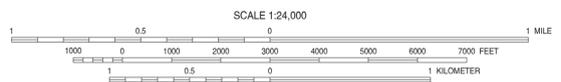


Base from U.S. Geological Survey,  
Fisher Towers 7.5' provisional quadrangle, 1985

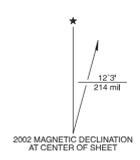


Field work by author in 1989, 1990, and 1994  
Michael L. Ross and Grant C. Willis, Project Managers  
James W. Parker, Cartographer

CONTOUR INTERVAL 40 FEET  
DATUM IS MEAN SEA LEVEL

### GEOLOGIC MAP OF THE FISHER TOWERS 7.5' QUADRANGLE GRAND COUNTY, UTAH

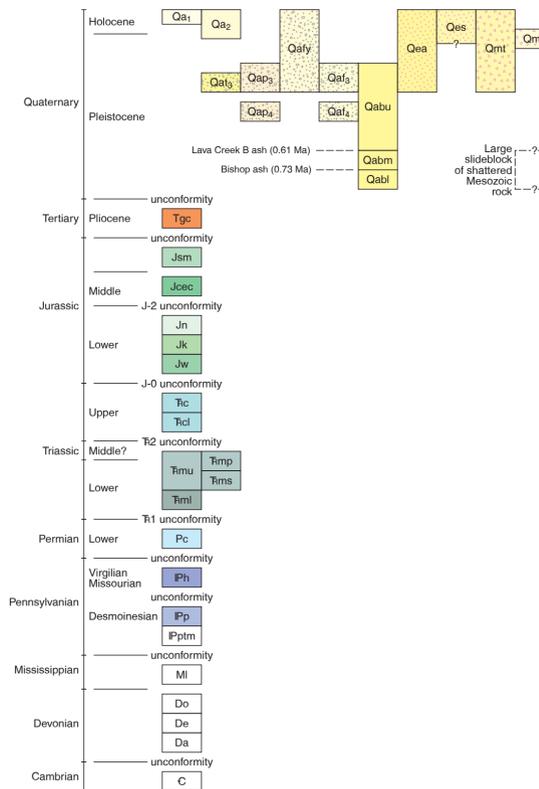
by  
**Hellmut H. Doelling**  
2002



DESCRIPTION OF GEOLOGIC UNITS

- Quaternary Deposits**
- Artificial Deposits**  
Qld Fill and disturbed areas -- Human-placed fill and disturbed areas for dikes, dams, and roads. Small deposits not mapped.
- Alluvial Deposits**  
Qa1 Younger alluvial deposits -- Sand, gravel, silt, and clay deposits along the Colorado River and along the more active tributaries and washes; 0-20 feet (0-6 m) above active river and stream channels; 0-20 feet (0-6 m) thick.  
Qa2 Older alluvial deposits -- Sand, silt, mud, and gravel deposited by ephemeral streams; contains sheet-wash and debris-flow deposits mixed with smaller amounts of residual, colluvial, and eolian materials; includes Qa1 deposits in places where they cannot be mapped separately; 20-40 feet (6-12 m) above active channels; 0-25 feet (0-7.5 m) thick.  
Qa3 Terrace-gravel deposits -- Gravel, sand, and silt, mostly from metamorphic and igneous terranes, deposited by the ancestral Colorado River; deposits are 50 to 100 feet (15-30 m) above river level; 0-20 feet (0-6 m) thick.  
Qa4 Pediment-mantle deposits -- Poorly sorted, sandy and silty, subangular to angular, matrix-supported gravel; locally contain lenses of sand or clay-supported gravel; contain large angular to subangular boulders; deposits are locally derived and have an orange, red, or purple hue; deposited as a relatively thin veneer on uneven pediment surfaces by mixed alluvial-fan, ephemeral-stream, colluvial, and eolian processes; Qa3 age is similar to or slightly younger than Qa3 deposits; Qa3 are 50 to 100 feet (15-30 m), and Qa4 are 120 to 180 feet (37-55 m) above principal drainages; 0-20 feet (0-6 m) thick.  
Qa5 Alluvial-fan deposits -- Poorly sorted sand, gravel, and boulders; locally contain lenses of sand and/or clay-supported gravel; deposits are locally sourced; Qa5 deposits are composed of sheet wash and debris flows that commonly continue to receive sediments, but locally contain materials as old as those in the Qa3 deposits; Qa3 and Qa4 form dissected stony surfaces and subtle ridges in Castle Valley; full thickness is rarely exposed; 0-40 feet (0-12 m) thick.  
Qabu Basin-fill deposits -- Upper basin fill (Qabu) consists of crudely stratified sand, gravel and silt as much as 66 feet (20 m) thick with the Lava Creek B ash (0.61 Ma) at the base; middle basin fill (Qabm) is similar but contains more gravel and is as much as 90 feet (27 m) thick with the Bishop ash (0.73 Ma) at the base; lower basin fill (Qabl) is dominated by partly consolidated coarse clastics forming ledges and pinnacles, and is as much as 100 feet (30 m) thick.
- Mass-Movement Deposits**  
Oms Landslide deposits -- Very large rotated blocks (up to a few hundred feet in average diameter) to sand-sized material on steep slopes below Wingate Sandstone cliff; vary from large blocks rotated a few degrees to broken fragments in chaotic hummocky mounds; minimum and maximum thicknesses not determined. (A very large shattered mass of Mesozoic rock on the northeast side of Fisher Mesa that rotated and dropped onto mostly upper Paleozoic rocks is mapped as structurally deformed bedrock; part may be large landslide mass and part may be bedrock that collapsed due to dissolution of underlying salt; the sole of the slide is probably in Triassic rocks; edges of this mass are indicated by tick marks on the map.)
- Talus Deposits and Colluvium**  
Qmt Talus deposits and colluvium -- Poorly sorted, angular to subangular boulders in a matrix of coarse to fine sand, silt, and clay mantling the steep slopes beneath cliffs; derived from resistant overlying units; small deposits are not mapped; 0-10 feet (0-3 m) thick.
- Eolian Deposits**  
Qes Eolian sand deposits -- Generally fine- to medium-grained quartzose sand and silt forming sand sheets and small dunes; mostly fine, silty, unstratified sand overlying Qabu deposits; 0-30 feet (0-9 m) thick.
- Mixed-Environment Deposits**  
Qea Mixed eolian and alluvial deposits -- Crudely stratified sand, silt, loess, and small pebbles; eolian component generally more abundant than alluvial component, part may be residual in origin; commonly present on old surfaces in areas of limited alluvial influence; gradational with Qes and various older alluvial deposits; 0-15 feet (0-6 m) thick.
- Tertiary Deposits**  
Tgc Geyser Creek Fonglomerate -- Light-gray conglomerate with angular igneous clasts derived from the La Sal Mountains and subordinate, rounded, Mesozoic sandstone and siltstone clasts; clast-supported; crudely stratified; semi-indurated; massive, but consists of alternating lenses of fine, medium, and coarse pebbles; gritty and sandy, calcareous matrix; as much as 85 feet (26 m) thick; fills a paleocanyon.
- Jurassic Rocks**  
Jsm Morrison and Summerville Formations, undifferentiated -- Interbedded siltstone and sandstone; siltstone is maroon, red, green, and gray and is slope- or recess-forming; siltstone includes claystone, sandy siltstone, and silty sandstone; sandstone is light yellow gray to yellow gray, medium to coarse grained, poorly sorted, cross-bedded, and forms resistant ledges; locally, red, lavender, and brown mudstone and siltstone containing nodular gray limestone and large siliceous chert concretions of the Tidwell Member of the Morrison Formation are present; locally, yellow-gray or light-brown, thin-bedded, leaty sandstone and red, slope-forming siltstone of the Summerville Formation are also identifiable. Preserved on south side of Onion Creek diapir; not measured due to structural complications, but the Summerville Formation is locally 25-45 feet (7.6-13.7 m) thick, the Tidwell Member is locally 48 feet (11.6-14.6 m) thick, the Salt Wash Member is as much as 105 feet (32 m) thick, and the Brushy Basin Member is less than 200 feet (60 m) thick; the complete undifferentiated section in the quadrangle is probably less than 400 feet (122 m) thick.
- Triassic Rocks**  
Joc Moab Member of Curtis Formation, Slick Rock Member of Entrada Sandstone, and Dewey Bridge Member of Carmel Formation, undifferentiated -- Pale-yellow, pale-yellow-brown, pale-orange, gray-orange, and red-brown sandstone; mostly fine grained; loosely cemented with iron oxide and calcite cement; mostly massive; forms steep slopes and cliffs; Moab and Slick Rock Members locally identifiable; preserved on south side of Onion Creek diapir; faulted, steeply dipping, and possibly attenuated; thickness not measured due to structural complications; the undifferentiated section in neighboring areas is about 350 feet thick (107 m); (formerly all included as members of the Entrada Sandstone -- see text discussion).
- Permian Rocks**  
Jn Navajo Sandstone -- Orange to light-gray, eolian sandstone; mostly fine grained; cemented with silica or calcite; crops out as vertical cliffs in deep canyons and as domes and rounded knolls elsewhere; well-developed, high-angle cross-beds; probably 200-240 feet (61-73 m) thick as deposited across quadrangle, but upper contact no longer exposed because of erosion; incomplete section of 160 feet (49 m) thick measured on south end of Fisher Mesa.  
Jk Kayenta Formation -- Moderate-orange-pink, red-brown, and lavender sandstone interbedded with subordinate dark-red-brown to gray-red silty mudstone, lavender gray intraformational conglomerate, and limestone of fluvial or lacustrine origin; light-orange to light-gray and white eolian sandstone beds become more prominent in upper third of unit; commonly micaceous; mostly calcite cemented; forms thick, resistant, step-like ledges between the more massive Navajo and Wingate Sandstones; upper part less resistant and forms prominent bench; 260-320 feet (79-98 m) thick.  
Jw Wingate Sandstone -- Mostly light-orange-brown, moderate-orange-pink, or moderate red-orange, fine-grained, well-sorted, cross-bedded sandstone; calcareous or siliceous cement; forms nearly vertical cliffs along canyon walls; cliff surfaces commonly veneered with dark-brown desert varnish; about 300 feet (91 m) thick.
- Triassic Rocks**  
Tc Chinle Formation -- Moderate red-brown or gray-red, fine- to coarse-grained sandstone and siltstone with subordinate pebble conglomerate or gritstone, and gray limestone; slope-forming with prominent ledges; slope-forming units are fine grained and indistinctly bedded; ledge-forming units are fine to coarse grained, and platy to very thick bedded; resistant ledge of sandstone or pebble conglomerate near base underlain by mottled siltstone; basal mottled siltstone (Tcl) is mapped separately on north end of Priest and Nuns butte; 295-475 feet (90-145 m) thick; thin eastward; thicker sections located peripherally to salt-cored anticlines.
- Moenkopi Formation**  
Tmu Upper Member -- Pale-red-orange to gray-red, slope-forming siltstone with subordinate red-brown, fine-grained sandstone; thinly laminated to thin bedded; commonly cemented with gypsum; sandstone is locally ripple-marked; forms slope; divided into Parion (Rmp) and Sewenup (Rms) Members at north end of Priest and Nuns; 110-460 feet (34-140 m) thick; thinning eastward; thickest in synclines adjacent to salt-cored anticlines.  
Tmi Lower member -- Upper part is dark-red-brown and lavender, silty, mica- and feldspar-bearing, platy to thick bedded; commonly ripple-marked, ledge-forming sandstone and conglomeratic sandstone interbedded with slightly darker red-brown to red-orange, slope- and recess-forming sandstone, siltstone, and silty mudstone; lower part is slightly lighter red-brown, fine-grained, mica- and feldspar-bearing, thick bedded to massive sandstone; in west part of quadrangle forms smooth slopes and contains gypsum bed; 250-350 feet (76-107 m) thick along outcrops.
- Permian Rocks**  
Pc Cutler Formation -- Red-brown and red-purple, subarkosic to arkosic sandstone, conglomeratic sandstone, and conglomerate interbedded with silty and sandy mudstone and shale; thin bedded to massive; forms steep slopes, ledges, and cliffs; maximum of about 3,500 feet (1,067 m) exposed; estimated to range from 0 to 8,300 feet (0-2,530 m) in thickness across the quadrangle and averages about 4,500 feet (1,370 m) in thickness between salt-cored anticlines.
- Pennsylvanian Rocks**  
Ph Honaker Trail Formation -- Interbedded arkosic and micaceous sandstone, conglomerate, and limestone; sandstone is gray, light brown, and red, fine to coarse grained, and thick bedded to massive; conglomerate consists of angular pebbles and cobbles of granitic gneiss, schist, sandstone, and gneiss; limestone is gray, thick bedded to massive, bioclastic, and interbedded with shaly to sandy calcareous partings; incomplete outcrop at least 700 feet (213 m) thick; in subsurface is mostly 3,800 to 4,800 feet (1,158-1,463 m) thick across quadrangle; missing on top of salt-cored anticlines but may be as thick as 6,500 feet (0-1,980 m) along their margins.  
Ip Paradox Formation -- Salt, shale, gypsum, and limestone; surface exposures (cap rock) are devoid of salt and are white, gray, and pink, impure saccharic-weathering gypsum, light to dark-gray shale, and thin- to medium-bedded gray sandy limestone; all commonly exhibit contorted bedding; exposed cap rock is at least 600 feet (183 m) thick; formation is estimated to be 1,000 to more than 14,000 feet (305-4,267 m) thick in the subsurface.
- Subsurface units penetrated by local drill holes**  
Ipptm Pkerton Trail and Molas Formations -- 150 to 250 feet (46-76 m) thick.
- Mississippian Rocks**  
MI Leadville Formation -- 450 to 560 feet (137-170 m) thick.
- Devonian Deposits**  
Do Ouray Limestone -- 94 to 160 feet (28-49 m) thick.  
De Elbert Formation (includes McCracken Sandstone) (De) -- 200 to 280 feet (60-84 m) thick.  
Da Aneth Formation -- 70 to 80 feet (21-24 m) thick.
- Cambrian Rocks**  
C Cambrian units, undifferentiated.

CORRELATION OF GEOLOGIC UNITS

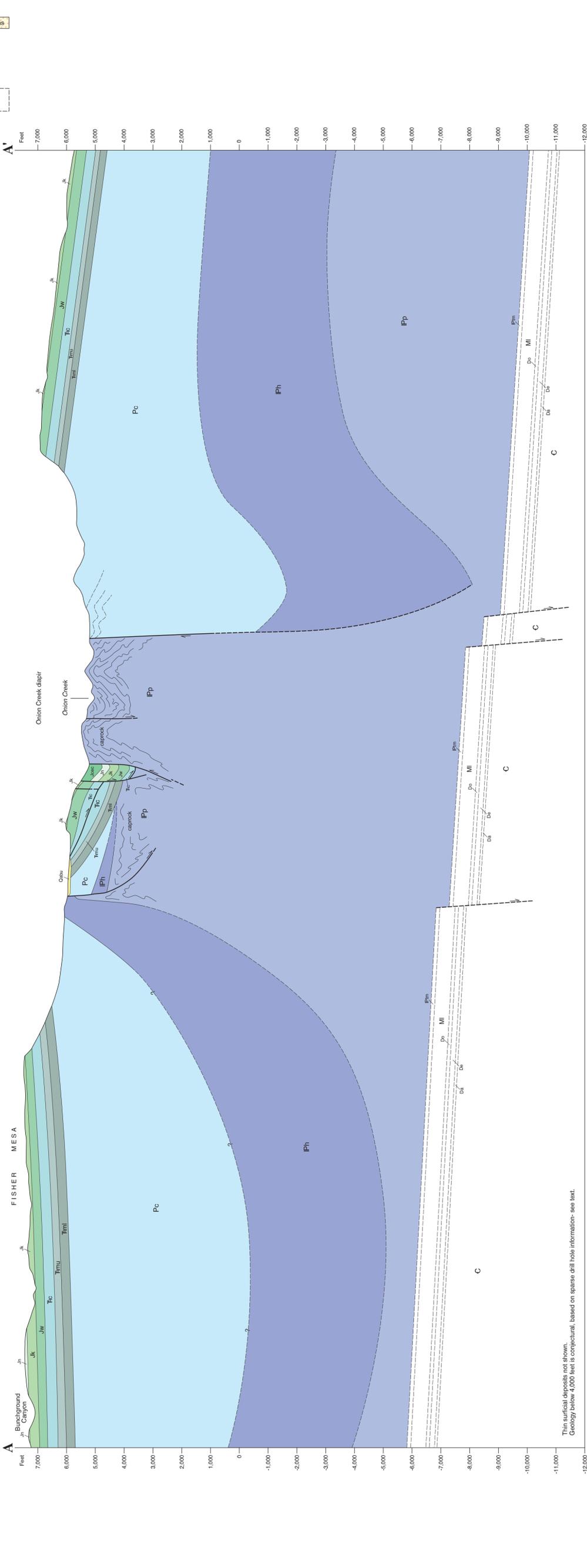


STRATIGRAPHIC COLUMN

SYSTEM	SERIES	FORMATIONS and MEMBERS	MAP SYMBOL	THICKNESS (feet/meters)	LITHOLOGY and COMMENTS
QUATERNARY	Holo-Pleist.	surficial deposits	Various	Various	
		Geyser Creek Fonglomerate	Tgc	80-85 (24-26)	Basin-fill deposits Fills paleocanyon
JURASSIC	Upper	Morrison and Summerville Fms	Jsm	~400 (~122)	In structurally deformed blocks on south side of Onion Creek diapir
	Middle	Moab Mbr of Curtis Fm, Slick Rock Mbr of Entrada Ss, and Dewey Bridge Mbr of Carmel Fm, undiff.	Joc	~350 (~107)	High-angle cross-bedding
	Lower	Navajo Sandstone	Jn	200-240 (61-73)	Ledges and benches
		Kayenta Formation	Jk	260-320 (79-98)	Castle Rock cliff former Priest and Nuns
TRIASSIC	Upper	Chinle Formation	Tc	295-475 (90-145)	Red-brown slope Tci (basal unit) Light-brown silt
	Lower	Upper Member	Tmu	110-460 (34-140)	Dark-brown cliff or ledges Gypsum bed to west
		Lower Member	Tmi	250-350 (76-107)	Fisher Towers
PERMIAN	Lower	Cutler Formation	Pc	0-8,300 (0-2,530) averages ~4,500 (~1,370)	Subarkosic and arkosic sandstone About 3,500 feet (1,067 m) exposed Fonglomerate
		Honaker Trail Formation	Ph	0-6,500 (0-1,980) averages ~4,300 (~1,310)	Virgilian fusulnids Coarse granitic conglomerate Mostly subsurface
PENNSYLVANIAN	Missourian-Virgilian	Paradox Formation	Ip	1,000-14,000 (305-4,267)	Exposed cap rock 600+ feet (183+m) Salt in subsurface

SYMBOLS

- Contact -- dashed where approximately located
- .-.- High-angle fault -- dashed where approximately located or inferred; dotted where concealed; bar and ball on downthrown side; bar and ball not shown if offset is unknown; box symbol where overprints diapiric contact (box on diapiric material); queried where uncertain
- Landslide (including slump block) scarp or fractures
- Approximate edge of large shattered landslide block on northeast side of Fisher Mesa
- Collapse zone boundary--approximately located and locally buried
- Axial trace of anticline
- Axial trace of syncline
- Structure contour -- 200-foot (60 m) interval on base of Wingate Sandstone; dashed where approximately located or where the Wingate Sandstone has been eroded
- 17 Strike and dip of bedding -- vertical, inclined
- 15 Strike and dip of overturned bedding
- ◇ Location of drill hole (dry and abandoned)
- x Prospect
- Adit
- Mine V = vanadium, U = uranium, Cu = copper, Ba = barite
- Barite veins



Thin surficial deposits not shown. Geology below 4,000 feet is conjectural, based on sparse drill hole information-- see text.

# **GEOLOGIC MAP OF THE FISHER TOWERS 7.5' QUADRANGLE, GRAND COUNTY, UTAH**

*by*

*Hellmut H. Doelling  
Utah Geological Survey*

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# GEOLOGIC MAP OF THE FISHER TOWERS QUADRANGLE, GRAND COUNTY, UTAH

by

*Hellmut H. Doelling*  
*Utah Geological Survey*

## ABSTRACT

The Fisher Towers quadrangle is located in the northeast part of the salt-anticline region of the Paradox basin in east-central Utah. Exposed bedrock ranges in age from Pennsylvanian to Jurassic; a small outcrop of a late Tertiary conglomerate is also present. In ascending order units include: the Pennsylvanian Paradox Formation, 1,000 to 14,000 feet (305-4,267 m) thick, and Honaker Trail Formation, 0 to 6,500 feet (0-1,980 m) thick; the Permian Cutler Formation, 0 to 8,300 feet (0-2,530 m) thick; the Triassic Moenkopi Formation, 360 to 810 feet (111-247 m) thick, and Chinle Formation, 295 to 475 feet (90-145 m) thick; and the Jurassic Wingate Sandstone, about 300 feet (90 m) thick, Kayenta Formation, 260 to 320 feet (79-98 m) thick, Navajo Sandstone, 200 to 240 feet (61-73 m) thick; combined Dewey Bridge Member of the Carmel Formation, Slick Rock Member of the Entrada Sandstone, and Moab Member of the Curtis Formation (new informal designation), which together are about 350 feet (107 m) thick; and Summerville and Morrison Formations (here undifferentiated), about 400 feet (122 m) thick. As much as 85 feet (26 m) of the upper Tertiary Geyser Creek Fonglomerate fills a small paleocanyon in the east-central part of the quadrangle. Mapped surficial deposits are of alluvial, eolian, mass movement, and mixed eolian and alluvial origin, and are locally nearly 260 feet (79 m) thick.

The dominant structural feature in the Fisher Towers quadrangle is the east-west-trending Professor Valley-Fisher Valley salt-cored anticline, a type of salt diapir. Also, a part of the Castle Valley salt-cored anticline is present in the southwest corner of the quadrangle. These structures are the result of a complex history that includes Pennsylvanian and Permian salt diapirism, Triassic to Tertiary burial, and late Tertiary and Quaternary erosion and salt dissolution. Very thick sections of Honaker Trail and Cutler Formations accumulated in rim synclines as salt in the Paradox Formation moved to form the diapirs. Late Tertiary regional uplift induced the erosion of overlying sediments. Thereafter, fresh ground water reached the upper parts of the diapir and removed salt. Salt removal resulted in the collapse of the remaining overlying rock strata, which were complexly tilted and faulted. Local basins formed in which Quaternary and possibly latest Tertiary deposits were preserved.

Strata between the two diapirs are cut by a few high-angle, low-displacement faults and are gently warped. North of the Professor Valley-Fisher Valley diapir, strata dip about 7° northward, into the Uinta Basin.

Uranium and vanadium have been produced in the quadrangle. Copper and barite are present in some prospects, and small quantities may have been produced. Other potentially economic resources include oil, natural gas, and gold. Ground water is also locally important. At present, the most important economic resource of the quadrangle is the scenery. Within the boundaries of the quadrangle are the oft-photographed and filmed Fisher Towers, Castle Rock, Priest and Nuns, and the "Grand Canyon" of Onion Creek. The Onion Creek diapir, a 1 by 2-mile (1.6 by 3.2 km) exposure of cap rock in the Professor Valley-Fisher Valley structure, is one of the best exposed diapirs in the United States.

Principal geologic hazards include erosion, debris flows, stream flooding, rock falls, expansive and collapsible soils, soluble rock (mostly gypsum), and blowing sand. Earthquake and landslide hazards appear to be low.

## INTRODUCTION

The Fisher Towers quadrangle is named for a collection of erosional pinnacles located in the north-central part of the map area. Other scenic monuments, buttes, and mesas surround a low area known as the Richardson Amphitheater (plate 1). The scenic mesa cliffs rise more than 2,000 feet (710 m) above the amphitheater. Many people consider the area to be among the most beautiful in Utah, and it has been the setting for several Hollywood western movies and television commercials. Also scenic (and geologically interesting) is an east-west-trending zone of faulted and tilted strata collapsed over a salt diapir (salt-cored anticline) in the central part of the quadrangle (Professor Valley-Fisher Valley).

The Colorado River flows across the northwest corner of the quadrangle. Onion and Professor Creeks head in the southeast part of the quadrangle and flow northwest to the Colorado River (plate 1). Castle Creek flows down Castle Valley in the southwest corner of the quadrangle.

Altitudes within the quadrangle range from 4,070 feet (1,240 m) along the Colorado River to about 7,720 feet (2,353 m) on the southeast end of Fisher Mesa. Much of the

Richardson Amphitheater surface and the tops of the mesas are bare sandstone or sandy soil. Stands of pinyon and juniper trees dominate the higher elevations and desert shrubs and grasses are common at lower altitudes. Bitterbrush, blackbrush, Mormon tea, prickly pear cactus, rice grass, and scattered juniper trees are in the amphitheater below the cliffs. Cattle are grazed both on the mesas and in the amphitheater. Hay and pasture fields are maintained along the southeast side of the Colorado River and along the lower reaches of Professor Creek.

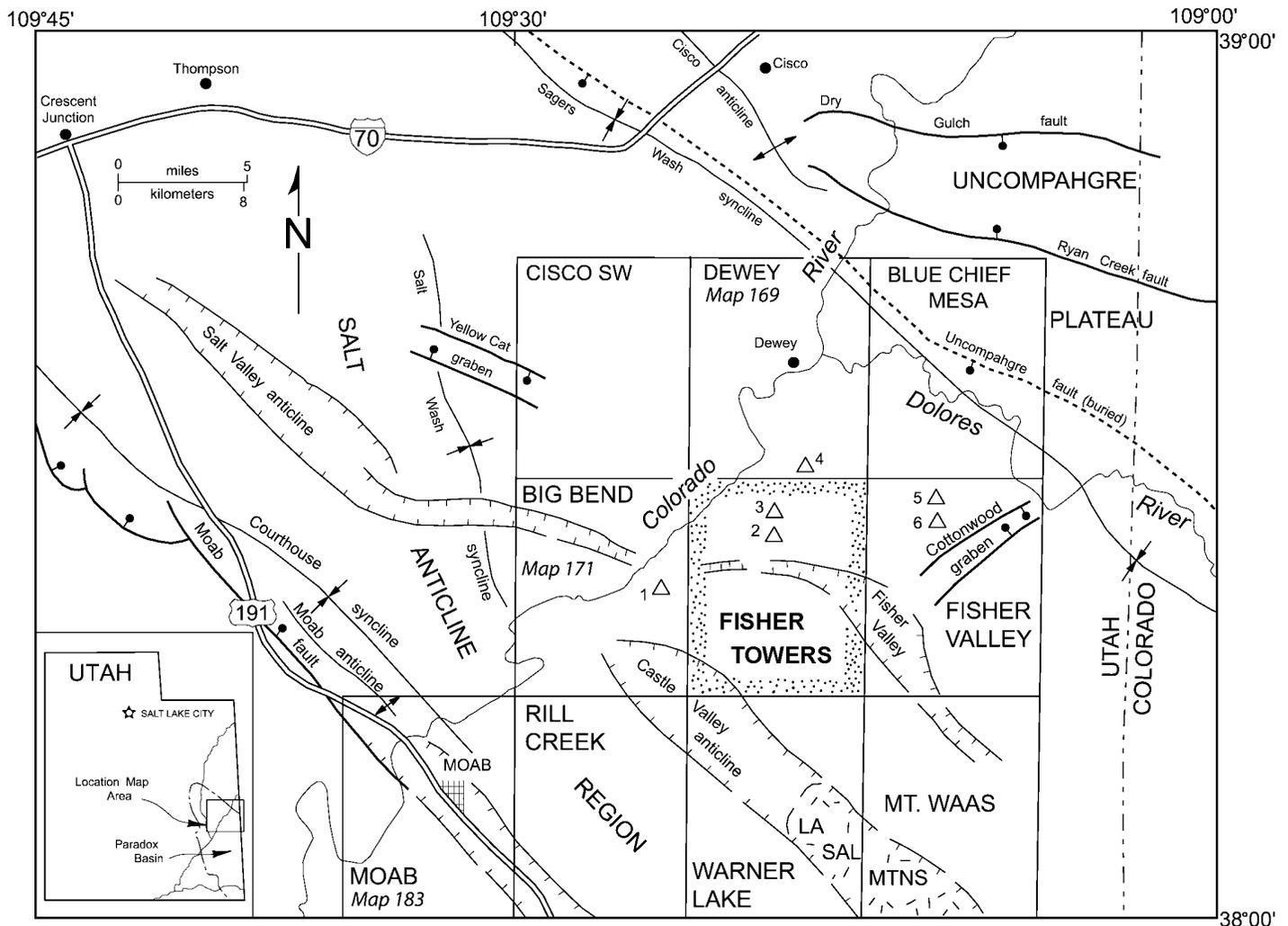
The quadrangle is located in east-central Utah about 25 miles (40 km) northeast of Moab (figure 1), and is accessed by Utah Highway 128 (U-128), along the southeast side of the Colorado River. Access into Richardson Amphitheater and Castle Valley is provided by secondary roads extending southeasterly from U-128. Access to Adobe and Fisher Mesas is from the La Sal Mountain Loop Road, and access to the unnamed mesa in the northeast corner of the quadrangle is by connecting roads joining U-128 at Dewey. The U.S. Geological Survey (USGS) 1:100,000 scale, 30 x 60-minute Moab quadrangle map shows most of these connecting

roads. The northwest bank of the river has no vehicle access.

The Fisher Towers quadrangle area was first geologically mapped by Dane (1935) at a scale of 1:63,500. Stokes (1948) briefly described the Onion Creek salt diapir, which Shoemaker (1954) later mapped. Williams (1964) mapped the area as part of the Moab 1 x 2-degree quadrangle at a scale of 1:250,000. Colman and Hawkins (1985) mapped some of the surficial units of the Fisher Towers quadrangle at a scale of 1:24,000. Doelling (2001) geologically mapped the area as part of the Moab 30 x 60-minute quadrangle at a scale of 1:100,000.

## STRATIGRAPHY

Bedrock formations exposed in the Fisher Towers quadrangle range in age from Middle Pennsylvanian to Late Jurassic (plates 1 and 2). One late Tertiary semi-consolidated deposit and several kinds of Quaternary surficial deposits are also present. The total thickness of the exposed strata in the quadrangle is about 7,800 feet (2,345 m).

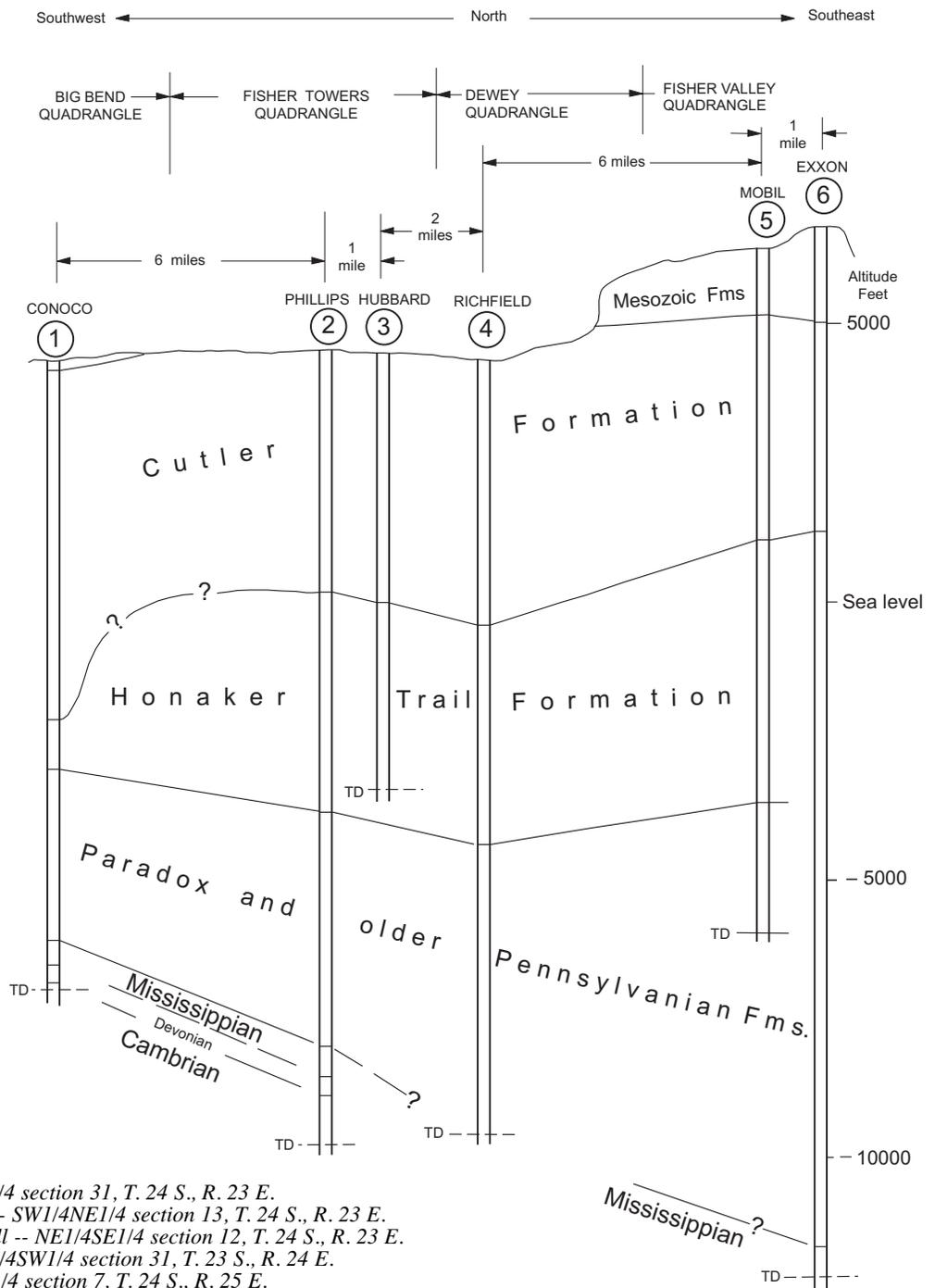


**Figure 1.** Map showing area of Fisher Towers and adjacent quadrangles in east-central Utah. Principal structural features, highways, and settlements are also shown. Adjacent quadrangles have published UGS maps shown by map numbers. Numbered triangles locate drill holes shown on figure 2. Small inset shows map area with respect to the state and the Paradox basin.

### Pre-Pennsylvanian Rocks

Two deep boreholes have been drilled in the quadrangle, and four others are in adjacent quadrangles (figures 1 and 2). Of the six, one reached total depth in Cambrian rocks, one in Devonian rocks, and one in the Mississippian Leadville Formation; the others bottomed in Pennsylvanian rocks. Based on well log correlations by C.D. Morgan of the Utah Geological Survey, the Phillips Petroleum No. 2 Onion Creek (Phillips well), located in the Fisher Towers quadrangle in SW 1/4 NE 1/4 section 13, T. 24 S., R. 23 E., penetrated 536 feet (163 m) of Mississippian Leadville Formation, 94 feet (29 m) of Devonian Ouray Formation, 86 feet (26 m) of upper Elbert Formation, 194 feet (59 m) of McCracken Sand-

stone Member of the Elbert Formation, 74 feet (22 m) of Aneth Formation, an unconformity (Devonian on Cambrian), 348 feet (106 m) of Cambrian Lynch Dolomite, and 126 feet (38 m) of Bright Angel Shale, and reached its total depth about 200 feet (61 m) into the Cambrian Ignacio (Tintic) Quartzite. The Conoco Federal No. 1-31 well (Conoco well of figure 2), located in the Big Bend quadrangle, penetrated 452 feet (138 m) of Leadville Formation, 104 feet (32 m) of Ouray Formation, 96 feet (29 m) of upper Elbert Formation, and 200 feet (61 m) of McCracken Sandstone Member. Conoco Petroleum Corporation reported the Elbert Formation overlying Cambrian rocks near the base of this well (Utah Division of Oil, Gas and Mining files). Additional study would be required to determine if the Aneth is present.



**Figure 2.** Diagram of six deep drill holes indicating the thicknesses of Pennsylvanian and Permian units in and around the Fisher Towers quadrangle. Drill-hole locations are shown on figure 1. (Data from Utah Division of Oil, Gas and Mining files).

1. Conoco Federal No. 1-31 -- NW1/4SE1/4 section 31, T. 24 S., R. 23 E.
2. Phillips Petroleum No. 2 Onion Creek -- SW1/4NE1/4 section 13, T. 24 S., R. 23 E.
3. Harry P. Hubbard No. 1 Gov't-Campbell -- NE1/4SE1/4 section 12, T. 24 S., R. 23 E.
4. Richfield Oil No. 1 Onion Creek -- NE1/4SW1/4 section 31, T. 23 S., R. 24 E.
5. Mobil Oil Federal No. 1-7 -- SW1/4SE1/4 section 7, T. 24 S., R. 25 E.
6. Exxon Federal No. 1 Onion Creek -- SW1/4NW1/4 section 18, T. 24 S., R. 25 E.

## Pennsylvanian Rocks

The contact between Mississippian and Pennsylvanian rocks in the area is an erosional unconformity (Welsh and Bissell, 1979). The basal unit of the Pennsylvanian is the Molas Formation, which primarily consists of limestone clasts in a red muddy siltstone matrix (Wengerd, 1958) and is present only in the subsurface in the Fisher Towers quadrangle.

The Molas Formation is overlain by the Hermosa Group, which in ascending order consists of the Pinkerton Trail (subsurface only), Paradox, and Honaker Trail Formations. The relatively thin Molas and Pinkerton Trail Formations are combined on plate 2 and labeled IPptm. The Pinkerton Trail and Honaker Trail Formations contain predominately shallow marine limestone and clastic deposits (Wengerd, 1958). The Paradox Formation is a sequence of cyclically bedded halite, anhydrite, dolomite, limestone, siltstone, and shale. The Paradox Formation was deposited in a subsiding basin (Paradox basin) southwest of the rising Uncompahgre uplift, now the Uncompahgre Plateau (figure 1). Coarse- to medium-grained clastics shed from this highland are interbedded with marine deposits in the Honaker Trail Formation and to a lesser extent in the Paradox Formation (White and Jacobson, 1983).

### Paradox Formation (IPp)

Only the cap rock portion of the Paradox Formation is exposed at the surface. Defined as the less soluble gypsum and shaly residue of former salt-bearing rock, it is exposed along Onion Creek in the east-central part of the quadrangle. The largest exposure is known as the Onion Creek diapir. The gypsum is white, gray, and pink, impure, thick to massively layered, sucrosic-weathering alabaster. Other rock types include light-gray to black shale, thin to medium beds of gray sandy limestone, and light-gray micaceous sandstone (figure 3). The shale is commonly clayey and weathers to earthy slopes. The cap rock is highly contorted and deformed and its thickness is difficult to measure. The diapir



**Figure 3.** Closeup of Paradox Formation cap rock showing thin-bedded limestone, gray shale, and gypsum. Locally, these beds are highly contorted.

rises to an elevation of about 600 feet (180 m) above the Onion Creek Narrows, indicating that at least locally cap rock exceeds 600 feet (180 m) in thickness. Other, smaller exposures of cap rock are present along the trend of the Professor Valley-Fisher Valley salt structure (plate 1).

The upper contact of the Paradox Formation with the overlying Honaker Trail Formation is a regional unconformity (Welsh and Bissell, 1979). The contact is a disconformity, but Dane (1935) thought the contact was gradational and conformable in parts of the Paradox basin.

In the subsurface, the thickness of the Paradox Formation probably ranges from 1,000 to more than 14,000 feet (305-4,267 m) (cross section A-A', plate 2, deep interpretation modified from Hudec, 1995). Thicknesses vary greatly due to salt flowage associated with diapirism. Thicknesses exceeding 8,000 feet (2,400 m) are limited to the flow-thickened diapirs. Thinnest intervals are in areas where salt has been removed. The Conoco well, drilled into the northeast flank of the Castle Valley salt-cored anticline 2 miles (3.2 km) west of the Fisher Towers quadrangle, penetrated about 3,000 feet (900 m) of the Paradox Formation and older Pennsylvanian formations (figure 2). The Phillips well, located in the quadrangle, penetrated 4,200 feet (1,280 m) of Paradox Formation; the Richfield well, located just north of the quadrangle, penetrated an incomplete section of nearly 5,200 feet (1,585 m); and the Exxon well, located 2.5 miles (4 km) east of the quadrangle, penetrated more than 5,500 feet (1,676 m) of salt in a Paradox section that may exceed 7,800 feet (2,377 m) in thickness (thicknesses from Utah Division of Oil, Gas and Mining well-data files).

### Honaker Trail Formation (IPH)

The Honaker Trail Formation is exposed in a steeply dipping, partly overturned outcrop band on the southwest flank of the Fisher Valley salt-cored anticline in section 34, T. 24 S., R. 24 E. (plate 1). At other places the Honaker Trail is missing and Paradox Formation cap rock is juxtaposed against the Permian Cutler Formation. Holes drilled between the diapirs indicate the unit is generally present in the subsurface (figure 2).

The Honaker Trail Formation consists of arkosic sandstone, gritstone, conglomerate, and limestone. The sandstone is gray, light brown, and red, fine to coarse grained, and thick bedded to massive. It is locally micaceous and feldspathic. Conglomerate consists of angular pebbles and cobbles of white and pink crystalline feldspar, quartz, schist, sandstone, and gneiss. Limestone is gray, thick to massive, poorly bedded, bioclastic, and interbedded with shaly to sandy calcareous partings. Limestone is uncommon in outcrop, except for resistant beds near the top of the unit. Elston and others (1963) indicated that the Honaker Trail consists chiefly of gray conglomeratic arkose about 12 miles (19 km) southeast of the quadrangle, and of red and gray conglomeratic arkose interbedded with red mudstone and subordinate limestone in the Fisher Towers exposures. The Honaker Trail sandstones become less arkosic, finer grained, and increase in the number of limestone beds southwest of the quadrangle. In

much of the Paradox basin, the Honaker Trail Formation consists primarily of shelf carbonates (Wengerd, 1958; Wengerd and Matheny, 1958). In the salt-cored anticline region, the Honaker Trail contains a sizeable clastic component, which increases northeasterly toward the Uncompahgre Plateau (figure 1).

Limestone beds at the top of the formation contain abundant fossils. Dane (1935) provided a list of macrofossils collected from the outcrop in the Fisher Towers quadrangle. Fusulinids from a limestone bed include *Triticites* aff. *T. whetstonensis*, *Triticites coronadoensis*, *Triticites callosus sensu* and *Triticites bensonensis* of middle to early Virgilian age (Fusulinid Biostratigraphy, Inc., Tulsa, Oklahoma, written communication, 1991). The identified specimens do not correlate with the known fauna of the type Honaker Trail Formation in San Juan County, thus correlation with the type section remains uncertain.

Dane (1935) measured 855 feet (261 m) of Hermosa Formation (Honaker Trail Formation) in unsurveyed section 34, T. 24 S., R. 24 E., but structural relationships are unclear. The upper contact with the Permian Cutler Formation is exposed, but the lower part of the interval abuts a diapiric outcrop of Paradox Formation cap rock, and the lower contact is not exposed. Honaker Trail Formation overlain by collapsed Cutler Formation is also present on the north side of the cap rock exposure. The exposure on the north side dips 30° NE. I believe the north-side exposure is right-side-up and is a duplicate of part of the exposure on the south side.

The thickness of the Honaker Trail Formation is variable in the vicinity of salt structures. The formation is generally missing over the salt-cored anticlines, such as the Onion Creek structure, but is present everywhere else. It is about 930 feet (283 m) thick in the Conoco well; 3,950 feet (1,204 m) thick in the Phillips well; almost 4,000 feet (1,219 m) thick in the Richfield well; and almost 4,800 feet (1,463 m) thick in the Mobil well (figure 2) (thicknesses from Utah Division of Oil, Gas and Mining well-data files). The thickness of the Honaker Trail Formation averages about 4,300 feet (1,310 m) in areas unaffected by salt diapirism (figure 2), and probably varies between 0 and 6,500 feet (1,980 m) near the salt-cored anticlines (cross section A-A', plate 2).

## Permian Rocks

### Cutler Formation (Pc)

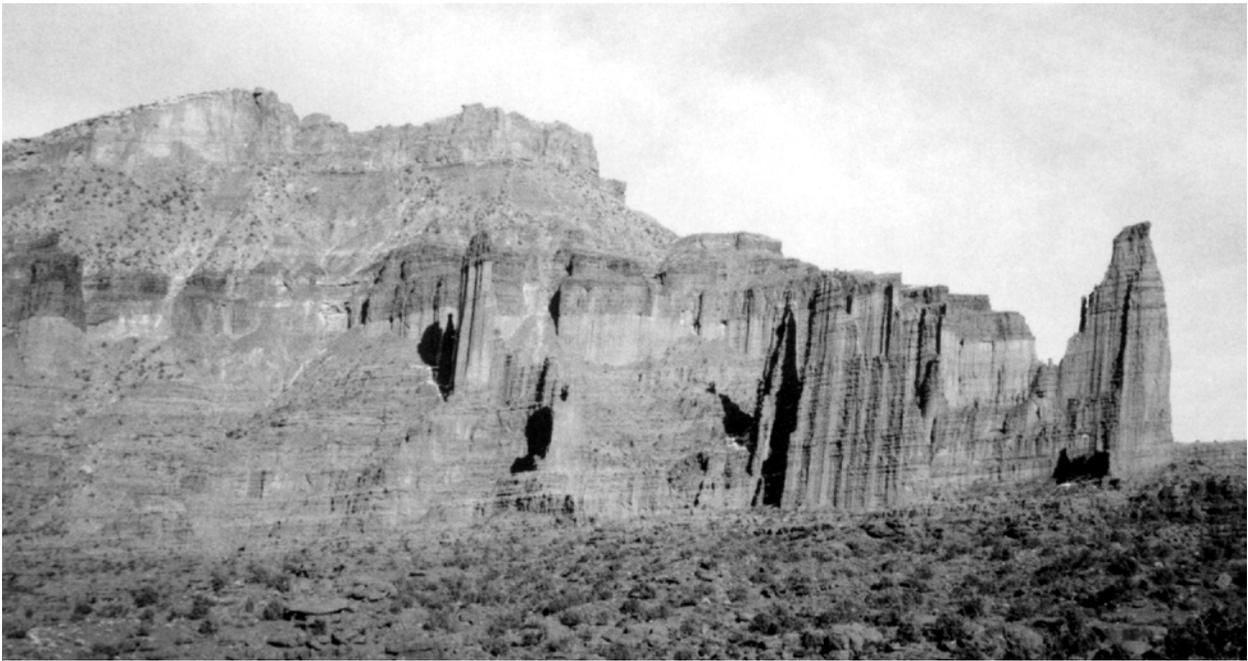
The Lower Permian Cutler Formation is widely exposed in Professor Valley, the Richardson Amphitheater, and north of Onion Creek. The unit consists primarily of subarkosic to arkosic sandstone, conglomeratic sandstone, and conglomerate interbedded with silty and sandy mudstone. Subordinate lithologies are quartzose sandstone, cherty limestone, and hard, dense mudstone. Because of lithologic heterogeneity and variable cementation, the outcrop appearance ranges from near-vertical cliffs to alternating ledges and slopes that form step-like escarpments. Outcrops are mostly red brown, red purple, red orange, and maroon, with subordinate brown orange, pale-red, gray, gray-red, and gray-white hues. Arkosic sandstone is fine to very coarse grained and micaceous. Grains are generally subangular to subrounded and individual lenses vary from poorly to well sorted. Many lenses of arkosic sandstone display small-scale trough cross

bedding and cut-and-fill structures with basal gravel lenses, suggesting deposition by fluvial processes. Gravelly conglomerate ranges from moderately sorted granule and pebble conglomerate to poorly sorted cobble conglomerate. Finer clasts are primarily quartz, feldspar, and mica, with pebbles and cobbles of granite, gneiss, schist, and quartzite. Subarkosic to quartzose sandstone is composed of fine- to medium-grained, subrounded, moderately well-sorted grains. Tabular planar cross-stratification and laminations with inversely graded bedding in some lenses suggest deposition by eolian processes (Campbell, 1979). Eolian sandstone in the Cutler Formation generally displays an orange to red tint, in contrast to the red-purple shades of the fluvial sandstone. Mudstone and siltstone are micaceous and generally structureless.

The Cutler Formation represents a large alluvial fan complex shed from the ancestral Uncompahgre highland. Campbell (1979, 1980) and Campbell and Steele-Mallory (1979) present extensive information on the depositional environment of this formation. The fluvial system consisted of braided streams on a fan surface and the toe of the fan was near sea level, periodically allowing marine conditions to influence sedimentation. The Cutler Formation in the Fisher Towers quadrangle was deposited in the upper to medial parts of the fan.

A maximum of 3,500 feet (1,067 m) of the Cutler Formation is exposed on the north side of Fisher Valley in the Fisher Towers quadrangle (Doelling, 1981). In contrast, Dane (1935) measured only 1,730 feet (527 m) on the northeast slope of Fisher Mesa. The lower member of the Moenkopi Formation rests directly on the Paradox Formation cap rock of the Onion Creek diapir; the Honaker Trail and Cutler Formations were never deposited there or were not preserved. The differences in thickness are most likely due to contemporaneous salt movement (cross section A-A', plate 2). Harper (1960) measured a 931-foot (284-m), incompletely exposed section of the Cutler Formation in section 9, T. 25 S., R. 23 E., along the northwest margin of Castle Valley (Big Bend quadrangle). In the Conoco well (figure 2), 2.5 miles (4 km) west of the quadrangle, the Cutler Formation is an estimated 6,235 feet (1,900 m) thick adjacent to the Castle Valley salt-cored anticline. The Phillips, Hubbard, and Richfield wells were located on Cutler surface outcrops and therefore record incomplete thicknesses. The Phillips well reached the Honaker Trail at a depth of 4,350 feet (1,326 m), the Hubbard well at a depth of about 4,500 feet (1,372 m) and the Richfield well at a depth of 4,738 feet (1,444 m). The Exxon well, located about 2.5 miles (4 km) east of the quadrangle, penetrated about 3,700 feet (1,128 m) of Cutler Formation (thicknesses from Utah Division of Oil, Gas and Mining well-data files). The thickness of the Cutler varies drastically adjacent to the salt-cored anticlines. In the Fisher Towers quadrangle the Cutler thickness probably ranges from 0 to 8,300 feet (0-2,530 m). Regionally, the Cutler is thickest adjacent to the Uncompahgre Plateau, northeast of the quadrangle.

The top of the Cutler Formation is a slight angular unconformity marked by a color change from gray red or lavender to medium brown (chocolate brown) of the lower member of the Moenkopi Formation (figure 4). Cutler bedding is indistinct whereas the Moenkopi is mostly well bedded. Cutler beds dip at slightly greater angles than those of



**Figure 4.** Fisher Towers, after which the quadrangle is named. The lower and middle parts of the cliffs and tower, up to the top of the lighter interval, are the Cutler Formation. The lower member of the Moenkopi Formation forms the upper, darker part. The lower slope in the background is the upper part of the Moenkopi Formation and the upper slope is the Chinle Formation, overlain by the cliff-forming Wingate Sandstone.

the overlying Moenkopi. In one exposure in the cove east of bench mark 5185-T along the north-central edge of the quadrangle, Cutler beds dip as much as 24° to the west and are overlain by gently dipping Moenkopi beds. The Cutler Formation locally displays anomalous strikes and dips and has lost as much as 1,000 feet (305 m) of its thickness to erosion below the surface of the unconformity.

## Triassic Rocks

### Moenkopi Formation

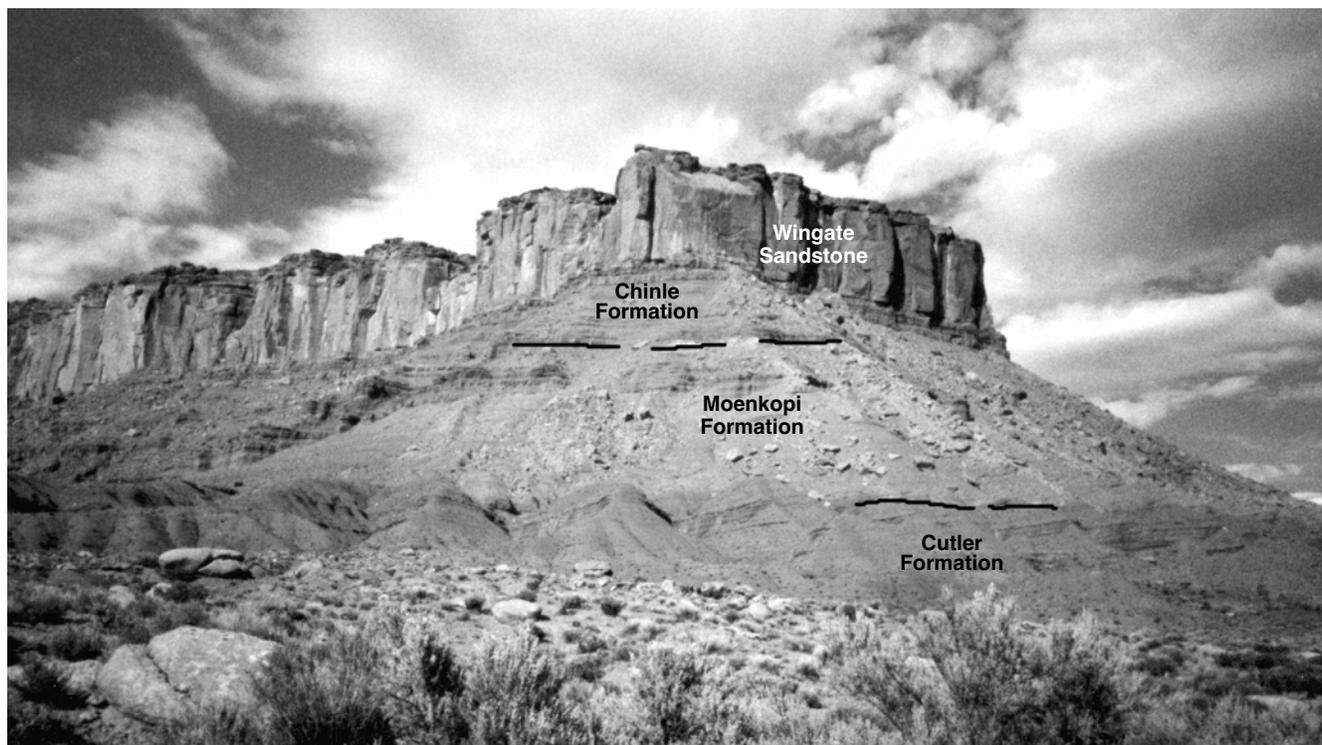
The Lower Triassic Moenkopi Formation is exposed in the steep slopes below the mesas in the Fisher Towers quadrangle (figures 5 and 6). Some partial and faulted intervals are also present along the east-west-trending Professor Valley-Fisher Valley salt-cored anticline, and remnants are found on top of the Onion Creek diapir. It consists of interbedded, orange-brown to dark-brown, thinly laminated to thin-bedded, micaceous mudstone, siltstone, and fine-grained sandstone. Subordinate lithologies include shale, gypsum, and conglomerate. The formation is characterized by ubiquitous oscillation ripples and mudcracks (Stewart and others, 1972a; Molenaar, 1987; Doelling, 1988). The Moenkopi Formation is mostly missing over the Uncompahgre Plateau to the northeast (Shoemaker and Newman, 1959; Case, 1991; Willis and others, 1996) and regionally thickens westward toward the Cordilleran miogeocline (Baars, 1987; Doelling, 1988). The Moenkopi is a sequence of intertonguing deltaic and paralic (coastal) deposits that represent the initial Mesozoic marine transgression in the Colorado Plateau region (Stewart and others, 1972a).

Shoemaker and Newman (1959) investigated the Moenkopi Formation in the salt anticline region and divided the formation into four members, the Tenderfoot, Ali Baba, Sewemup, and Pariott Members (ascending). These mem-

bers are well displayed to the west in the Big Bend quadrangle (Doelling and Ross, 1998). The Tenderfoot and Ali Baba Members are thinner and less easily defined, and the Pariott Member is probably missing in the eastern half of the Fisher Towers quadrangle (Shoemaker and Newman, 1959). Therefore, I divided the Moenkopi into informal lower and upper members, which are easily recognized in the field. The lower member includes the Tenderfoot and Ali Baba Members of Shoemaker and Newman (1959) and the upper member consists of their Sewemup and Pariott Members. The lower member of the Moenkopi Formation, as defined for the Fisher Towers quadrangle, is a dark-brown, cliff- and ledge-forming unit whereas the upper member is a light-brown slope-former. The lower member is 250 to 350 feet (76-107 m) thick and the upper member is 110 to 460 feet (34-140 m) thick in the Fisher Towers quadrangle.

**Lower member of the Moenkopi Formation (Tml):** In the western half of the quadrangle the lower member is divisible into three parts based on outcrop characteristics. The lowest part (Tenderfoot Member?) is indistinctly to thin bedded and slope forming. A gypsum bed 2 to 5 feet (0.6-1.5 m) thick is present 20 to 30 feet (6-9 m) above an irregular lower contact (figure 5). The member is crisscrossed by a myriad of gypsum veinlets 0.02 to 0.12 inches (0.5-3 mm) thick and locally as much as 0.8 inches (2 cm) thick. A few coarse-grained sandstone beds up to 1 foot (30 cm) thick and thin siltstone partings are also present. The middle of the lower member forms a cliff of medium-brown, fine- to medium-grained, thick-bedded to massive sandstone. The upper part of the member forms a steep rounded slope of dark-brown, thinly laminated sandstone and a few subordinate siltstone and gritstone beds.

Below Adobe Mesa, section 10, T. 25 S., R. 23 E., the lower member is 293 feet (89 m) thick (the lower slope is 185 feet [56 m] thick and the middle and upper parts combined are 108 feet [33 m] thick) (figure 5). Shoemaker and



**Figure 5.** View looking south toward Adobe Mesa in the southern part of the Fisher Towers quadrangle. Cutler Formation outcrops are present at the base of the mesa. A white gypsum bed is near the bottom of the lower member of the Moenkopi Formation (just above marked contact). The Kayenta Formation (not marked) caps the top of the Wingate Sandstone.

Newman (1959) measured a complete 443-foot (135 m) section of the lower member on the south side of Parriott Mesa in section 5, T. 25 S., R. 23 E., 2 miles (3.2 km) west of Castle Rock in the Big Bend quadrangle. They assigned 220 feet (67 m) to the lower and 223 feet (68 m) to the middle and upper parts of my lower member.

In the eastern half of the quadrangle the lower member is divisible into a lower cliff and an upper well-bedded ledge-former. The cliff (Tenderfoot[?] Member of Shoemaker and Newman, 1959) is 110 to 120 feet (34-37 m) thick and consists of medium-brown, fine- to medium-grained sandstone. The lower half of the cliff weathers into medium, blocky to indistinct beds. The upper cliff is massive except for a few less-resistant beds at the top. The well-bedded ledge-former at the top of the lower member is red-brown, mostly fine-grained sandstone (about 80 percent) alternating with medium- to coarse-grained subarkosic sandstone (about 15 percent) and subordinate mudstone and sandy siltstone. The fine-grained sandstone is micaceous, contains streaks of coarse clasts, including some pebbles and cobbles, and weathers into blocky thin to thick beds. Many of the beds are ripple marked. The medium- to coarse-grained subarkosic sandstone contains angular grains and conglomerate lenses, and is dark red-brown, cross-bedded, and generally softer and more friable than the fine-grained sandstone. Pebbles and cobbles consist mostly of quartzite, gneiss, granite, and amphibolite. The mudstone or sandy siltstone is dark red brown, thinly laminated to thin bedded, and forms recesses between the ledges. The amount of fine-grained sandstone increases upward, except for the uppermost 20 to 30 feet (6.1-9.1 m), where mudstone increases. The contact between the lower and upper members is gradational.

The lower member of the Moenkopi Formation is 259 feet (79 m) thick north of Fisher Valley, in the NW<sup>1</sup>/<sub>4</sub> section 14, T. 24 S., R. 24 E. The lower cliff is 114 feet (35 m) thick and the well-bedded ledge-former is 145 feet (44 m) thick. Dane (1935) measured a section of the Moenkopi Formation about 2 miles (3.2 km) north of the Fisher Towers quadrangle. He did not subdivide the Moenkopi Formation, but his section indicates the lower cliff is about 117 feet (36 m) thick and the well-bedded ledge-former is 134 feet (41 m) thick. Stewart and others (1972a) divided the unit into about 112 feet (34 m) of Tenderfoot Member (cliff) and 152 feet (46 m) of Ali Baba Member (well-bedded ledge-former) near the same place. The thickness range within the quadrangle is probably about 250 to 350 feet (76-107 m).

**Upper member of the Moenkopi Formation (R<sub>mu</sub>, R<sub>ms</sub>, R<sub>mp</sub>):** The upper member of the Moenkopi Formation is mostly a light-brown, silty, fine-grained, micaceous sandstone that Shoemaker and Newman (1959) divided into the Sewemup (R<sub>ms</sub>) and Parriott (R<sub>mp</sub>) Members. These are not divided on plate 1 except on the north end of the Priest and Nuns butte. The rocks are finely laminated to indistinctly bedded and slope forming (figures 5 and 6). Some of the platy weathering beds are ripple-marked or mud-cracked. Slight ledges are present where banks of thin beds are present. The unit is commonly cemented with gypsum. Resistant sandstone ledges are present near the top in western exposures that correspond to Shoemaker and Newman's (1959) Parriott Member (R<sub>mp</sub>). They consist mainly of red-brown to lavender sandstone interbedded with "chocolate-brown," orange-brown, and red siltstone, mudstone, and shale. Orange and red mudstone units in the Parriott Member are distinctive and resemble the overlying Chinle Formation.

The contact between the upper member of the Moenkopi Formation and the Chinle Formation is a disconformity with little relief.

The upper member of the Moenkopi Formation is 456 feet (139 m) thick below Adobe Mesa. It is 123 feet (37 m) thick on the north side of Fisher Valley in NW<sup>1</sup>/<sub>4</sub> section 14, T. 24 S., R. 24 E., in the eastern part of the quadrangle and 113 feet (34 m) thick 2.5 miles (4 km) north in the Dewey quadrangle. A few ledgy beds at the top of the upper member may correlate with the Pariott Member of Shoemaker and Newman (1959).

### Chinle Formation (Tc, Tcl)

The Chinle Formation was divided into upper and lower members in the Big Bend quadrangle (Doelling and Ross, 1998). In most parts of the Fisher Towers quadrangle the lower member consists of a thin basal sandstone or gritstone bed and mottled strata too thin to show at the map scale. It is mapped at the north end of the Priest and Nuns (Tcl). Dane (1935) recognized at least 22 feet (7 m) of such beds in the Dewey quadrangle.

Chinle Formation outcrops are present at the base of the high sandstone cliff that surrounds Professor Valley and the Richardson Amphitheater (figures 5 and 6). Other outcrops are present at various places along the Professor Valley-Fisher Valley structural belt. The lower 20 to 30 feet (6.9 m) consists of gray-purple to mottled, indistinctly bedded siltstone and pale-gray-red and white pebbly, cliffy or ledgy, quartzitic conglomerate. Gypsum is locally interbedded with the siltstone. Most of the remainder of the Chinle Formation consists of red-brown or gray-red, silty, fine-grained sandstone. This sandstone is indistinctly bedded and forms a steep slope with slight ledges. The rock weathers into angular, pebble- to cobble-sized clasts that litter the slope. Subordinate pink-gray, nodular-weathering limestone beds are also present. Locally, the upper 50 feet (15 m) of the formation consists of red-brown to orange, fine-grained, medium to thick beds of sandstone. The upper contact with the Wingate Sandstone is generally sharp and may be a disconformity. Sandstone on both sides of the contact is lithologically similar, but the sandstone in the uppermost Chinle is thick bedded rather than massive.



**Figure 6.** Castle Rock and the Priest and Nuns buttes as seen looking southwest from Professor Valley. The steep slope beneath the buttes consists of the Triassic Chinle and Moenkopi Formations. The top of the dominant ledge in the slope is the top of the lower member of the Moenkopi.

The thickness of the Chinle Formation in the Fisher Towers quadrangle ranges from 295 to 475 feet (90-145 m). The thickest sections are found in the rim synclines and basins adjacent to the salt-cored anticlines. The Chinle Formation thins regionally to the northeast. Dane (1935) measured 264 feet (80 m) of Chinle Formation on the southeast side of the Colorado River in the Dewey quadrangle. Stewart and others (1972b) reported that the Chinle is about 296 feet (90 m) thick in the Richardson Amphitheater in section 25, T. 23 S., R. 23 E. On the north side of Fisher Valley, SE<sup>1</sup>/<sub>4</sub> section 14, T. 24 S., R. 24 E., the Chinle Formation is 339 feet (103 m) thick. North of the Priest and Nuns, NE<sup>1</sup>/<sub>4</sub> section 33, T. 24 S., R. 23 E., the Chinle Formation is about 475 feet (145 m) thick (the upper 100 feet [30 m] forms a cliff and the thickness is estimated).

### Jurassic Rocks

With the exception of deeply collapsed formations on the south side of the Onion Creek diapir, the Jurassic rocks of the quadrangle are all assigned to the Lower Jurassic Glen Canyon Group. The Glen Canyon Group consists of the Wingate Sandstone, Kayenta Formation, and Navajo Sandstone, and is about 770 feet (235 m) thick in the quadrangle. Two Middle Jurassic units, the undifferentiated Carmel, Entrada, and Curtis Formations, and the Summerville Formation, and the Upper Jurassic Morrison Formation, have been identified in dissolution-collapsed zones.

### Wingate Sandstone (Jw)

The Wingate Sandstone is the oldest formation in the Glen Canyon Group and forms a prominent, nearly vertical cliff along the margins of the Richardson Amphitheater and Professor Valley (figure 5). It consists of red-brown sandstone that is commonly streaked and stained to a darker brown or black by desert varnish. Thick sandstone slabs sporadically separate from the cliffs along vertical joints above the much weaker underlying Chinle Formation and fall to the slopes below. Wingate Sandstone rubble and talus are ubiquitous on many of the Chinle, Moenkopi, and Cutler Formation slopes below the cliffs. The Wingate Sandstone is mostly light orange-brown, moderate-orange-pink, moderate-red-orange, pink-gray, or pale-red-brown, fine grained, well-sorted, cross-bedded sandstone. High-angle cross-beds indicate that the Wingate Sandstone is dominantly wind deposited.

The formation appears massive and uniform from top to bottom; partings and other dividing features are present, but are not prominently displayed. They are more common near the base of the unit. Cementation varies from calcareous to siliceous. The upper contact with the Kayenta Formation is conformable and is placed where the lighter, massive sandstone of the Wingate is overlain by darker, thick-bedded, red-brown sandstone. Kayenta sandstones, although also thick bedded to massive, better display bed and lens boundaries in outcrop. The vertical outcrop habit of the Wingate Sandstone precludes direct measurement. Drill-hole data are unavailable and the thickness is esti-

mated. Regionally, the Wingate is 250 to 400 feet (76-122 m) thick (Doelling, 1981). In the Fisher Towers quadrangle the Wingate Sandstone is about 300 feet (91 m) thick as determined using topographic map contours and a photogrammetric stereoplotter.

### **Kayenta Formation (Jk)**

The Kayenta Formation overlies the Wingate Sandstone and caps most high mesas of the quadrangle, except where removed at paleochannel locations (figure 5). Along the cliff faces the formation overlies the Wingate Sandstone to form a higher cliff. Although individual beds and lenses display various hues, the overall color of the formation is orange pink, red brown, and lavender. Prominent benches commonly form on the tops of thicker sandstone lenses. Bare rock exposures predominate, and where surficial cover is present, it is typically thin.

The lower fourth of the formation is dominated by very thick to massive fluvial sandstone lenses. Thin partings of dark-red-brown siltstone locally separate sandstone lenses, which collectively form a vertical cliff above the Wingate cliff. The middle half of the Kayenta consists of medium to thick sandstone beds, sporadic intraformational conglomerate lenses, and abundant siltstone partings. Benches have formed on the sandstone lenses, giving the middle-half outcrop a step-like configuration. The upper fourth is generally slope-forming with sporadic, thick, ledge-forming, light-hued lenses of fluvial or eolian sandstone. Locally, these sandstone lenses form an upper cliff-forming sequence under the overlying Navajo Sandstone. The Kayenta-Navajo contact is placed at the top of a white-weathering, cliff-forming sandstone bed that is 3 to 15 feet (1-5 m) thick. It contrasts with immediately overlying tan or light-brown Navajo sediments, which may or may not form cliffs.

The Kayenta is dominated by fluvial sandstone, but eolian and lacustrine interbeds are also present, especially in the upper third of the formation. Most of the fluvial sandstone tends to be moderate orange pink; silty mudstone interbeds are dark red brown or gray red. Sandstone lenses normally display low-angle cross-beds, channeling, current ripple marks, and slump features. The grain size is variable, ranging from very fine to medium. Very fine flakes of mica are common in some of the sandstone beds and cementation is commonly calcareous. The upper part of the formation more commonly includes intraformational pebble conglomerate; cliff-forming, light colored, high-angle cross-bedded sandstone (eolian); slope-forming, red-brown to dark-red brown, sandy siltstone; very fine-grained, silty sandstone; and scarce, thin beds of gray limestone.

The complete Kayenta Formation is exposed in the southeast part of the quadrangle. In section 16, T. 25 S., R. 24 E., the Kayenta is 316 feet (96 m) thick. Complete sections may be present in collapsed blocks adjacent to the Onion Creek diapir, but they are too shattered to yield reliable thickness measurements. The formation is incomplete at all other quadrangle locations. Pre-erosion Kayenta Formation thickness is thought to range from 260 to 320 feet (79-98 m) in the quadrangle.

### **Navajo Sandstone (Jn)**

Navajo Sandstone exposures in the Fisher Towers quad-

range are largely covered with sand and are limited to the southeast corner of the quadrangle. The Navajo Sandstone is mostly orange to light-gray, tan or light-brown-weathering, fine-grained sandstone cemented either with silica or calcite. Medium to coarse grains of quartz sand are common along cross-bed laminae. The Navajo is a cliff-former, but the sandstone is commonly friable in hand specimen. The formation is mostly massive and is divided into 15- to 25-foot (4.6 to 7.6 m) thick cross-bed sets. Thin red siltstone partings are locally present. Cross-bed angles locally exceed 30°.

The upper contact of the Navajo Sandstone is not exposed in the quadrangle. At least 160 feet (49 m) (measured) of uneroded Navajo is present; perhaps 200 to 240 feet (61-73 m) had originally been deposited across the area prior to the present erosional regime. The contact between the Navajo and Dewey Bridge Member of the Carmel Formation is a disconformity of regional extent (J-2 unconformity of Pipingos and O'Sullivan, 1978), separating Lower Jurassic from Middle Jurassic rocks.

### **Carmel Formation, Entrada Sandstone, and Curtis Formation, undifferentiated (Jcec)**

The Middle Jurassic below the Summerville Formation in the Fisher Towers area consists of three units, the Dewey Bridge, Slick Rock, and Moab, that have generally been assigned as members of the Entrada Sandstone (for example: Wright and others, 1962; Doelling, 1985; Peterson, 1988; Doelling and Ross, 1998). However, over the past several years, continued work in the area has made it apparent that the Dewey Bridge Member is an eastern extension of the Carmel Formation (O'Sullivan, 2000), and that the Moab Member is an eastern extension of the Curtis Formation as generally mapped in the San Rafael Swell and Green River area to the west (Doelling, 2001). For this map, these three units are thus classified as members of these three separate formations. The Moab Member designation is considered informal pending formal reclassification. For Dewey Bridge strata, this represents a return to the original classification since these beds were formerly mapped as part of the Carmel Formation (Dane, 1935; McKnight, 1940), until Wright and others (1962) reassigned them to the Entrada Sandstone based on lithologic criteria (O'Sullivan, 2000). This will be a new classification for the Moab Member.

The undifferentiated Carmel, Entrada, and Curtis Formations unit is exposed along the wash on the south side of the Onion Creek diapir. These three units are typically mapped separately, but I could not consistently identify outcrops in the structurally deformed strata of the quadrangle. Most outcrops are either Slick Rock or Moab Member.

The Dewey Bridge is a red-brown, muddy to silty, mostly fine- to medium-grained sandstone with irregular, contorted to "lumpy" bedding. It weathers to distinct irregular and contorted rounded ledges. The unit is medium to thick bedded and cemented with iron oxide or calcite.

The Slick Rock Member is a massive, fine-grained, banded sandstone locally displaying discontinuous partings of siltstone. Coarse, frosted, equant grains are common along cross-bed laminae. Cementation is calcareous and hematitic. The Slick Rock Member weathers into cliffs and steeply rounded smooth slopes. Outcrop colors include pink gray, yellow gray, gray, light brown, orange, and pink. In the

area on the south side of the Onion Creek diapir, the combined unit is highly shattered and earthy weathering along much of the outcrop.

The Moab Member is white, yellow-orange, or light-pink-gray, fine-grained sandstone with irregular yellow and pale-red patches. It displays horizontal laminations or medium- to large-scale cross-beds. The member weathers to a sugary rather than a smooth surface. The grains, which are mainly quartz, are frosted, subangular to subrounded, and equant. The unit is cemented with calcite and minor hematite. Cementation varies from friable to indurated, but generally the Moab Member is more resistant and cliff forming than the Slick Rock Member. Outcrop thickness of the combined unit was not determined in the quadrangle because of structural complications. The unit averages about 350 feet (107 m) in combined thickness in the Dewey quadrangle to the north (Doelling, 1996), and is probably similar in structurally undeformed areas of the Fisher Towers quadrangle.

### **Summerville and Morrison Formations, undifferentiated (Jsm)**

The Summerville Formation and members of the Morrison Formation are also exposed along the wash south of the Onion Creek diapir. They are mapped as a single unit on plate 1 because outcrops are thin and may be deformed by collapse along the margin of the diapir. These units can locally be differentiated, but contacts are not easily traced along the outcrop belts. Ascending, the Morrison Formation includes the Tidwell Member, Salt Wash Member, and the Brushy Basin Member.

The Summerville Formation and Tidwell Member of the Morrison Formation together form a dark-red marker zone between the Moab Member of the Curtis Formation and the Salt Wash Member of the Morrison Formation. The red marker is 30 to 60 feet (9-18 m) thick in surrounding quadrangles.

The Summerville Formation consists of thin- to medium-bedded, light-gray to brown, ledgy sandstone and slope-forming, red, sandy siltstone that together form a steep slope. These rocks are capped by a prominent, thin- to medium-bedded, blocky to platy sandstone ledge at the top. Several thin ledges of sandstone are commonly present that are fine to medium grained, well sorted, and quartzose. The upper ledge of sandstone is commonly ripple marked. At the copper mine or prospect, NW<sup>1</sup>/<sub>4</sub> section 28, T. 24 S., R. 24 E., the Summerville is about 35 feet (11 m) thick, is in near-vertical position, and consists of red and yellow siltstone, fine-grained sandstone, and platy to medium-bedded, gray to light-brown sandstone. It ranges from 25 to 45 feet (7.6-13.7 m) thick in the quadrangle.

The Tidwell Member of the Morrison Formation consists of red, maroon, lavender, or light-gray-weathering siltstone. Discontinuous zones of light-gray limestone nodules are interspersed throughout the siltstone, but are more common at the base and top of the unit. Large, mostly white chert concretions are commonly found associated with a thin limestone bed near the base of the unit. Some of these concretions are as much as 6 feet (2 m) in diameter and a few contain irregular red and brown patches of jasper. The outcrop dips steeply and may be attenuated. The Tidwell Member is 20 to 30 feet (6-9 m) thick at the copper prospect, where sev-

eral large chert concretions are present. It is up to 48 feet (14.6 m) thick in other areas.

The Salt Wash Member consists of interbedded 25 to 40 percent ledge-forming sandstone and 60 to 75 percent slope-forming mudstone or siltstone. Quartzose sandstone in the Salt Wash is cross-bedded, fine to coarse grained, and moderately to poorly sorted. The well-indurated sandstone forms resistant lenticular ledges that are generally light gray, yellow gray, or light brown, but weather to various shades of brown. Lens thickness ranges to 20 feet (6 m), but most are 2 to 4 feet (0.6-1.2 m) thick. The mudstone intervals consist of red, greenish-gray, maroon, and lavender siltstone and fine-grained clayey sandstone. Thin limestone beds and nodules are present in the Salt Wash Member mudstones. Only 105 feet (32 m) (incomplete section) are exposed near the copper mine or prospect in section 28, T. 24 S., R. 24 E.

The Brushy Basin Member is predominantly silty and clayey mudstone and muddy sandstone interbedded with a few local conglomeratic sandstone lenses. The steep-sloped outcrops are banded in various shades of maroon, orange, green, gray, and lavender. Most of the rock is indistinctly bedded, and has a high clay content as is evident from "popcorn"-weathered surfaces. Many of the mudstones are probably decomposed volcanic tuff beds. The sandstone is commonly cross-bedded, coarse grained to gritty, and has local pebblestone lenses. The sandstones locally form slight to medium ledges, and less commonly, cliffs. About 75 percent of the unit is mudstone. Probably less than 200 feet (60 m) of the member is preserved in the quadrangle.

No reliable thickness measurements can be made of the Summerville-Morrison Formation interval in the Fisher Towers quadrangle because of the structural complexities and because the section is incomplete (no top exposed). Combined, the two formations are about 560 feet (170 m) thick in the Dewey quadrangle to the north (Doelling, 1996). I estimate that a maximum of 400 feet (122 m) of these units may be present on the south side of the Onion Creek diapir.

## **Tertiary Deposits**

### **Geyser Creek Fanglomerate (Tgc)**

Shoemaker (1954) reported a small outcrop of Pliocene(?) conglomerate in the Fisher Valley area near the southeastern edge of the Onion Creek diapir. Colman and others (1988) described the outcrop as a clast-supported gravel in a matrix of fine to coarse sand with distinct planar cross-bedding. The cross-bedding dips up to 45° adjacent to Paradox Formation cap rock contacts. The deposit is massive, but is crudely stratified into layers of fine, medium, and coarse conglomerate. Pebbles are up to 2 inches (5 cm) in diameter. The clasts are predominantly intrusive igneous rocks derived from the La Sal Mountains and from Mesozoic sedimentary rocks. The matrix is calcareous. The exposed part of the deposit is 80 to 85 feet (24-26 m) thick and fills a paleocanyon or crack in the diapir. Hunt (1958) described similar conglomerates in Castle Valley. Carter and Gualtieri (1965) also found similar deposits in the Taylor Creek syncline on the southeast flank of the North Mountain group of the La Sal Mountains and named them the Geyser Creek Fanglomerate.

## Quaternary Deposits

The quadrangle is in an area undergoing relatively rapid downcutting and erosion. Thus, surficial deposits are mostly young (probably latest Pleistocene and Holocene), thin, and scattered. Older surficial deposits are limited to eolian and alluvial deposits on protected benches, pediments, and terraces. Locally, relatively thick Pleistocene deposits fill depressions or basins formed by the dissolution of salt.

### Alluvial Deposits

The materials that make up the alluvial deposits were derived from several sources. Modern alluvium and terrace-deposit sediments were transported into the quadrangle by the Colorado River from upstream source areas. Pediment-mantle deposits consist of materials eroded from nearby sources and carried to their present positions by fluvial processes. These older deposits are dissected such that remaining deposits are only found on the divides between washes. The pediment-mantle deposits are graded from the foot of the cliffs to levels 50 to 180 feet (15-55 m) above the Colorado River and larger tributaries.

**Younger alluvial deposits (Qa<sub>1</sub>):** Younger alluvial deposits consist of sediments deposited by the Colorado River and major tributaries. Colorado River alluvium consists of moderately sorted sand, gravel, silt, and clay that form bars and low terraces near normal water level in the active channel. The gravel clasts range from 0.5 to 10 inches (1.2-25 cm) in diameter, but locally boulders exceed 2 feet (0.6 m) in diameter. Clast composition is variable, and includes quartzite, pegmatite, felsite, pink granite, amphibolite, metaconglomerate, sandstone, and volcanic rock, but most are of metamorphic origin. Most clasts were clearly derived from metamorphic and sedimentary terranes in the Uncompahgre Plateau of western Colorado and easternmost Utah, and other areas of Colorado. The cobbles are rounded to subrounded; many are discoidal or are shaped into "rollers." Sandy intervals are largely quartzitic with a large component of black opaque grains that are commonly gold-bearing (small flakes and flour). Alluvium in the more active tributaries of the Colorado consists of locally derived materials. The deposits average 15 feet (4.5 m) and rarely exceed 20 feet (6 m) in thickness.

**Older alluvial deposits (Qa<sub>2</sub>):** These deposits are generally found 10 to 30 feet (3-12 m) above the younger alluvial stream deposits of the Colorado River and the more active streams and washes, but locally include younger deposits in active channels too small to map separately. They consist of sand, silt, mud, and gravel. They occasionally receive sediments from debris flows, sheetwash, and overbank flooding during periods of intense precipitation or flooding. They also include a small portion of sediment deposited by wind and mass wasting. These older deposits range to as much as 25 feet (7.5 m) thick.

**Terrace-gravel deposits (Qat<sub>3</sub>):** Terrace-gravel deposits consist of moderately sorted gravel, sand, and silt and are much like the modern Colorado River alluvium. They form flat-topped accumulations with steep-sided slopes 50 to 100 feet (15-30 m) above the current river level. These were deposited by the river during the Pleistocene and are now being destroyed by erosion. Generally the finer grained

components have been winnowed away from exposed surfaces by the wind. Like alluvium, the deposits are probably no thicker than 20 feet (6 m).

**Pediment-mantle deposits (Qap<sub>3</sub>, Qap<sub>4</sub>):** Pediment-mantle deposits are the uneroded parts of Pleistocene alluvial fans formed when more humid climatic conditions favored vigorous cliff retreat. They are present on the divides between washes and creeks in Professor Valley and the Richardson Amphitheater and consist of materials derived from the surrounding cliffs. The younger deposits (Qap<sub>3</sub>) are generally 50 to 100 feet (15-30 m) above the principal drainages, whereas the older deposits (Qap<sub>4</sub>) are 120 to 180 feet (37-55 m) above the principal drainages. Both grade upslope and merge with talus deposits (Qmt) that mantle parts of the cliff walls and the slopes beneath them. The Qap-Qmt boundary is arbitrarily placed at the most pronounced change in slope. The pediment-mantle deposits consist of orange sand and silt and angular to subangular fragments of sandstone. The sandstone fragments and boulders range to as much as 15 feet (5 m) in diameter, but most are less than 2 feet (0.6 m). The pediment-mantle deposits are as much as 20 feet (6 m) thick.

**Alluvial-fan deposits (Qaf<sub>3</sub>, Qaf<sub>4</sub>, Qaf<sub>y</sub>):** In Castle Valley, alluvial-fan deposits form apron-like slopes inclined down the valley from the La Sal Mountains and from the cliffs that surround the valley. Older alluvial-fan deposits (Qaf<sub>3</sub> and Qaf<sub>4</sub>) consist of poorly sorted, unstratified to poorly defined, subhorizontally bedded, sandy cobble gravel. Some gravel beds are clast-supported and imbricated, suggesting stream channel deposition. Other gravel beds are matrix supported and structureless, suggesting debris-flow deposition. In general, Qaf<sub>3</sub> deposits form a dissected, stony surface. Qaf<sub>4</sub> deposits are preserved as low-relief, subtle ridges. Qaf<sub>y</sub> deposits are not differentiated on the basis of age. They clearly contain Qaf<sub>3</sub> materials, but locally contain younger materials. Information from water-well logs (Utah Division of Water Rights, unpublished data) and cuttings from two petroleum wells (Utah Geological Survey Core Research Center, unpublished data) suggest that in lower Castle Valley at least 350 feet (107 m) of gravelly alluvium is present beneath the surface. The thickness in the southwest corner of the Fisher Towers quadrangle that includes part of Castle Valley is not known, but could be up to this amount. I would probably treat this gravelly alluvium as a basin-fill deposit (see below), because it was deposited into an area of salt dissolution. The thickness of alluvial fan deposits along the margin of the valley ranges to 40 feet (12 m) from exposures and water-well logs. Qafo (older undivided alluvial-fan deposits) have been mapped in Castle Valley (Doelling and Ross, 1998), but they are not exposed in the Fisher Towers quadrangle.

**Basin-fill deposits (Qabl, Qabm, Qabu):** Colman and Hawkins (1985) and Colman and others (1988) studied the Quaternary stratigraphy of Fisher Valley and called the thicker unconsolidated deposits that bury salt-cored anticlines or diapirs "basin-fill deposits." They are similar to pediment-mantle or alluvial-fan deposits, but they accumulated over collapsing or subsiding substrata and thicker intervals were preserved. The eroded edges of these units are exposed in the east-central part of the quadrangle, mostly in sections 26, 27, 34, and 35, T. 24 S., R. 24 E. The basin-fill deposits thicken toward the center of the basin or depression

(depo-center) in the Fisher Towers quadrangle. They dip and also thicken easterly off the east end of the Onion Creek diapir.

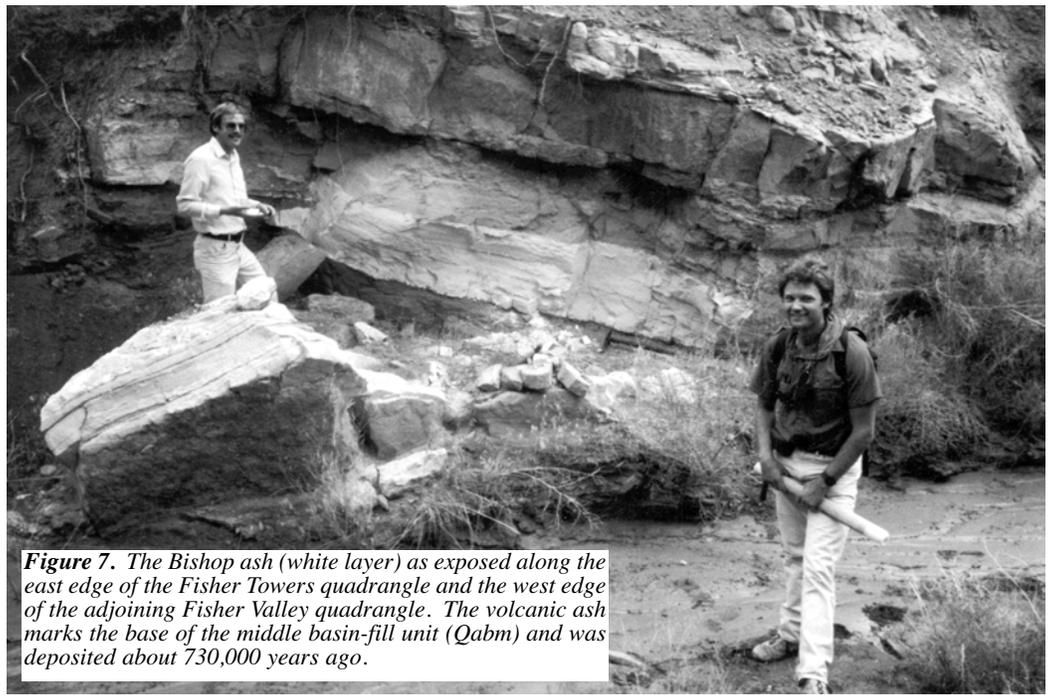
I divided the basin fill into three units. Qabl is a basal (lower) unit and contains the largest percentage of coarse gravel. It is as much as 100 feet (30 m) thick and consists mostly of partly consolidated gravel that commonly weathers to form hoodoo pinnacles. The middle unit (Qabm) consists of moderately indurated, fine to coarse sand interbedded with gravel. The upper unit (Qabu) consists mostly of moderately indurated sand with minor lenses of pebbly gravel. The contacts between units are defined by volcanic ash beds. The Bishop ash (figure 7), dated at about 0.73 million years, marks the base of the middle basin-fill unit (Qabm) and is present about 90 feet (27 m) below the base of the Lava Creek B ash, dated at 0.61 million years (Colman and others, 1988). The Lava Creek B ash is present at the base of the upper basin-fill unit (Qabu). The upper basin fill is at least 66 feet (20 m) thick in the quadrangle. Colman and others (1988) divided the basin-fill deposits into two parts; their lower unit includes both my conglomeratic lower (Qabl) and middle basin-fill deposits (Qabm) (figure 8).

### Mass-Movement Deposits

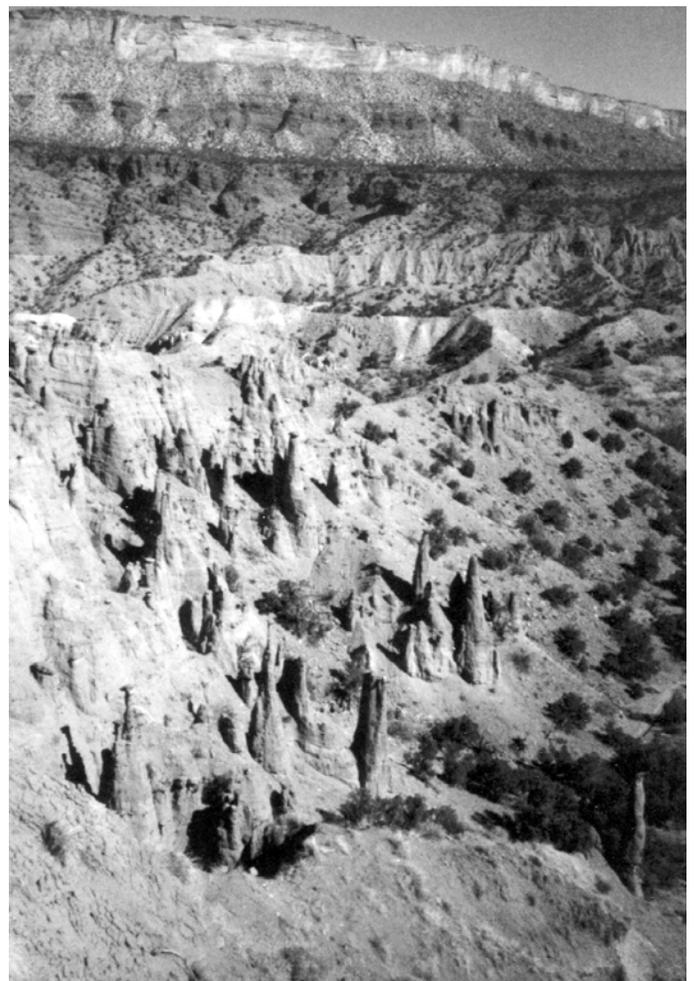
**Landslide deposits (Qms):** Huge blocks of the Wingate Sandstone have separated, rotated, and slid from the Fisher Mesa cliff above Mary Jane Canyon in the east-central part of section 8, T. 25 S., R. 24 E. The Qmt deposit beneath the slide displays an inordinate number of large Wingate sandstone blocks (derived from rock falls) that are probably related to the sliding. The fractures shown on the map associated with the landslide are largely open and are filled with blocks of sandstone. Eolian sand and sandy alluvium (Qea) have collected in depressions on the slide masses (figure 9).

On the northeast side of Fisher Mesa, large coherent blocks of Triassic and Jurassic formations separated from the mesa, probably during the early Pleistocene, rotated, and slumped into the valley below. The action was probably associated with escarpment retreat after the initial graben formed over the Professor Valley-Fisher Valley salt-cored anticline. I have mapped these units as faulted and tilted bedrock rather than as landslide deposits. Parts of these rotated and down-dropped blocks were later disturbed by dissolution and collapse along the south side of the Onion Creek diapir.

**Talus deposits and colluvium (Qmt):** Talus deposits and colluvium are found on steep slopes along canyon walls and below most cliffs. Talus and colluvium exhibit gradational contacts; therefore, they are combined into a single map unit. Talus deposits consist of rock-fall blocks, boulders, and smaller fragments. Colluvium consists mostly of slope-wash material characterized by poorly sorted, angular to subangu-



*Figure 7. The Bishop ash (white layer) as exposed along the east edge of the Fisher Towers quadrangle and the west edge of the adjoining Fisher Valley quadrangle. The volcanic ash marks the base of the middle basin-fill unit (Qabm) and was deposited about 730,000 years ago.*



*Figure 8. The conglomeratic lower basin-fill unit (Qabl) weathers into erosional pinnacles at the east end of the Onion Creek diapir. The lighter bed (one-third of the way down from the top of the photograph) is the Bishop ash. The Cutler, Moenkopi, Chinle, Wingate, and Kayenta Formations (ascending) are exposed in the background and form the north flank of Fisher Valley.*



**Figure 9.** Huge blocks of the Wingate Sandstone in the east-central part of section 8, T. 25 S., R. 24 E. These blocks and others have separated, rotated, and slid from the main Wingate Formation cliff above Mary Jane Canyon.

lar rock fragments in a matrix of coarse to fine sand, silt, and clay. Some colluvium may display a weak, discontinuous bedding parallel to slope, but most is structureless (Richmond, 1962). Colluvium generally supports vegetation, whereas talus contains little fine material between blocks and supports little vegetation.

The best preserved Qmt deposits are cones and sheets on slopes of Triassic and Permian formations beneath the overlying Jurassic Glen Canyon Group sandstone cliffs. The deposits range from a thin veneer to a layer 10 feet (3 m) thick, and may locally exhibit relatively smooth concave surfaces with shallow gullies. The Qmt deposits commonly interfinger with and grade into pediment-mantle (Qap) deposits at their downslope extent.

The development of talus and colluvium is favored by periods of local wet conditions. Canyon walls are more heavily and completely mantled with talus and colluvium in the southern part of the Fisher Towers quadrangle, adjacent to the north end of the La Sal Mountains, which receive greater precipitation because of their elevation.

### Eolian Sand Deposits (Qes)

Small-scale eolian sand dunes and accumulations of eolian sheet sand commonly fill surface depressions and

cover the protected sides of irregular bedrock outcrops. Silty, red-brown, fine-grained sand has accumulated over upper basin-fill (Qabu) deposits south and east of the Onion Creek diapir. Eolian deposits are generally thin, and reach a maximum thickness of about 30 feet (9 m) where they overlie the upper basin fill. Most eolian deposits support sparse vegetation and are partially stabilized.

### Mixed Eolian and Alluvial Deposits (Qea)

Surficial deposits commonly grade into one another. The most common combination is the mixed eolian and alluvial unit (Qea). Qea deposits generally have a higher eolian constituent than alluvial deposits and are generally older than the eolian sand deposits. Qea deposits are preserved in broad hollows in bedrock. Locally, washes cut deeply into the deposits and expose crudely stratified sand, sandstone fragments, silt, and small pebbles, some of which may be residual. Some show the development of weak calcification below the upper surface, indicating an older age than most other surficial deposits. In most cases the deposits are less than 15 feet (5 m) thick.

## STRUCTURE

### Professor Valley-Fisher Valley Salt-Cored Anticline

The Fisher Towers quadrangle is located in the salt-anticline portion of the ancestral Paradox basin of eastern Utah (plate 1). Salt anticlines are long, linear salt diapirs that bow up overlying strata, and form over deeply buried linear structures such as faults. The Professor Valley-Fisher Valley (PVFV) collapsed salt anticline trends east-west across the quadrangle. It extends westward into the Big Bend quadrangle as the Cache Valley salt diapir (Doelling and Ross, 1998), and southeastward into the Fisher Valley quadrangle (Goydas, 1990). The zone of deformation is 1.2 to 2 miles (1.9-3.2 km) wide where the effects of salt diapirism, dissolution collapse, and landsliding are well displayed.

The western third of the PVFV structure is mostly covered with Quaternary deposits, but faulted and tilted formations, collapsed to valley level, are exposed adjacent to cap rock. Cap rock is the residual part of the Paradox Formation remaining after evaporite minerals are dissolved, and is the part of the formation exposed in outcrops. The Wingate Sandstone is exposed as a low butte near the Jesse D. (Red Head) uranium mine, at the junction of sections 22, 23, 26, and 27, T. 24 S., R. 23 E., at an altitude of 4,592 feet (1,400 m), indicating collapse of nearly 2,000 feet (610 m) from its elevation at the south end of Fisher Mesa. The better-exposed, central part of the PVFV structure has collapsed less. Two prominent buttes of Wingate Sandstone north of Fisher Mesa have collapsed only 600 to 700 feet (183-213 m) and cap rock is not exposed in this segment. Between these buttes and the Onion Creek diapir (a pod of the PVFV diapir in the east-central part of the quadrangle near Onion Creek), collapse depth increases and the formations form a deep V-syncline between two faults 2,500 feet (762 m) apart. The eastward extensions of these two faults form the north and south boundaries of the Onion Creek diapir. The deepest collapse in the V-syncline lies just west of the diapir where the Wingate Sandstone has been lowered about 1,600

feet (490 m) to an altitude of 5,000 feet (1,524 m). The V-syncline appears to continue in the cap rock of the Onion Creek diapir where outcrops of the lower member of the Moenkopi Formation are preserved along the axial trend.

Cap rock of the Onion Creek diapir is exposed in the northern half of the eastern third of the PVFV structure (figure 10). The largest cap-rock mass is about 2 miles (3.2 km) long and 3/4-mile (1.2-km) wide, rising 500 to 600 feet (152-183 m) above the Onion Creek drainage. Shoemaker (1954) mapped several closely spaced folds in the exposed cap rock that illustrate its internal structure.

The north-bounding fault of the Onion Creek cap rock exposure probably marks the intrusive boundary of the diapir. The cap rock has also collapsed a small amount along this fault. North of the fault the Cutler Formation is folded into closely spaced anticlines and synclines. These folds are tighter and more closely spaced near the diapir. It is not clear whether these folds are the result of compression caused by the intrusion of the diapir or whether they are the result of dissolution collapse along fractures in the Cutler Formation. Several springs issue from these rocks and reveal that some of the fractures are open.

South of the Onion Creek diapir, deeply collapsed or slumped blocks of Jurassic formations cover Triassic, Permian, and Pennsylvanian strata, and small Paradox Formation cap rock masses. Bedding in the Honaker Trail and Cutler Formations is steeply inclined to nearly vertical along the south margins of these smaller cap-rock masses. I believe these smaller masses delineate the south or southwest intru-

sive boundary of the Onion Creek salt wall or diapir. The area between these smaller masses and the well-exposed part of the diapir collapsed deeply; Jurassic units slumped into the depression. There is no counterpart of the north-side folds on the south side of the diapir.

An east-west-trending fault along the south margin of the PVFV salt-cored anticline, mostly in section 26, T. 24 S., R. 23 E., may have moved since the deposition of the Qap<sub>3</sub> pediment mantle unit. Cutler Formation beds on the north-side downthrown block dip as much as 30° north, presumably into an area lowered by salt dissolution that is presently covered with Qap<sub>3</sub> deposits. The total amount of displacement is unknown, but Qap<sub>3</sub> deposits south of the fault are as much as 20 feet (6m) higher than Qap<sub>3</sub> deposits north of the fault. However, Qap<sub>3</sub> deposits on the south side of the fault may grade into Qmt deposits on the west edge of Fisher Mesa that Colman and Hawkins (1985) mapped as older Qap<sub>4</sub> deposits (their Qp<sub>1</sub> unit). Their interpretation would indicate that deposits on opposite sides of the fault are of different ages and that there was no offset after deposition. They may be correct because evidence of offset of the unconsolidated pediment mantle deposits is obscured or not present.

### Castle Valley Salt-Cored Anticline

A small part of the northeast side of the Castle Valley salt-cored anticline crosses the southwest corner of the Fisher Towers quadrangle. Within the quadrangle, Quaternary



**Figure 10.** View northeastward across the Onion Creek diapir from Fisher Mesa. The lighter rock in the center is Paradox Formation cap rock. The Triassic Moenkopi Formation laps onto the cap rock from the left. The Cutler Formation crops out directly north of the diapir, where more than 3,000 feet (914 m) of the unit is exposed. Rocks in the foreground are mostly collapsed Triassic and Jurassic units.

unconsolidated deposits cover cap rock and collapsed bedrock, and Cutler Formation strata dip as much as 17° northeastward along the margin of Castle Valley. Some deformation related to collapse is indicated by a few north-west-trending faults in the Cutler outcrops. A more detailed account of the Castle Valley structure is presented in Doelling and Ross (1998).

### Folds

Strata north of the PVFV salt-cored anticline generally dip 7 to 10° north toward the Uinta Basin. North of the Onion Creek diapir, Cutler Formation strata are folded into several anticlines and synclines with dips as high as 60° on the limbs. Immediately north of the folds, strata dip as much as 17° northward. The dip gradually decreases to the regional dip of 7 to 10°. The Cutler Formation also displays anomalous, generally steeper dips at scattered locations elsewhere on the quadrangle, suggesting deformation prior to deposition of the Moenkopi Formation. Cutler strata also commonly steepen adjacent to salt walls or diapirs.

A shallow syncline, herein termed the Mary Jane syncline, is evident in exposed post Cutler rocks between the Castle Valley and PVFV salt-cored anticlines. The axial trace parallels Mary Jane Canyon in the south part of the quadrangle and then crosses the west end of Fisher Mesa just south of the PVFV salt-cored anticline. Dips on Fisher Mesa are as high as 7° southwest. Dips on Adobe Mesa are gentle, averaging 2° to the northeast. A very shallow north-trending anticline is expressed in the Cutler Formation outcrops about 1 mile (1.6 km) west of the Mary Jane syncline. The rocks dip as much as 11° westerly on the west flank, but only a few degrees easterly on the east flank.

### Miscellaneous Faults

Most faults in the Fisher Towers quadrangle formed in response to salt dissolution or diapirism and parallel or splay off from the Castle Valley and PVFV salt structures. Elsewhere, a few faults are present whose origins are unclear. Some may be due to salt movement, or to adjustments to folding. A swarm of joints and small-displacement faults cut the Cutler Formation in the north-central map area. The sense of movement on these faults is difficult to resolve due to the lack of marker beds in the formation. Another fault about 1 mile (1.6 km) long cuts the Kayenta Formation in the northeast corner of the quadrangle. The downthrown block is on the east side and the amount of displacement does not exceed 40 feet (12 m). Two parallel faults are located in the southern part of the Richardson Amphitheater that have downthrown blocks to the south. The displacements are estimated to be less than 100 feet (30 m). Locally, drag on the northern of these faults has produced dips to the south of as much as 22°.

### Age of Structures

The salt-cored anticlines are believed to have formed along pre-existing "basement" faults (Szabo and Wengerd, 1975; Johnson, 1983) that were intermittently active from Pennsylvanian through earliest Triassic time. Thick beds of

salt were deposited in the Paradox Formation during the Pennsylvanian. During Late Pennsylvanian, Permian, and Triassic time the low-density salt moved into the weakened zones above the "basement" faults, where it diapirically intruded the overlying sediments (Prommel and Crum, 1927). Regionally, strata as young as Late Cretaceous are gently folded and warped. In the Fisher Towers quadrangle post-Cutler rocks are warped and tilted. This folding is commonly dated as early Tertiary (Doelling, 1985, 1988). Recent theories suggest that regional extension and local salt withdrawal may be responsible for the formation of the collapsed salt-cored anticlines, and the synclines between them (Ge and Jackson, 1994; Hudec, 1995). These ideas may explain why Tertiary normal faults cut apparently "folded" bedrock.

The most obvious structural features are those related to salt dissolution. Evidence in and adjacent to the quadrangle indicates that deformation was controlled by regional erosion of the Colorado Plateau. As the plateau was incised, the Colorado River and its tributaries cut through impermeable layers. This allowed fresh water to seep down through fault and joint conduits and dissolve salt. Overlying rocks tilted and collapsed into the voids. Collapse formed new faults that allowed the process to continue. The collapse structures formed mainly during the Pliocene and Pleistocene epochs, roughly during the last 3 million years, when the region experienced a wetter climate (Thompson, 1991). Dissolution is probably still occurring today at a reduced rate.

## LATE TERTIARY-QUATERNARY GEOLOGIC HISTORY OF THE FISHER VALLEY-ONION CREEK AREA

Hunt (1983) summarized the evolution of the southeastern Utah landscape. The Colorado River system developed during the Miocene when the landscape was largely plains developed on Cretaceous and possibly younger formations. Reworked Cretaceous pollen found downstream indicates erosion was generally removing Cretaceous rocks during the Pliocene (Fleming, 1994). The deepest canyons probably reached and cut into Glen Canyon Group rocks in the Fisher Towers area. The more resistant igneous rocks of the La Sal Mountains already stood high above the region, spawning drainages that flowed northward across the Fisher Towers quadrangle. These streams cut deep canyons into the Wingate Sandstone 2,800 feet (850 m) above the present river level. Some of these channels are still observable today. The deepest paleochannel in the Fisher Towers quadrangle is Waring Canyon, in which the erosion cut through the Wingate Sandstone into the Triassic Chinle Formation. The upstream end of Waring Canyon was cut off by subsequent erosion or by early dissolution-induced collapse. Other canyons were cut into the high, north-sloping mesa north of Onion Creek. Two small tributaries cut shallow channels across the narrow part of Fisher Mesa. The break between Adobe Mesa and Castle Rock may also have been an ancient channelway.

Fractures and joints formed along natural lines of weakness at the margins of the old salt-cored anticlines. Previously formed joints and faults (see Structure Section), may also have been present. The fractured areas above the salt-cored anticlines collapsed into grabens as the salt beneath

was dissolved, forming valleys. At first drainages crossed perpendicular to the salt structures, but eventually they were deflected as valleys formed above the structures. Early collapse lowered and preserved the Pliocene(?) Geysers Creek Formation south of the Onion Creek diapir. After the streams had cut through the Glen Canyon Group, erosion cut rapidly through the softer Triassic formations. The areas between the salt-cored anticlines stood as highlands and retreated slowly. When erosion reached the more resistant Cutler Formation sandstones, downcutting was slowed, the Fisher Valley-Onion Creek drainage area was widened, and the graben walls receded. Large "blocks" of the Fisher Mesa rim rotated, slid, and collapsed into the valley along the southwest margin. Dissolution continued irregularly during middle Pleistocene time. Deposition and erosion of the valley surface was graded to the ancestral Colorado River. A major surface developed about 1,800 feet (550 m) above the present river level. Interestingly, the present altitude of Fisher Valley and accompanying benches is about the same as that of the present Dome Plateau just north of the quadrangle on the north side of the Colorado River.

Pleistocene basin-fill deposits accumulated in a subsiding area along the east margin of the Fisher Towers quadrangle and in the Fisher Valley quadrangle to the east (Goydas, 1990). The 730,000-year-old Bishop ash and 610,000-year-old Lava Creek ash are found in these basin-fill deposits (Colman and Hawkins, 1985). At that time alluvium probably covered the Onion Creek diapir and the area looked much like Castle or Moab Valley does today.

During valley widening, the ancestral Fisher Creek was probably pirated into the Cottonwood graben (figure 1). Although surface water flowed down the Cottonwood graben to the Dolores River, ground water seeped west and northwest along the PVFV structure to the ancestral Colorado River where the flow emerged as springs near the river bank. The springs eroded headward, forming a deep canyon in the Cutler Formation and in the Onion Creek diapir. Springs still emerge from fractures in the Cutler Formation and from the base of the basin-fill deposits. The basin-fill deposits of Fisher Valley are slowly being headwardly eroded and eventually the relatively flat surface of Fisher Valley will be destroyed. About 1 mile (1.6 km) of basin-fill sediment will need to be removed before Fisher Creek can be recaptured.

## ECONOMIC GEOLOGY

### Vanadium and Uranium

#### Jesse D. (Red Head) Mine

A fracture-controlled vanadium, uranium, and copper deposit in the Richardson Amphitheater, SE<sup>1</sup>/<sub>4</sub> section 22, T. 24 S., R. 23 E., was first reported by Boutwell (1905). He noted that the mineralization consisted chiefly of compounds of vanadium, including vanadio-arsenates of copper, barium, and calcium. He described the presence of small, brittle, green, greenish-yellow, and yellowish-green crystals and small masses of carnotite (tyuyamunite?). The minerals were subsequently studied by Hillebrand and Merwin (1913) and Shoemaker (1956), who reported that the ore minerals are chiefly tyuyamunite, calciovolborthite, and conichalcite.

The mineralized area has been known as the Jesse D. (Boutwell, 1905) or Red Head (Shoemaker, 1956) deposits.

The mineralization extends along a 1,500-foot (457 m) east-west-trending zone that is as much as 350 feet (107 m) wide. The minerals are distributed along fracture surfaces, in fault gouge, and in small concretionary nodules scattered through highly fractured Wingate Sandstone. Salt-dissolution-related faults and fractures mostly trend N. 60° W. and the Wingate Sandstone dips 35 to 40° NW. The concentration of mineralization is very erratic in the zone; the best mineral concentrations and the higher radioactive readings are obtained at the east and west ends. Areas rich in copper do not overlap those containing stronger vanadium and uranium concentrations.

The deposit was discovered in March 1898 by a Mr. Welch and a Mr. Lofftus (Boutwell, 1905). In 1902 Mr. Lofftus sent about 500 pounds (0.23 metric tons) to Buffalo, New York for analysis. The minerals were discovered to be radioactive and samples were sent to Madame Curie in Paris, France in 1903, who found no radium. Through 1904 numerous cabinet specimens, 2,000 pounds (0.9 metric tons) of ore, and more than half a carload of ore had been shipped from the property. Workings consisted of at least 20 prospect pits, short tunnels, and shafts. At the southwest corner of the mineralized zone a 32-foot (9.8-m) shaft was dug and levels were driven northeastward at depths of 18 and 32 feet (5.5 and 9.8 m) for distances of 18 and 40 feet (5.5 and 12.2 m), respectively (Boutwell, 1905).

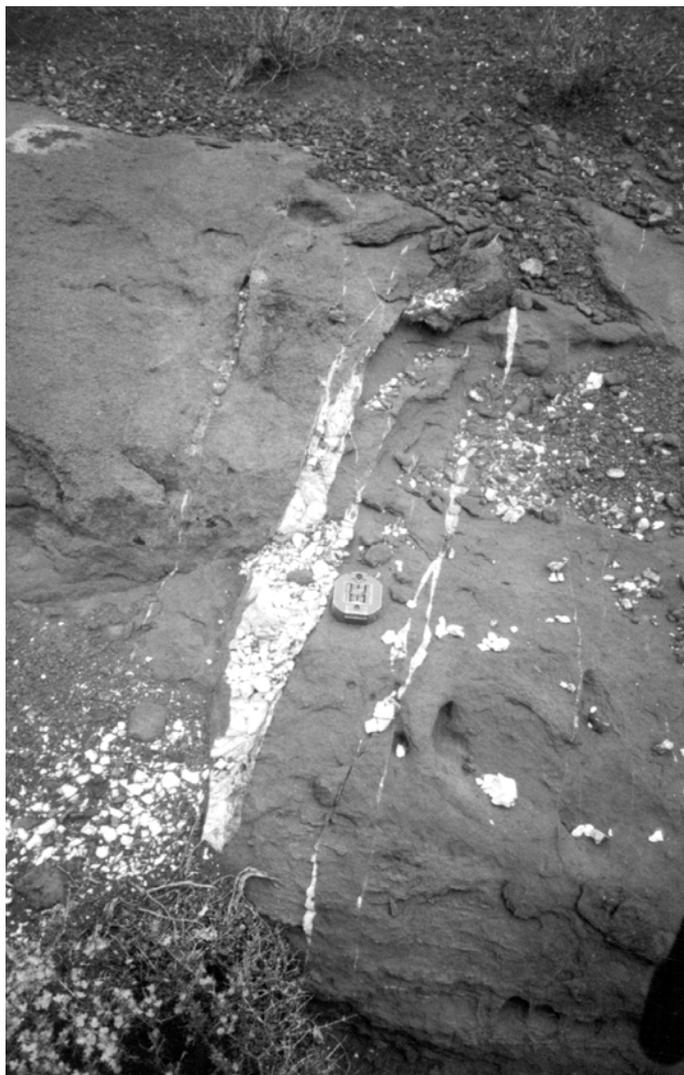
Chenoweth (1975) reported at least 500 tons (453.6 metric tons) was produced from the property during the 1950s for uranium values. Since then, additional earth-moving was done as development work to maintain claims. In 1996, the area was long abandoned; two open shafts, one 25 feet (7.6 m) deep, the other 15 feet (4.6 m) deep remained. The Bureau of Land Management sealed the openings of other adits for safety reasons during the early 1990s.

#### Unnamed Chinle Prospect

A shallow inclined shaft has been dug into the top of mottled siltstone beds near the base of the Chinle Formation, SE<sup>1</sup>/<sub>4</sub>SE<sup>1</sup>/<sub>4</sub>SW<sup>1</sup>/<sub>4</sub> section 23, T. 24 S., R. 23 E. The shaft is 12 feet (3.7 m) long and 8 feet (2.4 m) wide. Quartz and calcite veins are noticeable near the shaft and laterally along the strike of the formation. The rocks are inclined 30° SE and strike about 20° NE; tilting is probably the result of collapse related to salt dissolution. No uranium or vanadium mineralization was noted, but conglomerate at the base of the Chinle is commonly radioactive.

#### Barite

Barite veins in the Cutler Formation pinch and swell to as much as 2 feet (0.6 m) thick, though most are less than 6 inches (15 cm) thick. Most are located in NW<sup>1</sup>/<sub>4</sub>NW<sup>1</sup>/<sub>4</sub> section 23, T. 24 S., R. 23 E. These veins trend N. 22 to 60° E., and extend as much as 800 feet (250 m) in length across an area 360 feet (110 m) wide (figure 11). The barite is bladed and white. The larger veins have been handcobbled; the largest working is a pit 6 by 6 by 3 feet (1.8 x 1.8 x 0.9 m) on a vein striking N. 22° E. The exposed vein is 6 inches (15 cm) thick, nearly vertical, and exhibits a 6-inch-thick (15 cm) bleached zone on each side.



**Figure 11.** Barite veins in the Cutler Formation. Some are as much as 810 feet (247 m) long. Most are found in the NW<sup>1</sup>/<sub>4</sub>NW<sup>1</sup>/<sub>4</sub> section 23, T. 24 S., R. 23 E.

## Copper

Copper mineralization is present at five locations in the Fisher Towers quadrangle, in addition to the copper-bearing Jesse D. or Red Head vanadium and uranium deposits described previously. A copper mine or prospect is located on the south flank of the Onion Creek diapir, NW<sup>1</sup>/<sub>4</sub> section 28, T. 24 S., R. 24 E. Mostly malachite, azurite, and copper pitch are associated with a structurally collapsed section of the Salt Wash Member of the Morrison Formation. The east-west-trending, vertically oriented sandstone lenses are coated and locally impregnated with copper minerals. The outcrops were checked with a scintillation counter, but no anomalous radioactivity was detected.

Another working is present along the north edge of the Onion Creek diapir, NE<sup>1</sup>/<sub>4</sub>NW<sup>1</sup>/<sub>4</sub>SW<sup>1</sup>/<sub>4</sub>, section 22, T. 24 S., R. 24 E. The mine or prospect consists of several trenches and a short adit developed in gypsiferous black shale of the Paradox Formation or Paradox-derived alluvium and colluvium just south of the fault or diapiric margin with the Cutler Formation. The disturbed area is an equilateral triangle, 75

feet (23 m) to the apex and 195 feet (59 m) in length. Mineralization consists of frothy limonite, sulfates, sulfur, pyrite, arsenopyrite(?), a small amount of copper carbonate(?), and cuprite.

A small shaft was dug along the fault on the north side of the Onion Creek diapir, SW<sup>1</sup>/<sub>4</sub>SW<sup>1</sup>/<sub>4</sub>SW<sup>1</sup>/<sub>4</sub> section 21, T. 24 S., R. 24 E. The shallow 6 by 6-foot (2 x 2 m) shaft is dug into gray shale of the Paradox Formation. Some copper carbonate (mostly malachite) is present on the dump.

Another small shaft was dug in the lower member of the Moenkopi Formation, which strikes N. 80° W. and dips 35° NE in NE<sup>1</sup>/<sub>4</sub>SW<sup>1</sup>/<sub>4</sub>NW<sup>1</sup>/<sub>4</sub> section 34, T. 24 S., R. 24 E. Small quantities of copper carbonate coat fracture surfaces on the walls of the shaft.

## Other Workings

An adit has been cut into the Cutler Formation below Adobe Mesa, SE<sup>1</sup>/<sub>4</sub>SE<sup>1</sup>/<sub>4</sub> section 10, T. 25 S., R. 23 E. It trends S. 73° E. for about 54 feet (16 m) and has a short branch of 18 feet (5.5 m) extending N. 33° E. from a point 30 feet (9 m) into the abandoned working. Sparse vertical fractures coated with a green mineral and gypsum as much as 1.2 inches (3 cm) thick are found in the workings. The green mineral is found in reduction spots and a "favorable" horizon with abundant reduction spots can be traced laterally for several hundred feet. No tests were conducted on the mineral, which is not believed to contain copper. Only background readings were obtained with a scintillation counter.

## Sand and Gravel

Alluvium (Qa<sub>1</sub>) and alluvial-terrace deposits (Qat<sub>3</sub>) along the Colorado River contain sand and gravel that has been used for highway construction. Cutbank tests, conducted by the Utah Department of Transportation (UDOT, about 1967) on similar deposits at nearby localities (not in the Fisher Towers quadrangle), indicated that sand and gravel in this area is suitable as base and surfacing gravel and for use in concrete and asphalt mixtures. Tested alluvial and terrace deposits were non-plastic, had swell analyses ranging from 0.008 to 0.015, and an American Association of State Highway Officials (AASHO) classification of A-1-a.

## Petroleum

Six oil and gas test wells have been drilled in and near the Fisher Towers quadrangle (figures 1 and 2). Most were drilled on gentle, broad anticlines evident at the surface in the Cutler Formation. The Paradox Formation (Cane Creek zone) and Mississippian rocks were the drilling targets. All were dry holes and are presently plugged and abandoned. The Cane Creek zone and Mississippian strata are productive 20 to 25 miles (32-40 km) to the southwest, and Mississippian and Devonian rocks are productive 36 miles (58 km) to the south (Clem and Brown, 1984; Doelling and others, 1994).

## Gold Placer Deposits

Several abandoned gold placer workings are present in

adjacent quadrangles in the terrace gravels of the Colorado River and small amounts of gold were evidently recovered (Doelling, 1996). The gravels of the Colorado River (Qa<sub>1</sub>) and terrace alluvium (Qat) contain flour gold and rare flakes of gold (Butler, 1920). The gold occurs in black, magnetite-bearing, coarse, sandy streaks in the river alluvium. Vertically through the deposits, the gold is typically distributed uniformly, but the upstream ends of the gravel bars and higher terraces may be slightly richer in gold (Butler, 1920).

### Paradox Formation Evaporites

Halite, carnallite, sylvite, gypsum, anhydrite, polyhalite, syngenite, and kieserite have all been identified in the evaporites of the Paradox Formation (Ritzma, 1969). Carnallite and sylvite are potash salts; carnallite is the most abundant in the Paradox Formation, but has a low potassium content (14.1 percent). Pure sylvite contains 52.4 percent elemental potassium. It is solution mined at Potash, 20 miles (33 km) southwest of the Fisher Towers quadrangle (Doelling and others, 1994).

Sylvite extraction is hindered and made more expensive by the complex folding in the salt beds commonly associated with salt-cored anticlines. Less deformed Paradox Formation evaporites are probably present between the salt-cored anticlines of the Fisher Towers quadrangle, but may be too deep to compete with other sources. Gypsum is present in the cap rock of the Onion Creek diapir, but it is probably too impure for commercial use. The other aforementioned minerals are less common in the Paradox Formation and are not considered economically feasible to extract.

Brine extracted from the Moab Valley salt diapir contained about 310,000 parts per million (ppm) sodium chloride and 1,200 ppm calcium sulfate (Mayhew and Heylman, 1965). The Atlas Minerals uranium mill used the brine in their operation north of Moab. Fresh water was pumped into a massive salt bed, and the brine was extracted from a second well. Such an operation would be feasible in the Fisher Towers quadrangle if there was a market for the brine. However, at the present time operational salt and brine extraction companies, such as at Potash and in Moab Valley, have more than adequate reserves (Doelling and others, 1994, 1995, 2002).

## WATER RESOURCES

The Fisher Towers quadrangle lies in a steppe-climate area (mid-latitude steppe) and receives 8 to 14 inches (20-35 cm) of precipitation per year (Iorns and others, 1964). Average annual evaporation rates are 38 to 40 inches (97-102 cm) per year (Iorns and others, 1964). The Colorado River and Onion, Professor, and Castle Valley Creeks provide irrigation water for several locations in the quadrangle. Onion, Professor, and Castle Valley Creeks are tributaries of the Colorado River with recharge areas in the La Sal Mountains. The average discharge for Onion Creek is 1.13 cubic feet per second (32 dm<sup>3</sup>/s or 8.18 acre-feet per year); Professor Creek discharges about 2.1 cubic feet per second (59 dm<sup>3</sup>/s or 15.2 acre-feet per year); and Castle Creek discharges at least 2 cubic feet per second (57 dm<sup>3</sup>/s or 14.5 acre-feet per year) (Hendricks, 1964). Other drainages are ephemeral and catchment basins have been constructed to use the rainfall

and spring runoff for watering cattle.

The bedrock aquifers in the Fisher Towers quadrangle are mostly untested for water. The sandstone formations of the Glen Canyon Group are considered the most important bedrock aquifers in the region (Feltis, 1966; Blanchard, 1990). Small springs issue from these formations at several places in the quadrangle and the potential for small amounts of water is good. The quality of water obtained from these aquifers is generally good; concentrations of dissolved solids average less than 400 ppm. The water type is calcium bicarbonate or calcium magnesium bicarbonate, and the water is moderately hard to hard (Blanchard, 1990).

Triassic formations are aquicludes and rarely yield water. The Cutler Formation yields water on the southwest side of Castle Valley. According to Blanchard (1990), 30 wells in Castle Valley produced from 20 to 40 gallons per minute (1.3-2.5 L/s) from the Cutler Formation without measurable drawdown. Dissolved solids concentrations in these wells ranged from 1,420 to 3,450 ppm. Therefore, water from the Cutler Formation is expected to be slightly saline to saline in the area of the Fisher Towers quadrangle. The water also contained concentrations of selenium that exceeded State of Utah drinking-water standards.

Subsurface rocks have been divided into three hydrostratigraphic units based on similar hydrogeologic characteristics (U.S. Department of Energy, 1984). The upper hydrostratigraphic unit consists of the Permian Cutler Formation and the upper two-thirds of the Honaker Trail Formation. The middle unit includes the remainder of the Honaker Trail Formation and the Paradox Formation. The lower unit includes all the carbonate rock units below the Paradox Formation. The recharge area for the upper unit includes the La Sal Mountains. Water yields from the upper unit are expected to be small and of variable quality, tending to be saline. The middle unit consists of confining beds alternating with beds of variable water-bearing capacity. When water is found it is generally very saline. The lower hydrostratigraphic unit consists of carbonates with good porosity and permeability. Oil-well data generally indicate large quantities of salty water.

Stinking Spring, SE<sup>1</sup>/<sub>4</sub>SE<sup>1</sup>/<sub>4</sub> section 21, T. 24 S., R. 24 E., issues from Paradox Formation cap rock. Other springs issue from shallow alluvium or from bleached Cutler Formation, but all are suspected to have a flow path through Paradox Formation cap rock (figure 12). Although an analysis for the spring is lacking, Blanchard (1990) reported a specific conductance of 18,000  $\mu$ S/cm (microsiemens per centimeter at 25°C), suggesting a high total dissolved-solids content. The name of the spring is attributed to the strong odor of hydrogen sulfide gas emitted by the water and suggests that anaerobic bacteria may be reducing gypsum in the cap rock.

Ground water is also present in the surficial deposits of the quadrangle. More than 100 wells have been drilled in the unconsolidated deposits of Castle Valley (mostly outside the Fisher Towers quadrangle). Sampled wells indicate dissolved solids concentrations ranging from 169 to 1,020 ppm or mg/L (Sumsion, 1971). Recharge to the Castle Valley wells is assumed to be in upper valley locations along Placer and Castle Creeks, which originate in the La Sal Mountains. Mixing with subsurface spring sources in the Cutler Formation, and possibly in the salt diapir, accounts for the more saline water. Similarly, water from the Colorado River re-



**Figure 12.** White sulfate efflorescence on Cutler Formation outcrops near Onion Creek. The efflorescence indicates the water has seeped through the Paradox Formation cap rock before passing through the Cutler.

charges gravelly aquifers under adjacent bottom land. Unconsolidated sand on the benches and mesas collects rain-water and snowmelt that may provide small amounts of water for stock.

## GEOLOGIC HAZARDS

### Erosion, Debris Flows, and Floods

Erosion by running water is the most active and potentially damaging hazard in the quadrangle. The sparsely vegetated steep slopes and deep, narrow, ephemeral washes are subject to rapid erosion from waters generated by cloudburst storms and spring snowmelt runoff.

Debris flows, debris floods, and normal streams are mixtures of water and sediment that vary from mostly sediment to mostly water. Debris flows and floods generally remain confined to stream channels in high-relief areas, but may exit the channels and deposit sediment on alluvial fans where

slope gradients decrease. Almost all bedrock units consist of rocks that are conducive to the accumulation of talus and colluvium on slopes, providing ample source material for debris flows. Debris-flow deposits frequently cover sections of the back roads and spread across alluvial fans in the quadrangle. Cloudburst floods regularly damage back roads at wash crossings and along the steeper grades (deep gullying).

Flooding of the Colorado River occurs during unusually high spring runoff because the river is largely unregulated by engineered structures upstream of the Fisher Towers quadrangle. Pavement, embankments, and culverts of at least three segments of Utah Highway 128 (U-128) were damaged during the 1983 runoff period along the Colorado River between McGraw Bottom in the Dewey quadrangle and Professor Valley (Davis, 1989). Highway U-128 was closed for several weeks.

### Rock Falls

Rock falls are common in the rugged terrain of southern Grand County. In the quadrangle, the Kayenta, Wingate, Chinle, Moenkopi, and Cutler Formations commonly produce rock-fall debris. The most susceptible cliffs or slopes are those broken by fractures subparallel to cliff faces.

The high cliffs that face the Richardson Amphitheater and Professor Valley are active rock fall sources. No recent events have been reported, but several rock falls in similar terrain have been recorded in the Big Bend quadrangle to the southwest (Doelling and Ross, 1998). Joints and fractures are common in the massive cliffs of the Kayenta and Wingate Formations, which are slowly being undercut by erosion of the less resistant Chinle Formation. Large rocks may bounce, roll, and slide for great distances downslope at relatively high velocities.

### Problem Rock and Soil

Clay- and evaporite-bearing rock (gypsum) and soil that expand and contract as they absorb and lose moisture, or that dissolve and subside, are materials that regularly cause damage to roads on the quadrangle. Such materials are present in the Chinle and Paradox Formations. Collapsible soils are common on Qea deposits and are subject to volumetric changes upon excessive wetting that could damage structures built upon them (Mulvey, 1992).

### Landslides

A very large landslide or rotational block is present in the Fisher Towers quadrangle that slid into the valley formed over the PVFV salt-cored anticline during the early Pleistocene. The rock units remained coherent, acting as displaced fault blocks. Another landslide developed on the south-facing wall of Fisher Mesa, above Mary Jane Canyon, E $\frac{1}{2}$  section 8, T. 25 S., R. 24 E., where large rotated blocks of the Wingate Sandstone rest precariously above a slope of very coarse talus. Favorable landslide conditions are not extensive in the Fisher Towers quadrangle; however, there is potential for local activity. Under current climatic conditions, rock falls will likely be more common than slumping and sliding.

## Earthquake Hazard

The quadrangle is in the Colorado Plateau, a region of small- to moderate-magnitude earthquakes with low to moderate recurrence intervals (Wong and Humphrey, 1989). Earthquakes greater than magnitude 4 (large enough to be felt) are rare in the region, and the quadrangle is far from known active Quaternary tectonic faults (Arabasz and others, 1979; Hecker, 1993). Movement on faults in the area is mostly caused by salt dissolution along the salt-cored anticlines, but no earthquakes have been reported in historical time. The quadrangle is in Uniform Building Code seismic zone 1, the zone of lowest potential in Utah (International Conference of Building Officials, 1997).

## Blowing Sand

Sand may be blown across back roads during wind storms, causing reducing visibility and accumulating on the roads. Unimproved roads crossing deposits of eolian sand become very dry and soft during the hot summer months, making driving difficult.

## Radon

Radon is a known cancer-causing gas produced through decay of naturally occurring radioactive elements. It accumulates in basements and other enclosed areas (Black, 1993). Though most of the quadrangle is sparsely inhabited, the Fisher Towers quadrangle is in an area of moderate to high potential for elevated levels of radon.

## SCENIC RESOURCES

### Canyonlands and Monuments

Most of the Fisher Towers quadrangle displays scenic canyonland vistas. The Colorado River and its tributaries flow across wide valleys or through deeply incised canyons. High canyon walls are lined with the scenic vertical cliffs of the Glen Canyon Group. The quadrangle is crossed by Utah Highway 128 (U-128), a beautiful 35-mile (56 km) river drive from Moab to Dewey (figure 1). The highway extends 10 miles (16 km) to the north where it joins Interstate 70. Spectacular vistas await those who are adventurous enough to travel the arduous 4-wheel-drive roads to the tops of Adobe Mesa, Fisher Mesa, and the unnamed mesa north of Fisher Towers.

Onion Creek has eroded a "Grand Canyon" between the Richardson Amphitheater and the Onion Creek diapir. This very narrow canyon has an inner gorge cut 400 feet (122 m) into the Cutler Formation. Several rock monuments of the Cutler, such as the Totem Pole, remain on top of the gorge. Thick red-brown lenses of the Cutler create unusual auras at the bottom of the canyon at various times of the day. The Priest and Nuns, Castle Rock, and Fisher Towers are famous, oft-photographed buttes. The first two are remnants of the Wingate Sandstone. The Fisher Towers are carved in the lower member of the Moenkopi Formation and the upper part of the Cutler Formation. Because of the scenery, Professor Valley and the Richardson Amphitheater have been the sites

for the filming of several classic Hollywood western movies and many commercials.

## Onion Creek Diapir and Associated Salt Dissolution Collapse Features

The Onion Creek diapir is probably the premier exposure of salt-dome cap rock in the western hemisphere. The exposure is approximately 2 miles (3.2 km) long and about 3/4 mile (1.2 km) wide. It rises nearly 600 feet (180 m) above the Onion Creek drainage and exhibits highly contorted black shale, dolomite, and limestone, and thick beds of alabaster gypsum. Thin-bedded shale and carbonate beds are tightly folded and exhibit anticlines, synclines, and overturned folds. Surrounding the diapir, and equally well exposed, are the faulted, tightly folded, and collapsed formations that have participated in the diapirism and subsequent removal of subsurface salt.

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