by the Gulf-Gronning well (Lindsey and others, 1981) and was surveyed by a shallow seismic-reflection line (McDonald, 1976). Von Tisch and others (1985) and Planke (1987) have contoured both the bedrock-valley fill unconformity and the Sevier Desert detachment and their contour maps have been used in preparing the eastern third of figure 9. The Sevier Desert detachment appears to be a regional low-angle fault that can be traced in COCORP deep seismic-reflec-

Figure 7. Travertine quarry in section 10, T. 17 S., R. 11 W. The travertine formed along a nearly vertical normal fault. Slickensides show on the travertine surface at the lower right corner of the picture. The slickensides indicate nearly dip-slip movement on the fault.
Figure 8. Map of same area as figure 1 showing bedrock exposures, major basins filled with low-gravity Tertiary deposits, inferred major basin-range faults and Holocene fault scarps east of the Drum Mountains. Faults within the Long Ridge and Red Knolls quadrangles are not indicated because their displacement is small compared to the faults shown. Bouguer gravity map used to identify basins is shown on plate 2. Abbreviations for wells are the same as on figure 1.

Figure 9. Schematic cross-section of figure 8 with no vertical exaggeration showing inferred structures to a depth of 15 km (9.4 mi), based on surface geology, deep seismic interpretation (Von Tish and others, 1985) shallow seismic interpretation (Planke, 1987; McDonald, 1976), well data (Lindsey and others, 1981), and unpublished gravity and magnetic maps prepared by the U.S. Geological Survey. The reflection Moho is off the bottom of the section at a depth of 25 to 30 km (15-18 mi). Symbols: pCbm, Precambrian gneiss and schist; pCs, Precambrian quartzite and argillite; Pz, Paleozoic strata undivided; -Cq, Cambrian quartzite; -Cls, Cambrian limestone and dolomite; Jg, Jurassic granite; O, Oligocene conglomerate and tuff; M, Miocene basin-fill; Pb, Pliocene basalt; P, Pliocene basin-fill; T, Tertiary basin-fill undivided; Q, Quaternary surficial deposits (thickness exaggerated).
tion data for about 45 miles (72 km) dipping gently westward perpendicular to the north-south trend of major basins and ranges. Gaits (1985) indicated that refraction data shows that the Sevier Desert detachment occurs above a crustal low-velocity zone. Fault zone mylonitization, high temperatures, and elevated fluid pore pressure are believed to be responsible for the velocity reversal. Rheologic considerations suggest that ductile deformation may be important at or just below the detachment surface which is believed to be a zone of lithospheric decoupling along which much crustal extension has occurred. Von Tish and others (1985) concluded that extension beneath the Sevier Desert has occurred in two stages: early extension of 12 to 18 miles (19-29 km) began after middle Oligocene and continued into the Miocene. Later extension of perhaps 5 miles (8 km) began about 4 million years ago and continued to the present as indicated by the Holocene fault scarps on the west side of the Sevier Desert as shown on figure 8. A key reflector that enabled Von Tish and others (1985) to recognize the two-stage extension history of the Sutherland basin was identified as a 4.2-million-year-old basal sequence present in the Gulf-Gronning well. The basalts lies with angular discordance on older Miocene and Oligocene units as shown in figure 9.

Von Tish and others (1985) presented a systematic analysis of Cenozoic extension in the central Sevier Desert but they did not discuss pre-Cenozoic structural development of the area particularly with respect to two major Cretaceous thrusts that are believed to be present in Precambrian and Paleozoic strata beneath the Sevier Desert and within the House Range-Long Ridge-Red Knolls platform. However, Sharp (1984) equated the mid-Cenozoic Sevier Desert detachment with the latest Cretaceous Pavant Range thrust and he postulated that the same surface that had served for eastward thrust transport 70 million years ago was reactivated some 50 million years later to serve as a transport surface for westward extension. Even though it seems unlikely that similar rheological conditions would persist here this length of time, especially considering the great uplift of the Great Basin area in late Cenozoic time, his model nonetheless addresses the problem of trying to identify the location of a Mesozoic thrust surface in the COCORP data. Identifying the structurally higher Canyon Range thrust in the Sevier Desert subsurface is also a problem. This thrust was encountered at a depth of 8,364 feet (2,549 m) in the Cominco American well (shown on figures 1 and 8), and was tentatively identified by Sharp (1984) as one of the reflecting surfaces observed on the COCORP data beneath the House Range about 6 kilometers (3.7 mi) below the surface. We have shown this thrust at about the same depth on figure 9 as a near-bedding-plane fault surface that cuts within the thick column of Precambrian sedimentary strata. Also on figure 9 we show the Cretaceous Canyon Range thrust as possibly coinciding with the late Cenozoic detachment that comes toward the surface on the east side of the Chalk Knolls half-graben. Both the Canyon Range thrust and the younger Pavant Range thrust are well exposed just east of the Sevier Desert in the Canyon and Pavant Ranges (Hintze, 1980).

**SUMMARY OF STRUCTURAL HISTORY**

More than 40,000 feet (12,192 m) of Late Precambrian and Paleozoic shallow marine strata accumulated in central Millard County prior to being pushed eastward and upward as part of the Sevier orogenic hinterland in late Cretaceous time (Hintze, 1988). Erosion concurrent with Sevier uplift removed all Paleozoic strata above the Cambrian over a broad arch centered over the present House Range-Sevier Desert area (Harris, 1959). Erosion of the Sevier hinterland continued until volcanism commenced in the Tintic-Keg Mountain-Drum Mountain area about 40 to 38 million years ago in latest Eocene time. Oligocene tufts and volcanic-related sediments filled local basins. A large basin, the Sutherland basin, opened by westward extension of the Sevier Desert detachment sometime after 28 million years ago and continued to develop through most of Miocene time. After a short period of erosion that truncated Oligocene and Miocene deposits, a Pliocene basalt (4.2 m.y.) covered the truncated beds. Subsequently, extension was renewed in the Sutherland basin and in the Chalk Knolls half-graben resulting in the filling of these downwarps by terrestrial deposits of alluvial, playa, and volcanic origin. The rocks exposed in this quadraangle form a small, but important, part of the regional data upon which the above summary is based.

**ECONOMIC GEOLOGY**

**GRAVEL DEPOSITS**

Lake Bonneville gravel deposits have been mapped in several places in the quadrangle. In general, lacustrine gravel (Qlg) deposits are the thickest and most uniform of the Quaternary gravel units. However, lacustrine and alluvial deposits undifferentiated (Qla) has a high gravel content in places. In the SW, section 5, T. 18 S., R. 11 W., the Millard County road department has a large pit containing 12 feet (3.6 m) of good sand and gravel. Substantial reserve deposits are present south of the pit. The gravel is fairly well graded, angular to subrounded, and consists of about 95 percent limestone and/or dolomite and about 5 percent volcanic clasts.

**DIATOMACEOUS EARTH**

Lake Bonneville white marl, Qlm, is extensively exposed in the southeast corner of the map area. Claims have been staked intermittently on this material since World War I. The latest claims have been filed in section 30, T. 17 S., R. 10 W., by Bert Sorensen and J.L. Shields of Delta, Utah, in January, 1986. The marl is about 12 feet (3.6 m) thick here (figure 10). No recent production is obvious although one of the marl exposures along the old U.S. Highway 6 near Swasey Wash has been trenched. The marl is highly calcareous. As much as two-thirds of this sediment is composed of fine calcareous mud. Four samples taken from different levels in the wall of the deposit shown in figure 10 showed the following percentages, by weight, of calcium carbonate: 62, 52, 66, 57. Much of the remainder is broken siliceous diatomaceous debris. The marl may have potential for cement manufacture.

**TRAVERTINE**

Prospect pits have been opened along the Red Knolls fault in section 10, T. 17 S., R. 11 W. exposing good grade of white-banded travertine in vertical layers up to 3 feet (0.9 m) thick. A small loading ramp suggests some limited past production. No evidence of recent activity is apparent (see figure 7).
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 organic material. Beneath the Quaternary deposits the Oligocene conglomerates and tuffs are improbable sources of reservoir rocks without a cap or trap. And Paleozoic rocks at a depth of a few thousand feet are probably Cambrian carbonates and quartzites with little, if any, petroleum potential. However, no exploratory wells have been drilled within the quadrangle. Figures 1 and 8 show the locations of four deep wildcat wells to the east of this quadrangle. None of these showed commercial promise.

WATER RESOURCES

There are no perennial streams within the quadrangle, nor any water wells. A few small earthen dams have been placed across washes to catch infrequent runoff for stock-watering. These small reservoirs are dry most of the time. The U.S. Bureau of Land Management has built a small-diameter pipeline that extends across the southwest corner of the quadrangle to supply metal stock-watering tanks on the desert to the southeast beyond the edge of the quadrangle. It might be possible to obtain small quantities of ground water from a depth of several hundred feet. Thomas and others (1986) indicated that the water level in basin-fill deposits in this vicinity probably stands at an elevation of about 4,500 feet (1,372 m).

GEOLOGIC HAZARDS

Flash flooding and resultant erosion and debris flows are the most common geologic hazards in the Red Knolls quadrangle. Two drainages with substantial upstream catchment basins cross the quadrangle: Soap Wash cuts the southwestern corner of the map area and Swasey Wash cuts across the northeastern third of the area. Flooding of either wash is capable of producing extensive damage to the main gravel road (old U.S. Highway 6) during summer cloudbursts. Motorists and hikers should not attempt to cross flooding roadways and washes. The flooding usually subsides in a few minutes to an hour.

The lacustrine marl (Qlm) would not provide an adequate foundation support for a house, a building, or any other fairly heavy structure. If construction is absolutely necessary on a Qlm site, the best remedy would be complete removal of the material.
In this part of Millard County there have been no historical earthquakes of magnitude 4.0 or greater. The Red Knolls quadrangle is in seismic zone U-2b of the Uniform Building Code seismic zones for construction in Utah (Ward, 1979). Four seismic zones are plotted in Utah; U-1 to U-4 (greatest potential). The U-2 zone indicates a slight to moderate ground-shaking hazard. Because nobody lives in the quadrangle area, and because the only significant development within the quadrangle are the easily regradeable gravel roads, the possible loss of life or property damage during an earthquake is small.

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