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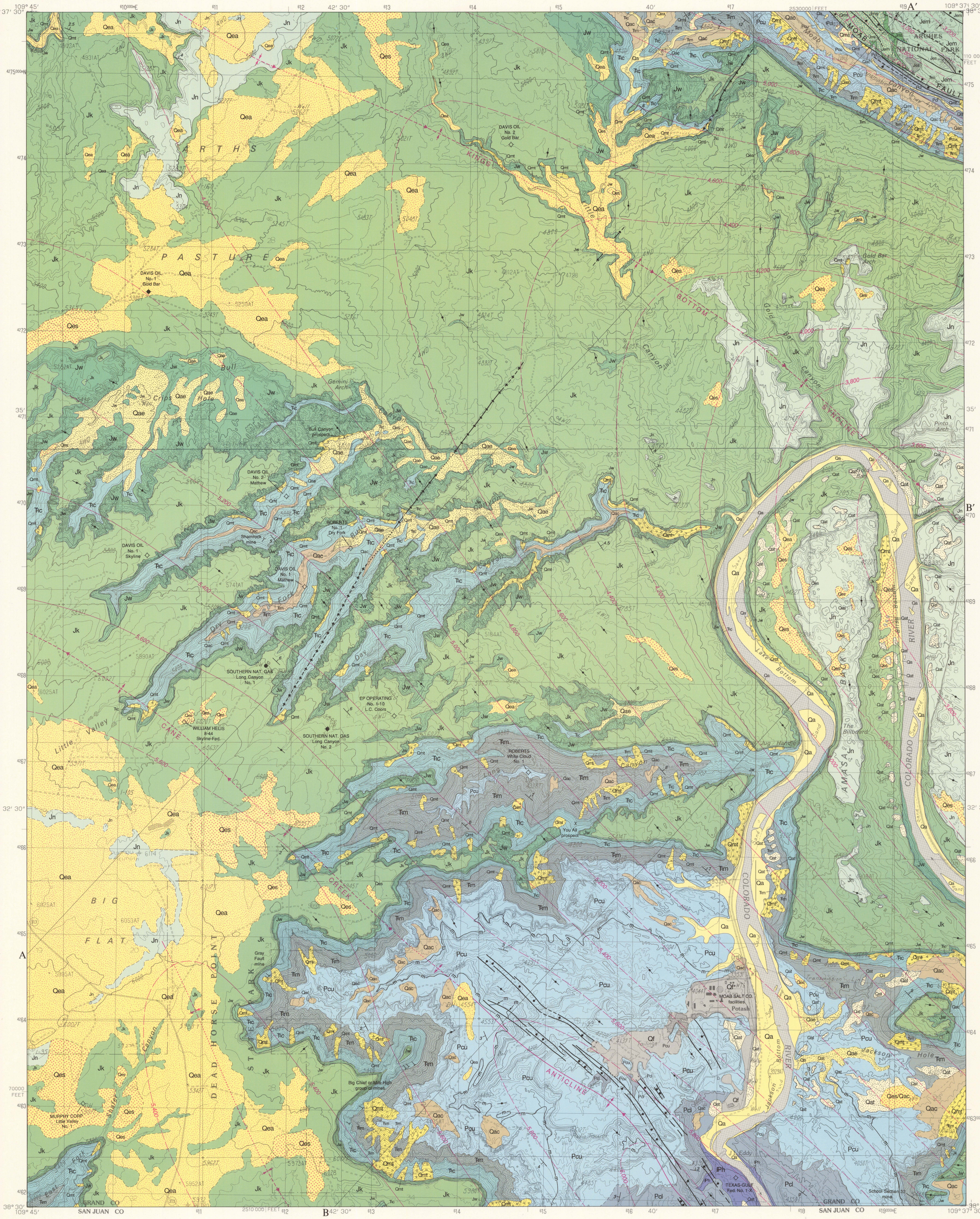
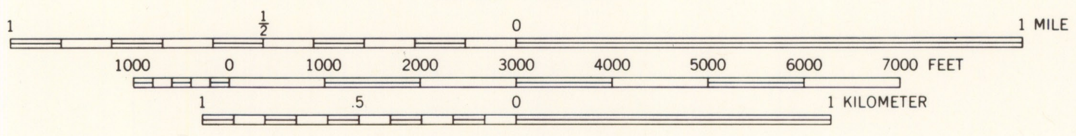


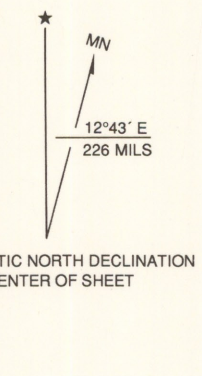
Base from U.S. Geological Survey,
Gold Bar Canyon 7.5′ provisional quadrangle, 1985

SCALE 1:24 000



CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

Field work: North half by H.H. Doelling, 1983 and 1991;
South half by J.S. Hand, 1988 and W.A. Yonkee, 1990-1991
Cartography by J.W. Parker



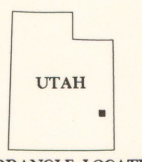
1994 MAGNETIC NORTH DECLINATION
AT CENTER OF SHEET

GEOLOGIC MAP OF THE GOLD BAR CANYON QUADRANGLE, GRAND COUNTY, UTAH

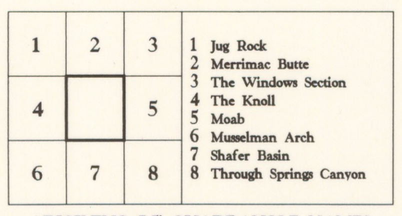
by

Hellmut H. Doelling, W. Adolf Yonkee,
and John S. Hand

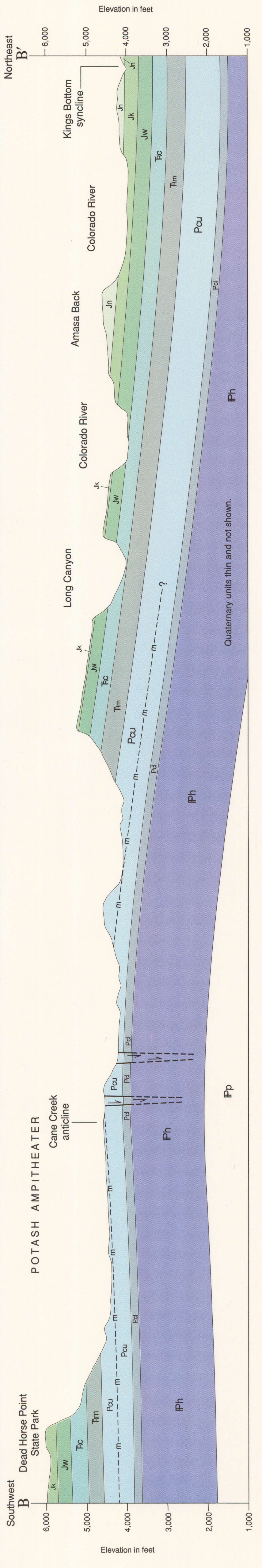
1994



QUADRANGLE LOCATION



ADJOINING 7.5′ QUADRANGLE NAMES



DESCRIPTION OF MAP UNITS

Qf Man-made fill-- *Tailings pond, railroad fill, foundation materials; mostly in the Potash area.*

Qa Alluvium-- *Clay, silt, sand, and gravel deposits along the more important active rivers, streams, and washes.*

Qat Terrace alluvium-- *Rounded, moderately sorted gravel (cobbles and pebbles) transported into the area by the Colorado River and deposited at several levels. Contains lenses of finer sand and silt, some of which contain flour gold and magnetite.*

Qac Mixed alluvial and colluvial deposits-- *Poorly sorted mixture of clay, silt, sand, pebbles, angular cobbles, and boulders; coarse clasts consist mostly of sandstone or sandy limestone.*

Qae Mixed alluvial and eolian deposits-- *Sand, silt, and gravel deposits of fluvial origin interspersed with sand and silt of eolian and colluvial origin deposited along less active washes.*

Qea Mixed eolian and alluvial deposits-- *Sand and silt of eolian origin interspersed with minor silt, sand, and gravel of fluvial origin that fills hollows and covers benches on sandstone deposits.*

Qes Dune and sheet sand deposits.

Qms Landslide deposits-- *Coherent to broken masses of bedrock units that have moved downslope.*

Qmt Talus deposits-- *Mostly rockfall blocks, boulders, and smaller angular fragments lying on slopes directly below the parent outcrop.*

Jms Salt Wash Member of Morrison Formation-- *Light-yellow-gray, cross-bedded, lenticular, fluvial sandstone interbedded with red and gray mudstone and siltstone; contains conglomeratic sandstone, gritstone, and thin limestone beds. Incomplete thickness is about 220 feet (67 m).*

Jmt Tidwell Member of Morrison Formation-- *Reddish, silty shale or mudstone with interbeds of fine-grained, yellow sandstone and gray concretions. Thickness 50-80 feet (15-24 m).*

Jem Moab Tongue of Entrada Sandstone-- *Light-yellow-gray, fine- to medium-grained, resistant, and massive sandstone, forming impressive bare rock exposures, usually jointed outcrops. Thickness 60-100 feet (18-30 m).*

Jes Slick Rock Member of Entrada Sandstone-- *Orange-red, fine-grained, massive, cliff-forming sandstone, poorly exposed on this quadrangle; outcrops expose only the upper 80 feet (24 m).*

NOTE: *The Moab fault cuts out outcrops of the lower part of the Slick Rock Member (Jes; 250 feet / 76 m thick) and all of the Dewey Bridge Member (Jed; 100 feet / 30 m thick) of the Entrada Sandstone, as well as the uppermost part of the Navajo Sandstone, on this quadrangle.*

Jn Navajo Sandstone-- *Massive, light-hued, eolian-cross-bedded sandstone; forms cliffs, rounded knolls, and domes; contains local thin, hard, carbonate beds; outcrops expose an incomplete 400-foot (122-m) section on this quadrangle.*

Jk Kayenta Formation-- *Reddish to lavender-gray sandstone with local white and dark-brown beds with thin interbeds of reddish siltstone and mudstone; ledgy, hard bench former; contains local micaceous sandstone and intraformational conglomerate beds. Thickness 220-340 feet (67-104 m).*

Jw Wingate Sandstone-- *Massive, fine-grained, well-sorted sandstone; forms orange to dark-brown prominent cliffs. Thickness 300-400 feet (91-122 m).*

TRc Chinle Formation-- *Reddish-brown, silty, fine-grained, fluvial sandstone interbedded with considerable mudstone and gritstone; locally contains thick-bedded, ledgy, hard sandstone that weathers black, known as the Black Ledge; base contains lenses of white, friable gritstone, mottled siltstone, and lenticular sandstone. Thickness 320-400 feet (98-122 m).*

TRm Moenkopi Formation-- *Brown, evenly bedded, sandy shale and micaceous, silty sandstone; forms smooth slopes interrupted by common thin ledges; commonly ripple-marked sandstone; in southern part of quadrangle a more resistant blocky-appearing unit, the Hoskinini Member, is found at the base. Thickness 300-520 feet (91-158 m).*

Pcu (m) Upper member of Cutler Formation-- *Red and maroon, mostly cliff-forming, arkosic sandstone and conglomerate with subordinate sandy mudstone; sandstones are both fluvial and eolian; limestone and calcareous mudstone marker (m) mapped in middle of unit in southern part of the quadrangle. Thickness 700-1,000 feet (213-305 m).*

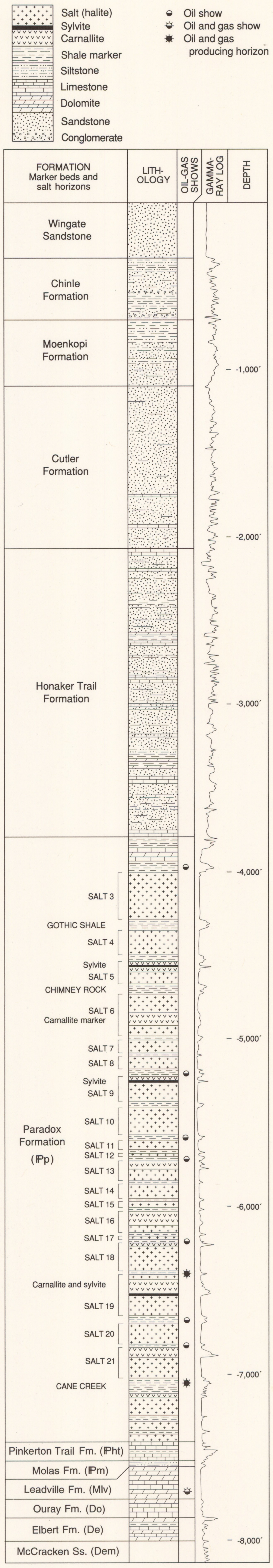
Pcl Lower member of Cutler Formation-- *Same as upper Cutler member, but contains a series of thin, fossiliferous, gray limestone beds or partings; represents part of former Elephant Canyon interval. Thickness 180-220 feet (55-67 m).*

IPh Honaker Trail Formation-- *Fossiliferous, gray limestone, cherty limestone, limy mudstone, yellow and purple siltstone, and thick arkosic sandstone, generally cliff-forming. Upper 240 feet (73 m) of 1,600-2,100 feet (488-640 m) exposed; remainder determined from well logs.*

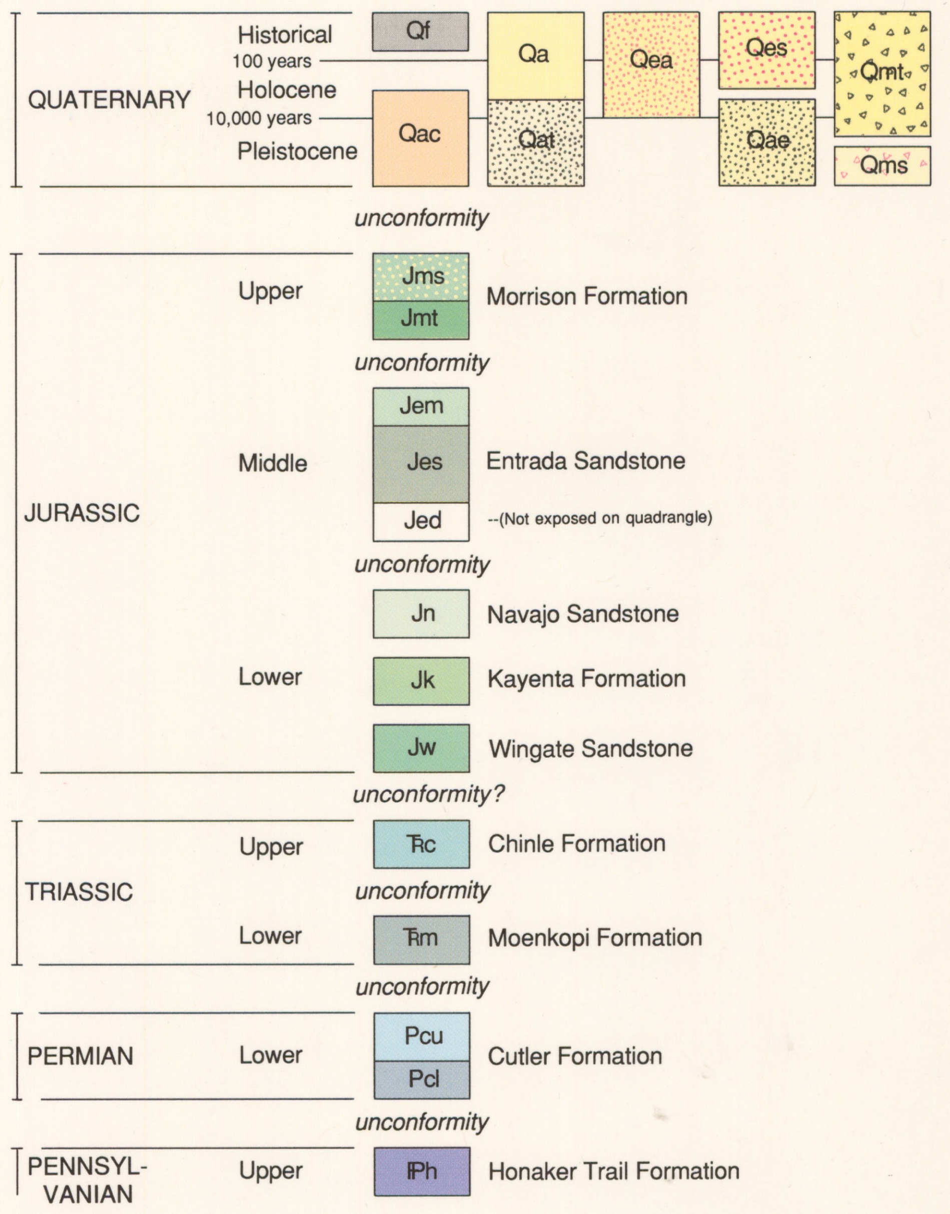
MAP SYMBOLS

- Contact-- *Dashed where location inferred.*
- Fault-- *Dashed where inferred, dotted where covered; bar and ball on downthrown side.*
- Fracture zone
- Trace of axial surface of fold-- *Arrows show direction of plunge; dashed where inferred, dotted where covered. Structure contours drawn on base of Wingate Sandstone. Contour interval, 200 feet (60 m).* --Anticline --Syncline
- 6 Strike and dip of bedding
- Strike of nearly vertical joints
- Oil and gas well
- Oil well
- Dry hole
- Shut-in oil well
- Uranium mine adit
- Prospect
- Qes/Qac Stacked map units-- *Indicate thin or discontinuous cover of one unit over another unit.*

LOG OF SOUTHERN NATURAL GAS
Long Canyon No. 1
Sec. 9, T. 26 S., R. 20 E.



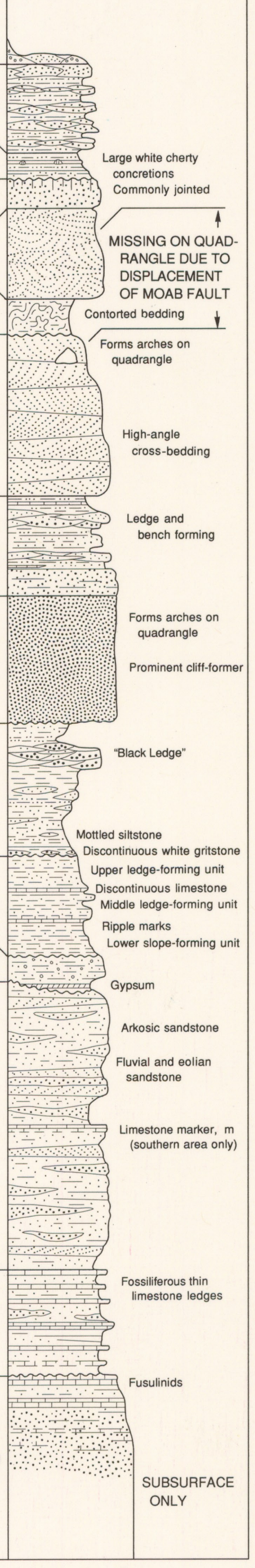
CORRELATION OF MAP UNITS



LITHOLOGIC COLUMN

PERIOD	SERIES	FORMATION and MEMBERS		SYMBOL	THICKNESS Feet (meters)
QUAT.		Surficial deposits		Q	0-50 (0-15)
JURASSIC	Upper	Morrison Formation	Salt Wash Member	Jms	200-250 (60-76)
			Tidwell Mbr.	Jmt	50-80 (15-25)
	Middle	Entrada Sandstone	Moab Mbr.	Jem	60-100 (18-30)
			Slick Rock Mbr.	Jes	250 (76)
			Dewey Bridge Member	Jed	100 (30)
	Lower	Glen Canyon Group	Navajo Sandstone	Jn	450-500 (137-152)
			Kayenta Formation	Jk	220-340 (67-104)
			Wingate Sandstone	Jw	300-400 (91-122)
TRIASSIC	Upper	Chinle Formation		TRc	320-400 (98-122)
	Lower	Moenkopi Formation	Upper member	TRm	240-440 (73-134)
			Hoskinnini Member		60-80 (18-25)
PERMIAN	Lower	Cutler Formation	Upper member	Pcu	700-1000 (213-305)
			Lower member	Pcl	180-220 (55-67)
PENNSYLVANIAN	Upper (Virgilian)	Honaker Trail Formation		IPh	1600-2100 (488-640)

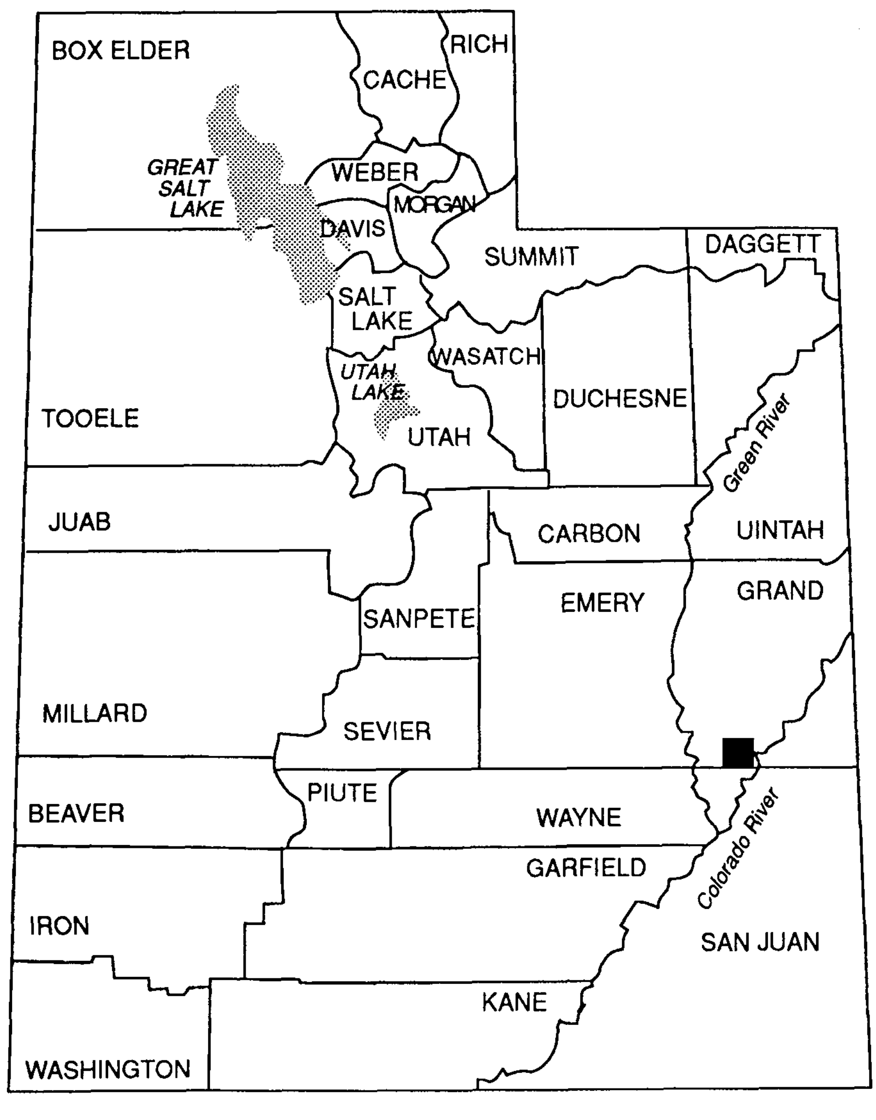
LITHOLOGY



GEOLOGIC MAP OF THE GOLD BAR CANYON QUADRANGLE, GRAND COUNTY, UTAH

by

Hellmut H. Doelling, W. Adolph Yonkee, and John S. Hand



MAP 155 **1994**
UTAH GEOLOGICAL SURVEY
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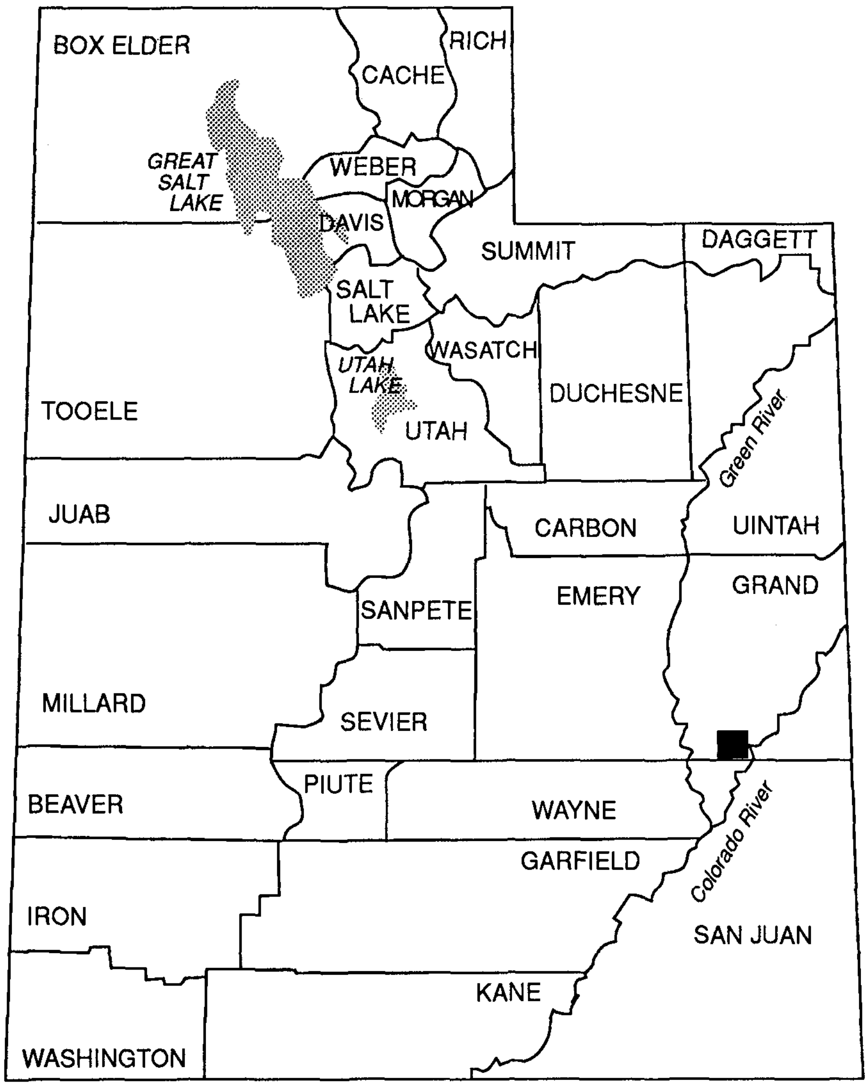
UTAH DEPARTMENT OF NATURAL RESOURCES

Doelling, Yonkee, and Hand
GEOLOGIC MAP OF THE GOLD BAR CANYON QUADRANGLE, GRAND COUNTY, UTAH
Utah Geological Survey Map 155

GEOLOGIC MAP OF THE GOLD BAR CANYON QUADRANGLE, GRAND COUNTY, UTAH

by
Hellmut H. Doelling, W. Adolph Yonkee, and John S. Hand



MAP 155 **1994**
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES

UTAH GEOLOGICAL SURVEY
2363 South Foothill Drive
Salt Lake City, Utah 84109-1491

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GEOLOGIC MAP OF THE GOLD BAR CANYON QUADRANGLE, GRAND COUNTY, UTAH

by
Hellmut H. Doelling[1], W. Adolph Yonkee[2], and John S. Hand[3]

ABSTRACT

The Gold Bar Canyon quadrangle, with its astounding canyonland overlooks, deeply entrenched Colorado River meanders, arches, and rock sculpture, is a favorite of recreationists, especially bicyclers, campers, and rafters. Colorful strata are well exposed on the canyon walls in alternating slopes and cliffs. Oil and gas, potash and salt, sand and gravel, uranium, and gold are or have been produced in the quadrangle.

The Gold Bar Canyon quadrangle is located 5 miles (8 km) west of Moab in Grand County, Utah, mostly on the west side of the Colorado River. Typical canyonlands topography and structure exists, with bedrock units warped into northwest-trending anticlines and synclines. The Moab fault, with about 3,000 feet (900 m) of displacement, cuts the formations in the northeast corner of the quadrangle. Numerous joints trend northwesterly and northerly across the area.

Exposed bedrock units range from Pennsylvanian to Jurassic in age, with overlying scattered Quaternary sediments. In ascending order the units include the Pennsylvanian Honaker Trail Formation (250+ feet [76+ m]); the Permian Cutler Formation (880-1,220 feet [268-372 m]); the Triassic Moenkopi (240-440 feet [73-134 m]) and Chinle (320-400 feet [98-122 m]) Formations; the Lower Jurassic Wingate (300-400 feet [91-122 m]), Kayenta (220-340 feet [67-104 m]), and Navajo (400+ feet [122+ m]) Formations; the Middle Jurassic Entrada Sandstone with the Dewey Bridge Member (100 feet [30 m]), Slick Rock Member (250 feet [76 m]), and Moab Member or Tongue (60-100 feet [18-30 m]); and the Upper Jurassic Morrison Formation with the Tidwell Member (50-80 feet [15-24 m]) and the Salt Wash Member (200-250 feet [61-76 m]).

Surficial units include alluvium, terrace alluvium, mixed alluvial and colluvial deposits, mixed alluvial and eolian deposits, mixed eolian and alluvial deposits, dune and sheet sand deposits, landslide deposits, talus deposits, and man-made fill deposits.

Significant geologic hazards identified on the quadrangle include low-level seismicity related to solution mining, rockfall, and periodic flooding. A few older landslides were mapped, sand was locally noted to blow across and cover dirt roads, and small areas of shrinking or expanding soils were noted overlying the clay-bearing Chinle and Morrison Formations.

INTRODUCTION

Gold Bar Canyon empties into the Colorado River near a prominent bar of gold-bearing sand and gravel for which the quadrangle is named. The Gold Bar Canyon quadrangle is also significant for other mineral resources including oil and gas, potash fertilizer and other salts, sand and gravel, and uranium. The quadrangle is not only important because of its minerals, but because of its scenic resources as well.

The Colorado River and its tributaries have incised and carved the rock strata to form deep canyons, arches, vertical cliffs, and a myriad of sculpted forms to inspire the imagination.

1. Utah Geological Survey, 2363 Foothill Drive, SLC, Utah 84109
2. Currently at Weber State Universtity, Ogden, Utah 84408
3. Currently at Celsius, Las Vegas, Nevada

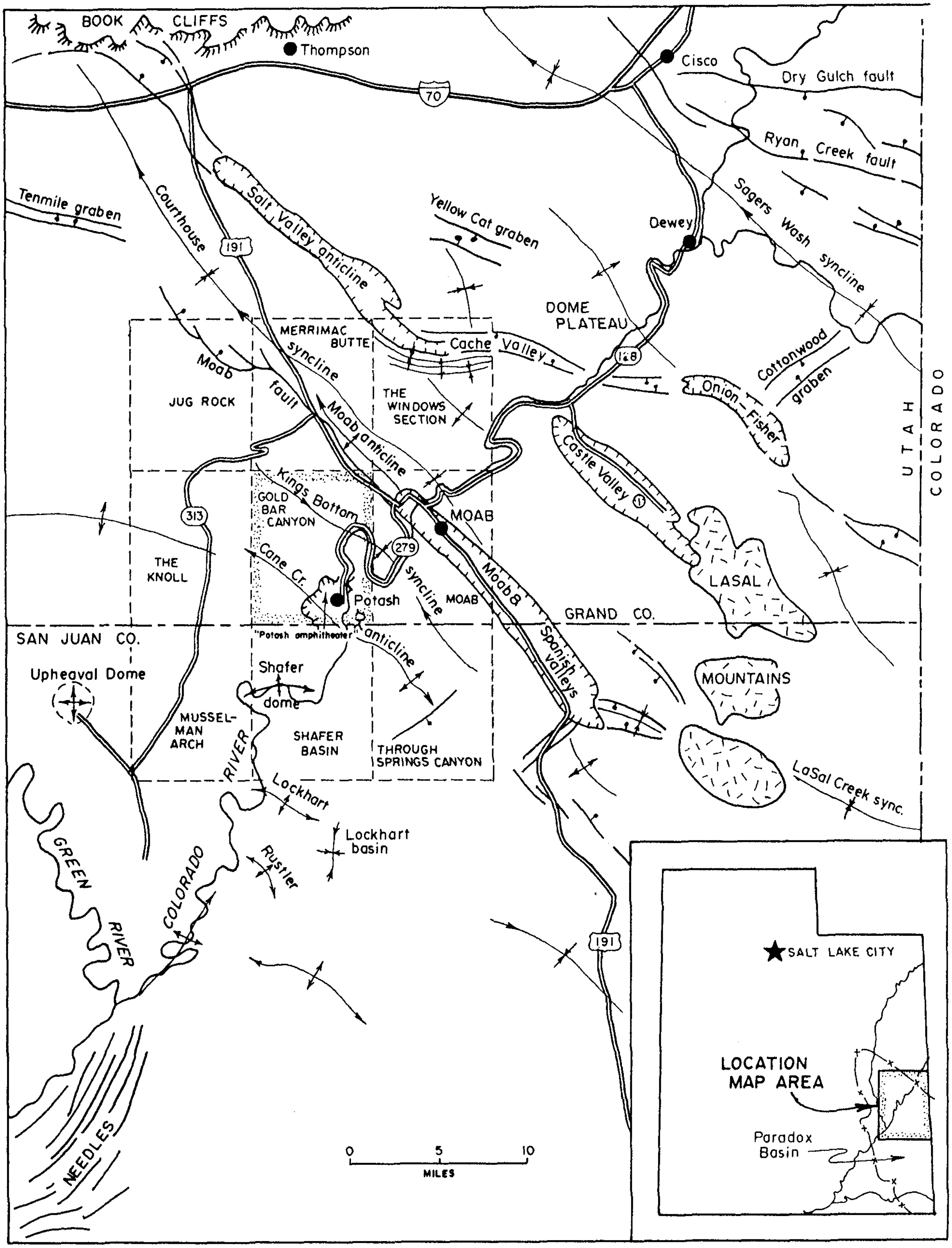


Figure 1. Map showing structural and geographic features in eastern Utah (important features and places are labeled) in the vicinity of the Gold Bar Canyon 7.5 minute quadrangle. The Gold Bar Canyon quadrangle is bounded on the north by the Jug Rock, Merrimac Butte, and The Windows Section quadrangles, on the west by The Knoll quadrangle, on the east by the Moab quadrangle, and on the south by the Musselman Arch, Shafer Basin, and Through Springs Canyon quadrangles.

The quadrangle is found in the midst of the Colorado Plateau (figure 1), a vast region of mostly flat-lying colorful rock centered about the point where the four corners of Utah, Colorado, Arizona, and New Mexico join together. The alternating colors of the rock strata are especially well displayed on canyon walls of the quadrangle like the side of an enormous "layer cake."

The Gold Bar Canyon quadrangle is in eastern Utah and its eastern margin lies about 5 miles (8 km) west of the Grand County seat of Moab. The dominant landform is a gently warped tableland deeply incised by the Colorado River and its tributaries. The Colorado River traverses the southeast part of the quadrangle in a large meander loop. Altitudes range from about 3,920 feet (1,195 m) along the Colorado River to 6,114 feet (1,864 m) on a small prominence at Big Flat. The quadrangle is in the Paradox basin (figure 1). The earth's crust, in what is now southeastern Utah and northwestern Colorado, gradually subsided along northwest-trending faults 320 to 230 million years ago and thick layers of salt and other rock types filled the developing basin. The salt, being less dense and stable than the rocks deposited over it, migrated to weakened crustal areas (fault zones) where it thickened and displaced the other rock types. Abnormal thicknesses of rock strata near the weakened areas and later collapse of rocks over dissolving salt provided a geologic "paradox" for early geologists.

Principal access roads are shown on figure 1. Several four-wheel drive roads (not shown on figure 1) provide access to other parts of the warped tableland. A railroad spur parallels Utah Highway 179 to the Moab Salt Company's potash mine headquartered in the SW ¼, section 24, T. 26 S., R. 20 E.

All streams on the quadrangle are ephemeral except for the Colorado River. Most of the washes are prone to flooding, especially after severe summer thunderstorms. Flooding damages roads, trails, and artificial catchment basins. Crude oil production, potash and salt mining, cattle grazing, and recreation comprise the present land use. Recreationists, especially bicyclers, regularly visit the quadrangle's astounding overlooks, scenery, and arches, over four-wheel drive roads. There are no permanent settlements or habitations in the quadrangle (1993).

Numerous geologic reports, mentioned later in the section on economic geology, have been issued concerning the potash, uranium, and petroleum possibilities of the quadrangle and surrounding area. Previous geologic maps that cover or partly cover the quadrangle include those of Baker (1933), McKnight (1940), Sable (1956), Williams (1964), Huntoon and others (1982), and Doelling (1985). Doelling was responsible for mapping the northern half of the quadrangle for this study. Yonkee, building on preliminary work by Hand, mapped the remainder of the quadrangle and reported on the subsurface rocks and petroleum.

STRATIGRAPHY

Consolidated sedimentary rocks exposed at the surface in the quadrangle include strata of Upper Pennsylvanian, Permian, Triassic, and Jurassic age (plate 1). Above the Precambrian basement, Cambrian, Devonian, Mississippian, and the remainder of the Pennsylvanian rocks are present in the subsurface (plate 2).

Subsurface Rocks

Cambrian to Pennsylvanian rocks below the upper part of the Pennsylvanian Honaker Trail Formation have been identified in drill holes in the quadrangle but are not exposed at the surface (see figure 9, petroleum section). Formations encountered in drill holes in ascending order are the Lynch Dolomite, Elbert Formation, Ouray Limestone, Leadville Formation, Molas Formation, and the Hermosa Group consisting of the Pinkerton Trail, Paradox, and Honaker Trail Formations (see log of Southern Natural Gas No. 1 Long Canyon well, plate 2).

The Cambrian is represented in the Paradox basin area by the Ignacio Formation, Bright Angel Shale, Muav Limestone, and Lynch Dolomite. Drilling in the quadrangle has only extended into the upper Lynch Dolomite, but the total thickness of Cambrian rocks is assumed to be about 1,000 feet (305 m)(Baars, 1958). The Devonian Elbert Formation paraconformably overlies the Lynch Dolomite.

In the Paradox basin the Devonian is represented by the Aneth, Elbert, and Ouray Formations, but the Aneth is missing in the quadrangle area (Parker and Roberts, 1963). The Elbert Formation is composed of a lower McCracken Sandstone Member and an upper unnamed member. The McCracken, less than 50 feet (15 m) thick, consists of white and light-gray, very fine-grained, quartzose sandstone interbedded with sandy dolomite. The upper member of the Elbert Formation consists of sandy limestone, dolomite, and minor shale. Thickness of the Elbert Formation encountered in two drill holes in the quadrangle ranges from 240 to 260 feet (73-79 m) and 200 to 250 feet (61-76 m) in drill holes near the quadrangle (Parker and Roberts, 1963).

The Devonian to Early Mississippian Ouray Limestone consists of light- to medium-gray, finely crystalline dolomite and limestone, with very widely spaced, thin stringers of greenish shale (Parker and Roberts, 1963). The formation thickness is about 125 feet (38 m) in the Gold Bar Canyon quadrangle area. Deposition may have been continuous or interrupted across the Devonian-Mississippian boundary.

The Mississippian Leadville Formation consists of limestone, dolomite, and widely spaced chert pods (Wengerd and Matheny, 1958). The limestone is finely crystalline and light gray with local greenish and brownish tinges. Dolomite is irregularly interbedded with the limestone. The thickness of the Leadville ranges from 210 to 580 feet (64-177 m) in quadrangle drill holes. The contact with the overlying Pennsylvanian Molas Formation is an unconformity that represents a 25-million-year period of subaerial erosion (Wengerd and Matheny, 1958).

Pennsylvanian rocks are divided into the Molas, Pinkerton Trail, Paradox, and Honaker Trail Formations (ascending order). The Molas Formation includes a basal paleosol and paleokarst consisting of limestone clasts in a red, muddy, siltstone matrix (Wengerd and Matheny, 1958). The lower part of the formation fills depressions on a karst topography of the Leadville Formation. The upper part of the Molas is reddish-brown to variegated siltstone, red shale, calcareous sandstone, and lenses of gray to reddish-yellow limestone deposited during marine transgressions (Wengerd and Matheny, 1958). The thickness ranges from 0 to 50 feet (0-15 m) and is disconformably overlain by the Pinkerton Trail Formation of the Hermosa Group.

The remaining Pennsylvanian formations belong to the Hermosa Group. The Pinkerton Trail Formation consists of interbedded limestone, dolomite, silty carbonaceous shale, calcareous siltstone, and anhydrite (Wengerd and Matheny, 1958). Limestone and dolomite are finely crystalline and some beds are argillaceous. The formation marks a transition from open to restricted marine conditions. The thickness of the Pinkerton Trail varies from 100 to 250 feet (30-76 m) and its upper contact is gradational with the Paradox Formation.

The Paradox Formation consists of cyclically interbedded evaporite and clastic sequences deposited under restricted marine conditions within a subsiding basin. Twenty-nine cycles of paired evaporite and clastic sequences have been identified and have been numbered sequentially from youngest (1) to oldest (29) by Hite (1960, 1961). Not all of these cycles are preserved in individual drill holes in the Gold Bar Canyon quadrangle. Evaporite sequences consist mostly of finely crystalline, finely laminated halite, with widely spaced undulatory anhydrite bands as much as 4 inches (10 cm) thick. Colors range from gray to grayish brown to reddish brown. Sylvite and carnallite are interbedded with halite; cycles 5, 9, and 19 contain particularly thick or pure salt intervals (plate 2). Thicknesses of individual evaporite sequences encountered in drill holes range from 10 to 500 feet (3-152 m), but deformation may have modified the original stratigraphic thicknesses, especially near salt anticlines. Clastic sequences consist of interbedded shale, siltstone, limestone, dolomite, and anhydrite. Shale and siltstone are mostly black, argillaceous, and variably carbonaceous. Limestone and dolomite range from dark gray to gray and are micritic. Thicknesses of individual clastic sequences range from 10 to 200 feet (3-61 m).

The upper contact of the Paradox Formation was placed at a distinctive peak in gamma ray intensity observed in logs for drill holes in the Gold Bar Canyon quadrangle (plate 2). This peak corresponds to a marker sequence of interbedded anhydrite and calcareous siltstone above salt 2. However, only limestone and dolomite occur in the interval corresponding to salt 2 in some drill holes, and salt 1 occurs above the marker sequence in others. Total apparent thickness of the formation cut by drill holes ranges from 3,320 to 4,530 feet (1,012-1,381 m) in the quadrangle, but is greater than 7,100 feet (2,164 m) in the Delhi Oil Utah No. 2 well immediately north of the quadrangle along the Moab anticline. The formation is 5,240 feet (1,597 m) thick in the Texas Gulf Federal No. 1-X well immediately south of the quadrangle along the Cane Creek anticline (see figure 9, petroleum section). Hintze (1988, p. 35) indicated that the Honaker Trail Formation unconformably overlies the Paradox in the Canyonlands-Moab area.

The Honaker Trail Formation consists of interbedded sandstone, siltstone, limestone, and dolomite. Most sandstone beds are very light gray to yellowish gray, micaceous, very fine to fine grained, and highly calcareous. Sandstone beds also contain some coarse grains of quartz and limited amounts of feldspar. A few sandstone beds are reddish, arkosic, and fine to medium grained. Well-sorted, quartzose sandstone with siliceous cement is rare. Siltstone is mostly yellowish to greenish gray, highly micaceous, and variably calcareous. Limestone is gray to very light gray, finely crystalline, and generally argillaceous. Limestone beds increase in abundance and thickness within the lower part of the formation. The total thickness of the formation in drill holes varies from 1,600 to 2,100 feet (488-640 m), but the contact with the overlying Permian Cutler Formation is difficult to define from drill-hole data.

Pennsylvanian Rocks

Honaker Trail Formation (IPh)

Surface exposures of Pennsylvanian rocks in the Gold Bar Canyon quadrangle are limited to the upper 240 feet (73 m) of the Honaker Trail Formation (IP h), cropping out as ledgy cliffs at the southern end of the quadrangle along the Colorado River. The outcrop consists of interbedded sandstone, limestone, and siltstone, similar lithologically to the rest of the formation observed in drill-hole cuttings. Sandstone is mostly yellowish gray to gray, very fine to fine grained, well to moderately sorted, micaceous, and calcareous. Some layers display low- to high-angle cross-bedding. Limestone interbeds are gray to very light gray, variably argillaceous, and range from 1 to 10 feet (0.3-3 m) thick. Some of the limestone beds are fossiliferous, containing crinoid debris, brachiopods, bryozoa, gastropods, and rare trilobites. Types of limestone include biomicrite, biosparite, sandy sparite, and micrite. The siltstone is micaceous, greenish to yellowish gray, and displays widespread bioturbation and local ripple cross-stratification. Some beds contain plant remains of Late Pennsylvanian age (Tidwell and others, 1972). The Honaker Trail Formation exposed within the quadrangle records the complex interaction of shallow marine, beach, lagoon, and delta depositional environments (Melton, 1972).

The upper contact of the formation with the overlying Cutler Formation is placed above a limestone ledge that contains a distinctive fusulinid coquina. Fusulinids from the layer include, *Triticites coronadoensis*, *Triticites* sp., *Triticites* aff. *T. bungerensis*, and *?Triticites whetstonensis*, and indicate a Virgilian (uppermost Pennsylvanian) age for the upper part of the formation exposed on the quadrangle (written communication, Fusulinid Biostratigraphy, Inc., 1991). The samples submitted for identification also contained various combinations of smaller foraminifera, particularly bradyinids and paleotextularids with lesser occurrences of tetrataxids and globivalvulinids. The upper part of the Honaker Trail Formation, as here defined, was previously included in the Permian Elephant Canyon Formation (Baars, 1975) and within the upper member of the Hermosa Formation (Loope and others, 1990). The Pennsylvanian and Permian contact may be a paraconformity.

Permian Rocks

Cutler Formation

The Cutler Formation is the only Permian unit in the Gold Bar Canyon quadrangle. This formation consists of a complex sequence of intertonguing fluvial and eolian red beds, coastal deposits, and shallow marine strata that were deposited in the Paradox basin southwest of the Uncompahgre highland.

Cutler Formation outcrops in the quadrangle display subvertical cliffs to broad areas of alternating bedrock ledges and covered slopes. The formation crops out in the Potash amphitheater (figure 1 and plate 1) and along Moab Canyon. The unit can be divided into two informal members, a lower member (Pcl), distinguished by the presence of limestone beds, and an upper member (Pcu).

Lower member (Pcl): The lower member of the Cutler Formation consists of interbedded arkosic sandstone, quartzose to subarkosic sandstone, micaceous siltstone, and limestone. Individual limestone beds are mostly less than 6 feet (1.8 m) thick and consist of biomicrite, silty micrite, and biosparite. The number of limestone beds decreases northeastward from seven in the Potash amphitheater to three thinner ones along Moab Canyon. Limestone beds are generally fossiliferous, with brachiopods, bryozoa, gastropods, crinoid debris, and rare cephalopods and trilobites. The arkosic sandstone is very fine to coarse grained, well to poorly sorted, and generally micaceous. Many beds of arkosic sandstone display trough cross-bedding and cut-and-fill structures with basal conglomerates, indicating fluvial deposition. Conglomerate lenses contain granitic clasts as much as 6 inches (15 cm) in diameter, although most are less than 2 inches (5 cm). Colors include reddish purple and grayish red. Subarkosic to quartzose sandstone is composed mostly of fine, subrounded, well-sorted grains, and is generally micaceous. Many of these beds display tabular planar cross-beds and laminations with inverse graded bedding, indicating deposition by eolian processes (Campbell, 1979). Colors include orange and reddish orange, which contrast with the purple-hued fluvial sandstones. Some eolian beds display mottling and burrowing along their upper contacts.

Total thickness of the lower member ranges from 220 feet (67 m) in the Potash amphitheater to 180 feet (55 m) along Moab Canyon. Except for the limestone beds, the lower member is lithologically similar to the upper member. Strata included in the lower member of the Cutler Formation were previously included in the Elephant Canyon Formation (Huntoon and others, 1982). The lower member is conformable with the upper member and the contact is placed at the upper contact of the highest prominent or continuous limestone ledge in the Cutler Formation.

Upper member (Pcu): The upper member of the Cutler Formation consists of arkosic and conglomeratic sandstone, quartzose to subarkosic sandstone, and lesser amounts of siltstone and sandy mudstone. Arkosic sandstone varies from very fine to coarse grained, poorly to well sorted, and contains abundant mica and feldspar grains. Lenses of conglomeratic sandstone contain granitic pebbles, mostly 0.4 to 2 inches (1-5 cm), but locally as much as 6 inches (15 cm), in diameter. Trough cross-bedding and channels are widespread. Subarkosic to quartzose sandstone is mostly fine grained, well sorted, generally micaceous, and displays tabular planar cross-bedding and horizontal bedding. Inverse grading and coarse lag grains occur in some beds. Colors range from reddish purple for arkosic layers to reddish orange for subarkosic layers. Siltstone is mostly orange brown, micaceous, and locally bioturbated. Mudstone layers range from dark red, to purple, to green. The arkosic sandstone was probably deposited in meandering or braided streams, the mudstone and siltstone were probably deposited as overbank deposits, and the subarkosic sandstone was probably deposited in coastal dune systems (Campbell, 1979).

A marker bed of limestone in the middle of the upper member is mapped in the Potash amphitheater west of the Colorado River by a line marked with "m" on plate 1. The bed is 1- to 4-feet (0.3-1.2-m) thick and consists of gray micrite and biomicrite with crinoid debris, brachiopods, and rare cephalopods. East of the Colorado River a 1- to 5-foot (0.3-1.5-m) sequence of calcareous siltstone, gray mudstone, and discontinuous limestone is mapped. This sequence may correlate with the limestone marker bed, or with a mudstone layer that is stratigraphically 15 feet (4.6 m) below the limestone bed.

Thickness of the upper member ranges from 700 to 1,000 feet (213-305 m) in the quadrangle. Total thickness of the Cutler Formation in surface exposures or drill holes ranges from 920 to 1,350 feet (280-411 m). The thickness of the Cutler at the north edge of the quadrangle along Moab Canyon is 1,100 feet (335 m), but decreases to less than 400 feet (122 m) opposite the Arches National Park visitor center in the Moab quadrangle (Doelling, 1988, p. 15). The upper contact of the Cutler Formation with the Triassic Moenkopi Formation is sharp, marked by local scouring and channeling, and is unconformable. Local relief from channeling is less than 10 feet (3 m), but total relief on the unconformity is estimated at about 100 feet (30 m).

Triassic Rocks

Triassic strata in the Gold Bar Canyon quadrangle include the Moenkopi (₮m) and Chinle (₮c) Formations (figure 2). The formations were deposited in coastal and fluvial environments that were locally modified by growth of salt anticlines. Cumulative thickness of the formations determined from surface exposures and drill holes ranges from 620 to 920 feet (189-280 m), but may vary greatly near salt anticlines.

Moenkopi Fomation (₮m)

The Moenkopi Formation forms scree and mud-covered slopes with numerous ledges. The formation crops out along Long Canyon, in the Potash amphitheater, and on the south flank of Moab Canyon. A thin slice is also present between two branches of the Moab fault zone in Moab Canyon.

The formation consists of interbedded siltstone, sandy siltstone, and very fine-grained sandstone, with lesser amounts of mudstone, gypsum, and rare limestone. Siltstone is micaceous, well bedded, and displays widespread ripple cross-stratification. Sandstone is mostly very fine to fine grained, well to moderately sorted, quartzose to subarkosic, and variably micaceous. The formation has an overall reddish-brown to reddish-orange color, commonly described as "chocolate brown" in appearance (Doelling, 1988, p. 20).

The Moenkopi consists of the Hoskinini Member and an upper member. In detail, the upper member consists of a lower slope-forming unit, middle ledge-forming unit, and an upper

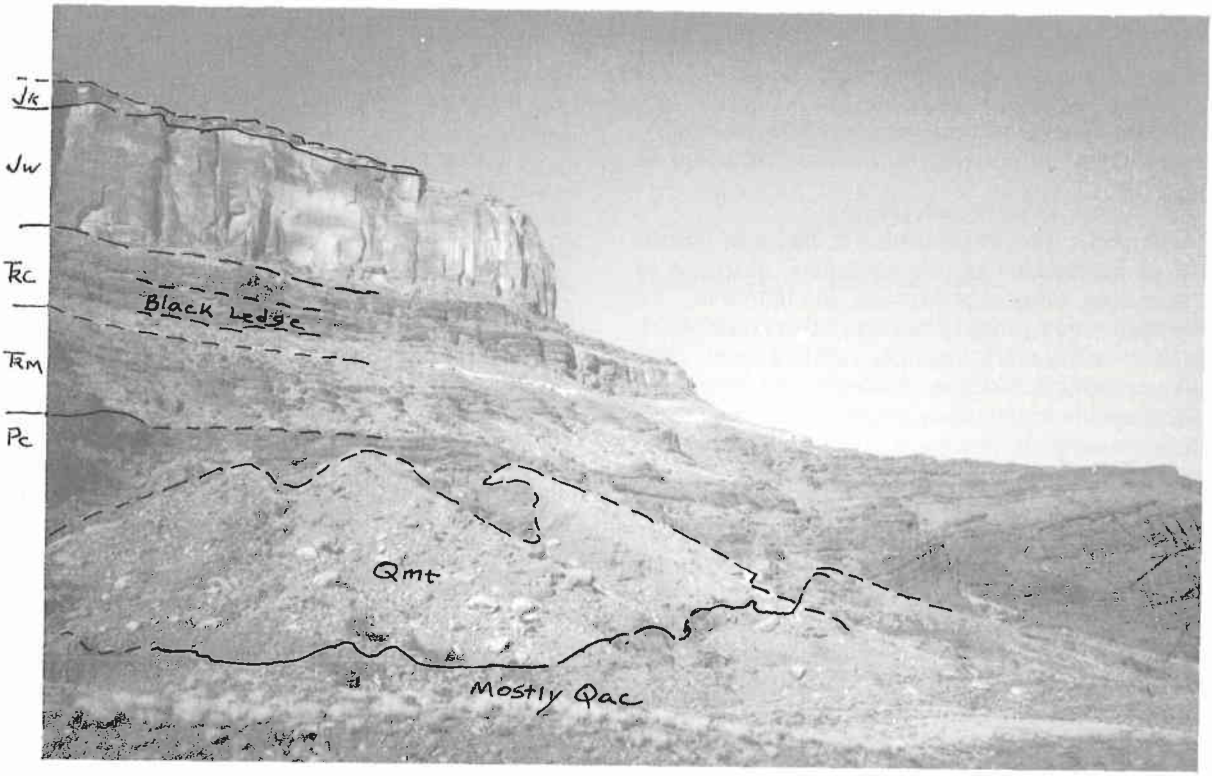


Figure 2. *Cliff on southwest side of Moab Canyon south of Little Canyon. Exposed units from top down include the Jurassic Kayenta Formation and Wingate Sandstone (Jk and Jw), the Triassic Chinle and Moenkopi Formations, (Ꞧc) and (Ꞧm), and the Permian Cutler Formation (Pc). Quaternary talus (Qmt) and mixed alluvial and colluvial deposits (Qac) are present in the foreground.*

slope-forming unit (Stewart and others, 1972 b). Members and units were not differentiated on the map (plate 1) because the contacts are gradational and the individual members are not thick. Siltstone and fine-grained sandstone were deposited in low-gradient fluvial, coastal plain, and marginal marine environments. The presence of gypsum beds may record restricted marine conditions.

The Hoskinini Member consists mostly of fine-grained, poorly sorted, micaceous to subarkosic sandstone. The sandstone contains dispersed, well-rounded, medium to coarse grains of quartz, is poorly bedded, and displays irregular to wavy lamination. A thin (less than 3-feet [0.9-m] thick) bed of gypsum occurs near the base of the member in Long Canyon.

The lower slope-forming unit of the upper member consists of thin-bedded, reddish-orange siltstone with widely spaced 1- to 3-foot (0.3-0.9-m) thick sandstone ledges. Ripple cross-stratification is particularly widespread. The middle ledge-forming unit consists of thin- to medium-bedded siltstone with numerous sandstone beds. Sandstone beds are 1 to 10 feet (0.1-3 m) thick and display low-angle cross-beds. Locally, a 1- to 3-foot (0.3-0.9-m) thick layer of yellowish-gray, micritic limestone and calcareous siltstone marks the base of this member and may correlate with the Sinbad Limestone Member of the Moenkopi Formation exposed in the San Rafael Swell. The upper slope-forming unit consists of homogeneous, grayish-red to pale-reddish-brown siltstone, with widely spaced, thin (less than 3-feet [0.9-m] thick) sandstone ledges. Siltstone displays horizontal and ripple cross-lamination, and is cut by thin gypsum veins.

Total thickness of the Moenkopi Formation ranges from about 300 to 520 feet (91-158 m) in the Gold Bar Canyon quadrangle. The Hoskinini Member ranges in thickness from 60 to 80 feet (18-25 m), the lower slope-forming unit of the upper member ranges from 100 to 160 feet (30-49 m), the middle ledge-forming unit ranges in thickness from 60 to 100 feet (18-30 m), and the upper slope-forming unit ranges from 60 to 120 feet (18-37 m). The contact with the overlying Chinle Formation appears sharp and unconformable, but the contact is generally poorly exposed. The contact is placed at the base of a distinctive white to mottled gritstone where present, or at a color change from the orangish-red siltstone of the Moenkopi Formation to the grayish-red mudstone and siltstone of the Chinle Formation.

Chinle Formaion (Ꞧc)

The Chinle Formation forms ledgy slopes partially covered with rubble along Bull Fork, Dry Fork, Little, and Long Canyons, along the edges of the Potash amphitheater, and on the southwest flank of Moab Canyon. The outcrop colors are reddish to grayish red.

The formation consists of complex arrangements of sandstone beds and lenses, pebble conglomerate lenses, siltstone, mudstone, and rare limestone. White to variegated gritstone locally marks the base of the formation. The grit is poorly sorted, massive, and contains rounded to angular, coarse to pebble-sized grains of quartz. Sandstone varies from very fine to coarse grained, moderately to well sorted, and is quartzose to slightly micaceous. Colors of sandstone layers include reddish brown, tan, and grayish red. Primary sedimentary structures include low-angle cross-stratification, horizontal stratification, asymmetric ripples, and channeling. Soft-sediment deformation, including disharmonic folds and low-angle detachments, is widespread especially below thick sandstone ledges. Folds are bounded by detachment and erosional surfaces. Pebble and intraformational conglomerate occur as lenses and in scour channels concentrated in the lower parts of sandstone beds. Clast types include chert, sandstone, and siltstone, and sizes are mostly 2 to 5 inches (5-10 cm) but can be as large as 20 inches (50 cm). Quartzose and micaceous siltstone occurs adjacent to sandstone lenses and displays low-angle cross-bedding and ripple lamination. Mudstone is grayish red to variegated, bentonitic, and generally poorly exposed. Mudstone is more abundant in the lower part of the formation. Sandstone lenses in the upper third of the formation locally coalesce to form a thick, sandstone-rich ledge, informally known as the Black Ledge (Stewart and others, 1972a) (figure 2). Interbedded orange-red siltstone and sandstone in the uppermost part of the formation are informally referred to as the Hite beds. The formation consists of stream, floodplain, and lacustrine deposits.

The thickness of the Chinle Formation ranges from 320 to 400 feet (98-122 m). The contact with the overlying Wingate Sandstone is sharp and accordant in most areas, and is commonly placed below the first appearance of the well-sorted, massive sandstone typical of the Wingate. Thick beds of orange, well-sorted sandstone, however, increase in abundance and thickness in the upper 10 to 50 feet (3-15 m) of the Chinle Formation, and thin siltstone partings locally occur in the lower part of the Wingate Sandstone. No regional channeling or angular unconformity is apparent in the quadrangle, but Hintze (1988, p. 42) shows the contact as unconformable. Locally, soft-sediment deformation in the Chinle Formation directly below the contact gives the impression of angularity.

Jurassic Rocks

Jurassic strata in the Gold Bar Canyon quadrangle include (ascending) the Wingate Sandstone, Kayenta Formation, Navajo Sandstone, Entrada Sandstone, and Morrison Formation. Cumulatively these formation are 1,660 to 1,930 feet (506-588 m) thick and are dominated by sandstone. Jurassic rocks crop out over much of the warped tableland and along most canyon walls. The lower three formations are members of the Glen Canyon Group and are shown as Triassic in age on past geologic maps (Williams, 1964; Doelling, 1985). The age of the Glen Canyon Group has been reevaluated and is presently thought to be Lower Jurassic (Pipiringos and O'Sullivan, 1978; Peterson and Pipiringos, 1979; and Imlay, 1980).

Wingate Sandstone (Jw)

The Wingate Sandstone, the lower formation of the Glen Canyon Group, forms prominent cliffs on the south flank of Moab Canyon (figure 2), in Bull, Dry Fork Bull, Day, and Long Canyons, along a portion of the canyon of the Colorado River, and around the Potash amphitheater. The Wingate forms reddish-brown, nearly vertical cliffs streaked and stained with desert varnish. The Chinle-Moenkopi slope below the cliff is generally littered with large blocks of the Wingate Sandstone.

Lithology of the Wingate Sandstone is nearly uniform from top to bottom. Partings or bedding planes are rare in this formation, which is commonly described as one massive unit. The Wingate consists mostly of light-orange-brown, moderate-orange-pink, moderate-reddish-orange, pinkish-gray, or pale reddish-brown, fine-grained, well-sorted, cross-bedded sandstone. A cap of somewhat lighter sandstone, as much as 10 feet (3 m) thick, forms the top of the unit in the northern part of the quadrangle. The rock is usually well cemented and well indurated; weathered exposures are nearly smooth. The cementation is partly siliceous and partly calcareous. The Wingate is an eolian deposit as indicated by high-angle cross beds.

The Wingate Sandstone is 300 to 400 feet (91-122 m) thick in the quadrangle. The contact of the Wingate with the overlying Kayenta Formation is generally sharp and conformable, but difficult to identify. The lower Kayenta sandstones are thick bedded to massive, and are commonly the same color as the underlying Wingate. Generally, the Kayenta is slightly more reddish or exhibits purplish colors. Identification of the lighter cap of the Wingate, where present, helps in placing the contact. Elsewhere the line is drawn at the horizon where the vertical cliff ends and is replaced by thick ledges.

Kayenta Formation (Jk)

The Kayenta Formation caps much of the warped tableland in the Gold Bar Canyon quadrangle (figure 2). Much of the formation is extremely resistant to erosion and generally forms ledgy bare-rock surfaces, although unconsolidated sand has been deposited on it locally.

The Kayenta Formation consists mostly of stream-deposited sandstone lenses, with subordinate eolian sandstone, intraformational conglomerate, siltstone, and shale. The appearance of the unit is primarily reddish, but individual lenses and beds vary considerably; some are purplish, lavender, red, tan, orange, or white. Most of the sandstone lenses are moderate orange pink and the mudstones are dark reddish brown to grayish red. In outcrop the Kayenta is ledgy or step-like, with thick-bedded lenses of sandstone between the more massive and cliffy Wingate and Navajo Sandstones. Sandstone in the Kayenta Formation exhibits both high-angle and low-angle cross-bedding. Some lenses display channeling, current ripple marks, and rare slump features. The grain size is more variable than in the Wingate and Navajo, ranging mostly from fine to medium grain. Sand grains are mostly quartz, but mica and minor quantities of darker minerals and feldspar have been noted. The cement is generally calcareous, but locally iron oxides or silica are present. Siltstone, shale, and intraformational conglomerate appear as partings or are interlayered with the sandstone. These finer-grained horizons and intraformational conglomerates are rare in the lower part of the formation and increase in abundance and thickness in the upper part.

The Kayenta Formation ranges from 220 to 340 feet (67-104 m) thick in the quadrangle. The contact with the overlying Navajo Sandstone is conformable and intertonguing over an interval of about 80 feet (24 m). The contact is placed at the horizon above which lighter, more massive eolian sandstone becomes dominant. Some of the reported thickness variation in the Navajo and Kayenta Formations may reflect differences in placement of the contact between them.

Navajo Sandstone (Jn)

Erosional remnants of the Navajo Sandstone are common along the trough of the Kings Bottom syncline (plate 1), especially in the east-central part of the quadrangle. The lower parts of the exposed sections are cliffy and the tops are commonly rounded. The exposures are largely bare rock, but hollows are filled with loose sand. The Navajo is a classic example of an eolian-deposited unit and is the uppermost formation of the Glen Canyon Group.

The Navajo is a mostly orange to light-gray, mostly fine-grained, generally well-sorted, massive sandstone. Locally, thin, hard, lenticular gray limestone (lacustrine) is also found in the unit, and is interpreted to have developed in oases, playas, or interdune lakes (Stokes, 1991, p. 16). Partings, where present, occur at the contacts of cross-bed sets, which are as much as 20 feet (6 m) thick. High-angle, cross-bed laminae lie as much as 30 degrees from the true attitude of the unit. Slight variations in the grain size are aligned along the laminae. Cementation of the sandstone is partly calcareous and partly siliceous and is not quite as uniform as that in the Wingate Sandstone, allowing the cross-beds to be etched in relief in response to weathering. Outcrops on Big Flat contain several horizons of Kayenta-like, reddish, sandy siltstone, sandy limestone, and a small amount of intraformational conglomerate intertongued with thinner-than-usual sets of more typical eolian sandstone. We mapped these outcrops as the basal part of the Navajo Sandstone following the lead of Williams (1964) and Huntoon and others (1982).

The J-2 unconformity of Pipiringos and O'Sullivan (1978) marks the contact of the Navajo Sandstone with the overlying Entrada Sandstone, but the contact is not exposed in the Gold Bar Canyon quadrangle. The Navajo Sandstone has a thickness of as much as 400 feet (122 m) on the quadrangle, which is thought to be a nearly complete section. The thickness in the Arches National Park area decreases eastward from 500 to 250 feet (152-76 m) (Doelling, 1985).

Entrada Sandstone

The Middle Jurassic Entrada Sandstone in the Moab area consists of three members, in ascending order, the Dewey Bridge and Slick Rock Members and the Moab Tongue. Only the upper part of the Slick Rock Member and the Moab Tongue are exposed in the Gold Bar Canyon quadrangle. The thickness of the Entrada Sandstone, at nearby localities where the unit is fully exposed, is estimated to be 410 to 450 feet (125-137 m).

Dewey Bridge Member (Jed): The Dewey Bridge Member was formerly mapped as the Carmel Formation (Dane, 1935) in the Arches National Park area, but Wright, Shawe, and Lohman (1962, p. 2059) proposed a change consistent with lithologic criteria used in naming units. This basal member is a soft, red, muddy sandstone with irregular, contorted bedding. The 100-foot-thick (30 m) member is exposed less than a mile (1.6 km) east of the northeast corner of the quadrangle near the Arches National Park visitor center. This member underlies the quadrangle northeast of the Moab fault and is conformably overlain by the Slick Rock Member.

Slick Rock Member (Jes): The Slick Rock Member is composed of thick-bedded, reddish-orange to brown sandstone. The sandstone is very fine to fine grained with sparse medium to coarse sand grains; it displays distinct high-angle cross-stratification and planar bedding. The sandstone is well indurated with calcareous cement, but weathers to rubbly slopes where fracture density increases near the Moab fault zone. The Slick Rock Member is about 250 feet (76 m) thick immediately northeast of the quadrangle (Doelling, 1985), but only the upper 80 feet (24 m) are exposed in the quadrangle. The contact with the overlying Moab Tongue is sharp and is placed along a bedding parting that is overlain by slightly coarser and lighter-colored sandstone of the Moab Tongue.

Moab Tongue (Jem): The Moab Tongue is a hard, resistant sandstone that forms the capping surface of much of the outcrop area northeast of the Moab fault zone in the northeast corner of the quadrangle. The Moab Tongue is a very-pale-orange, grayish-orange, pale-yellowish-brown, or light-gray, fine- to medium-grained, calcareous, massive, cliff-forming sandstone. The sandstone is well indurated, exhibits low-angle cross-stratification, and is usually highly jointed in outcrop. The sandstone resembles the Navajo Sandstone in color and cementation, with differential etching of cross-bed laminae. The Moab Tongue ranges from 60 to 100 feet (18-30 m) thick. The contact with the overlying Morrison Formation is the J-5 unconformity of Pipiringos and O'Sullivan (1978). This contact is sharp and drawn where the light sandstone of the Moab Tongue is overlain by reddish siltstones of the Tidwell Member of the Morrison Formation. The base of the Morrison commonly consists of 1 or 2 feet (0.3 or 0.6 m) of reworked Moab Tongue sand grains.

Morrison Formation

The Upper Jurassic Morrison Formation consists of three members in the Moab area, in ascending order, the Tidwell, Salt Wash, and Brushy Basin. Of these, the Tidwell and Salt Wash are exposed on the Gold Bar Canyon quadrangle northeast of the Moab fault. The Brushy Basin Member and upper part of the Salt Wash Member have been completely eroded from the quadrangle. The maximum thickness of the Morrison Formation exposed on the quadrangle is estimated at 280 feet (85 m).

Tidwell Member (Jmt): This member consists of thin-bedded, red, silty sandstone, muddy sandstone, sandy siltstone, and shale with a few thin to nodular beds of gray limestone associated with very large, white, siliceous concretions. These limestones and associated concretions are usually found in the upper third of the unit. The concretions have diameters of several feet (as much as a meter). Dane (1935, p. 106) thought that the member was deposited in quiet shallow waters on a gently sloping floodplain. On the Moab anticline a 1-foot (0.3 m) bed of reworked sand marks the base of the unit. The Tidwell weathers into a reddish slope, commonly littered with white concretionary rubble. Its thin, reddish outcrop between lighter-hued Entrada Sandstone and the Salt Wash Member make it an excellent marker unit. The Tidwell Member is 50 to 80 feet (15-24 m) thick. The Tidwell-Salt Wash contact is gradational and conformable. It is placed along the horizon where the reddish shaly or earthy exposures of the Tidwell are replaced by the cross-bedded and light-colored sandstone or by the gray, greenish-gray, or brown muddy siltstones of the Salt Wash Member. The Tidwell Member was formerly identified with the Summerville Formation as exposed in the San Rafael Swell to the west (Baker, 1933; McKnight, 1940). O'Sullivan (1980) and Peterson (1980) indicated that much of the interval formerly known as the Summerville Formation in the Moab area is actually a part of the Morrison Formation. The Summerville Formation thins considerably from the Green River eastward, and little of it may remain in the interval in the Gold Bar Canyon quadrangle area. In the quadrangle any Summerville Formation strata would be too thin to map separately.

Salt Wash Member (Jms): Outcrops of the Salt Wash Member are exposed on the southwest flank of the Moab anticline northwest of U.S. Highway 191. The member consists of alternating resistant and non-resistant units, the outcrops consist of "messy" blocky ledges of light-colored sandstone littered between greenish and reddish slopes. The member includes fluvial sandstone, mudstone, siltstone, shale, conglomerate, and conglomeratic sandstone. The coarser units represent paleo-river channels and exhibit trough cross-bedding. Sandstone colors include very light gray, grayish yellow, light greenish gray, and very pale orange. The grains and pebbles are poorly sorted and sizes vary between lenses. Sandstone is mostly cemented with calcite and the lenses are generally medium to thick. The finer-grained, softer sediments are found in the recesses between the sandstone lenses in colors of reddish brown, reddish gray, or light greenish gray. The Salt Wash Member regionally is 200 to 300 feet (61-91 m) thick (Doelling, 1988, p. 31). The maximum exposed thickness on the Gold Bar Canyon quadrangle is about 220 feet (67 m).

Quaternary Deposits

Nine Quaternary units are mapped in the Gold Bar Canyon quadrangle. Four are dominantly fluvial deposits, two are eolian, and two are mass-movement deposits. Some units grade into each other and those contacts are approximately placed. The source of the materials in these deposits is dominantly local bedrock with the exception of terraces of the Colorado River. Larger areas of engineered fill were also mapped.

Alluvial Deposits

Alluvium (Qa): This unit consists of alluvium that covers the modern floodplain of the Colorado River. The alluvium is well to poorly stratified, moderately to well sorted, and consists mostly of sand and pebble gravel intermixed with silt and minor clay. Bars and levees contain lenses composed of rounded cobbles of Tertiary volcanic rocks, Paleozoic and Mesozoic sandstone and limestone, and Precambrian high-grade metamorphic rocks. Overbank deposits consist mostly of silt. The alluvium was derived from the erosion of varied source areas largely outside the quadrangle. Thickness is probably less than 20 feet (6 m). The deposits are Holocene in age.

Terrace alluvium (Qat): Older alluvial deposits form terraces along the Colorado River and in Jackson Hole, a rincon (abandoned meander loop) in the southeast corner of the quadrangle. Deposits consist mostly of rounded, poorly stratified, clast-supported gravel with sand matrix. Interspersed deposits of moderately sorted sand are rare. Deposits at high elevations tend to have less matrix, possibly due to preferential removal of sand by the wind. Clasts range mostly from 2 to 8 inches (5-20 cm) in diameter, but some clasts are greater than 12 inches (30 cm) long. Clasts have varied lithologies reflecting erosion from varied source areas. Clast types include Precambrian granite and high-grade metamorphic rocks, Paleozoic to Mesozoic sandstones and carbonates, and Tertiary intrusive and extrusive igneous rocks. Some sandy matrix material is rich in heavy minerals and contains small amounts of "flour" gold.

Prominent gravel terraces are found 30 to 40 feet (9-12 m), 70 to 100 feet (21-31 m), and 140 to 160 feet (43-49 m) (preserved mostly in the Jackson Hole rincon), about 200 feet (61 m), 240 to 260 feet (73-79 m), 320 to 340 feet (98-104 m), and about 450 feet (137 m) above the present river level. Clasts display weak- to well-developed desert varnish in all but the lowest terraces. Soil with stage II carbonate development is preserved within sand-rich lenses in a terrace at an elevation of about 200 feet (61 m) above the current river level. Generally, the amount of calcium carbonate in soils is directly related to its age (Machette, 1985). Deposits located 30 to 40 feet (9-12 m) above the river, however, do not display significant soil development. The higher terrace deposits are therefore considered to be of Pleistocene age, but the lowest may be early Holocene in age.

Mixed alluvial and colluvial deposits (Qac): Mixed alluvium and colluvium form gentle to moderate slopes below steep slopes of talus and colluvium in the Potash amphitheater, in canyons cut into the Chinle Formation, and in Jackson Hole. Deposits are poorly sorted, crudely stratified, and consist of angular blocks, cobbles, and pebbles in a matrix of reddish-brown sand, silt, and clay, and vary from clast supported to matrix supported. Clasts are locally derived from the Glen Canyon Group and Triassic rocks. The deposits are a mixture of sheetwash, debris-flow, and rock or soil-creep materials. Mixed alluvium and colluvium grade into talus deposits, with the gradational contact placed at an increase in slope and boulder content. Deposits are probably less than 30 feet (9 m) thick and are interpreted to be late Pleistocene to Holocene in age.

Mixed alluvial and eolian deposits (Qae): Mixtures of alluvium and eolian sand are found within valleys and canyons of larger ephemeral streams. Poorly to moderately sorted, variably stratified alluvium is concentrated along channels. Alluvium consists mostly of locally derived sand, minor gravel, and silt, and includes reworked eolian sand. Eolian deposits consist of small sand sheets and partly stabilized dunes. Sand is fine to medium grained, well sorted, and mostly composed of quartz.

Deposits undergo erosion and deposition during flash floods, and are probably less than 20 feet (6 m) thick. A Holocene age is assigned to the deposits based on their lack of soil development.

Eolian Deposits

Mixed eolian and alluvial deposits (Qea): Eolian deposits significantly modified by sheetwash and shallow channel flow, and mixed with local alluvium, cover large areas of the warped tableland. The deposits are yellow, tan, and reddish-orange in color, reflecting different parent source materials. Deposits consist mostly of well-sorted, very fine- to medium-grained sand and silt, probably originally of eolian origin. The eolian silt and sand have locally been reworked and mixed with gravel from surrounding bedrock areas by fluvial processes. The uppermost surfaces of these deposits are dominated by eolian sand and silt. The deposits are considered Holocene in age because of lack of cementation and weak soil development, although the underlying bedrock surfaces may be very old. Maximum thickness of these deposits is about 15 feet (4.6 m).

Dune and sheet-sand deposits (Qes): Sheet sand and undulation dunes cover large parts of the warped tableland. Small, unmapped patches of sand also locally fill erosional surface depressions, especially near cliffs and bedrock ridges in the Glen Canyon Group. Sand is fine to medium grained, quartz rich, and mostly light reddish orange to light reddish brown. Most dunes are partly to completely stabilized by vegetation and active sand transport is limited. These deposits grade into mixed eolian and alluvial deposits and are locally modified by sheetwash. The source of the sand is probably local and largely derived from Navajo Sandstone remnants that rise from the tableland. The maximum observed thickness of these deposits is 20 feet (6 m). These deposits are interpreted to be Holocene in age, based on the lack of soil development.

Mass-Movement Deposits

Landslide deposits (Qms): Landslide deposits are not prevalent in the Gold Bar Canyon quadrangle. On the boundary between sections 18 and 19, T. 25 S., R. 21 E., in the northeast part of the quadrangle, a mass of the Salt Wash Member of the Morrison Formation, derived from bedrock exposures northeast of the Moab fault, slid southwesterly across the fault and over the Cutler Formation along a plane of separation subparallel to bedding. The surface of separation, at first glance, appears to be an angular unconformity between the Salt Wash Member and the Cutler Formation. The original landslide mass, now partially eroded, probably covered about 40 acres (16 hectares) and may be as much as 60 feet (18 m) thick. The slide is probably late Pleistocene in age based on the degree of erosion.

Erratic strikes and dips mark a second landslide, in SW 1/4 SW 1/4 SE 1/4, section 13, T. 25 S., R. 20 E., involving sandstone from the Black Ledge of the Chinle Formation and mudstone and claystone of the underlying lower slope-forming unit. The landslide probably moved as a viscous mass over the upper part of the Moenkopi Formation. The landslide covers 5 to 6 acres (2-2.4 hectares).

Talus deposits (Qmt): Talus deposits consist primarily of angular blocks, boulders, and smaller angular fragments in a sandy matrix that mantle the slopes below cliffs. Block size ranges to as much as 15 feet (4.6 m) in diameter, partly reflecting joint spacing and height in the overlying cliff faces. The deposits also include steeply sloping accumulations of colluvium derived from topographically higher talus at cliff bases. Colluvium is very poorly sorted and generally non-stratified, and accumulations have been modified by weathering, sheetwash, and rock creep. The colluvium consists of angular boulders and cobbles within a matrix of sand, silt, and minor clay. Deposits range from a thin veneer to 30 feet (9 m) thick, and vary from having relatively smooth surfaces to being scoured by gullies. Only the larger deposits have been mapped, where they completely cover the underlying slopes. The mapped deposits are probably late Pleistocene to latest Holocene in age.

Man-Made Fill Deposits (Qf)

A few places in the Gold Bar Canyon quadrangle have been covered during construction and mining projects. Fine-grained tailings derived from milled potash ore cover a natural hollow in the Cutler Formation in the west part of section 25 and the east part of section 26 in T. 26 S., R. 20 E. The service buildings and railroad spur of the Moab Salt Company plant at Potash were constructed on a leveled area consisting of broken Cutler Formation rock, mine-dump materials (from the mining of a shaft), and alluvial terrace deposits. Fill also underlies the Denver & Rio Grande Railroad tracks and various highways in the quadrangle, but was not mapped.

STRUCTURE AND GENERAL GEOLOGIC HISTORY

The formations in the Gold Bar Canyon quadrangle are presently warped into gentle northwest-trending anticlinal and synclinal folds and are cut by normal faults and joints. In Pennsylvanian to Triassic time, clastics and evaporites were deposited in the fault-generated, intermittently subsiding Paradox basin (Szabo and Wengerd, 1975). The evaporites (mostly halite) locally migrated and thickened to form elongate salt domes or anticlines along weakened faulted areas (figure 1). Much later, in early to middle Tertiary time, the bedrock formations were warped into broad northwest-trending anticlines and synclines (Doelling, 1985). Reactivation of some of the old northwest-striking normal faults cut the folds. This Tertiary faulting may be related to relaxation after the compressional folding ceased or may represent a separate extensional event.

The region was epeirogenically uplifted in late Tertiary time as part of the Colorado Plateau. Subsequent erosion cut deeply into the strata and allowed fresh ground water to locally reach the salt through existing fracture systems. The ensuing salt dissolution caused local collapse (tilting and faulting) of overlying strata during late Tertiary and Quaternary time.

Folds

Moab Anticline

The axial trace of the Moab anticline (figure 1) trends N. 45-50° W. and is located about 1/4 mile (0.4 km) northeast of the northeast corner of the quadrangle. The Moab fault cuts the southwest limb of the anticline in the quadrangle. Dips on the southwest flank of the anticline reach 37 degrees northeast of the fault (McKnight, 1940, p. 117). In most places, however, dips are less than 25 degrees. Southwest of the Moab fault, dips are 15 degrees or less. The anticline plunges gently northwestward and decreases in amplitude north of the quadrangle. Several faults, subparallel with the anticlinal axis and with minor displacements, are thought to represent brittle failure during flexing. These faults do not appear to be related to Moab fault-zone activity.

Kings Bottom Syncline

The axial trace of the Kings Bottom syncline trends N. 50-70° W. and plunges 2 to 3 degrees southeasterly on the quadrangle (plate 1). The syncline has approximately planar limbs with a comparatively broad hinge region, so that the steeper dips occur at a considerable distance from the axis. Bedding dips about 8 degrees southwestward on the northeastern limb of the syncline. The dips of strata between the Kings Bottom synclinal axis and the Cane Creek anticlinal axis mostly range between 2 and 4 degrees but locally reach 11 degrees.

Cane Creek Anticline

The crest of the Cane Creek anticline trends N. 50-70° W. and is located in the southwest part of the quadrangle (plates 1 and 2, and figure 3), about 4.5 miles (7.2 km) southwest of the trough of the Kings Bottom syncline. The anticline has planar limbs with a rounded hinge region. Bedding dips about 8 degrees northeastward on the northeastern limb and generally less than 5 degrees southwestward on the southwestern limb. The crest of the anticline varies from gently northwest-plunging to horizontal. Northwest of the Potash amphitheater the anticline is asymmetric with a subhorizontal southwestern limb and a poorly defined crest (plate 1). Structural relief between the crest of the Cane Creek anticline and the trough of the Kings Bottom syncline reaches a maximum of about 2,600 feet (793 m) in the southeast part of the quadrangle and decreases to about 1,000 feet (305 m) to the northwest.

The oldest unit exposed along the crest of the anticline is the Pennsylvanian Honaker Trail Formation. At depth, the Paradox Formation is thicker near the crest of the anticline (Carlton, 1958, p. 255), partly reflecting minor folding and faulting. Minor folds within salt observed in the Potash mine vary from open to tight, have northwest-trending hinge lines, and display consistent asymmetric relations across the hinge of the Cane Creek anticline (Evans and Linn, 1970) (figure 4). Minor northwest-striking thrust faults core most of these folds (Huntoon, 1985), consistent with internal shortening of beds along the inner arc of the anticline. However, higher-level Permian to Triassic strata have been locally extended perpendicular to the fold axis by minor normal faults and joints along the outer arc of the anticline.

The location of the anticline may reflect old, deeper faults which cut Mississippian and older rocks but do not continue above the lower part of the Paradox Formation. Cross section A-A′ shows a high-angle fault cutting Mississippian units, based on proprietary seismic data. This fault was probably active during deposition, weakening and providing space in the lower part of the Paradox Formation, and resulting in a somewhat thicker salt section near the future anticline.

Faults

Moab Fault

The Moab fault is a narrow zone of faults that strike N. 50 to 60° W. and dip 60 to 80 degrees northeastward in the northeast part of the quadrangle (figure 5). The fault and associated splay

Figure 3. *Cane Creek anticline looking northwest from Hurrah Pass in San Juan County. Note Moab Salt Company's facilities at Potash to the right.*

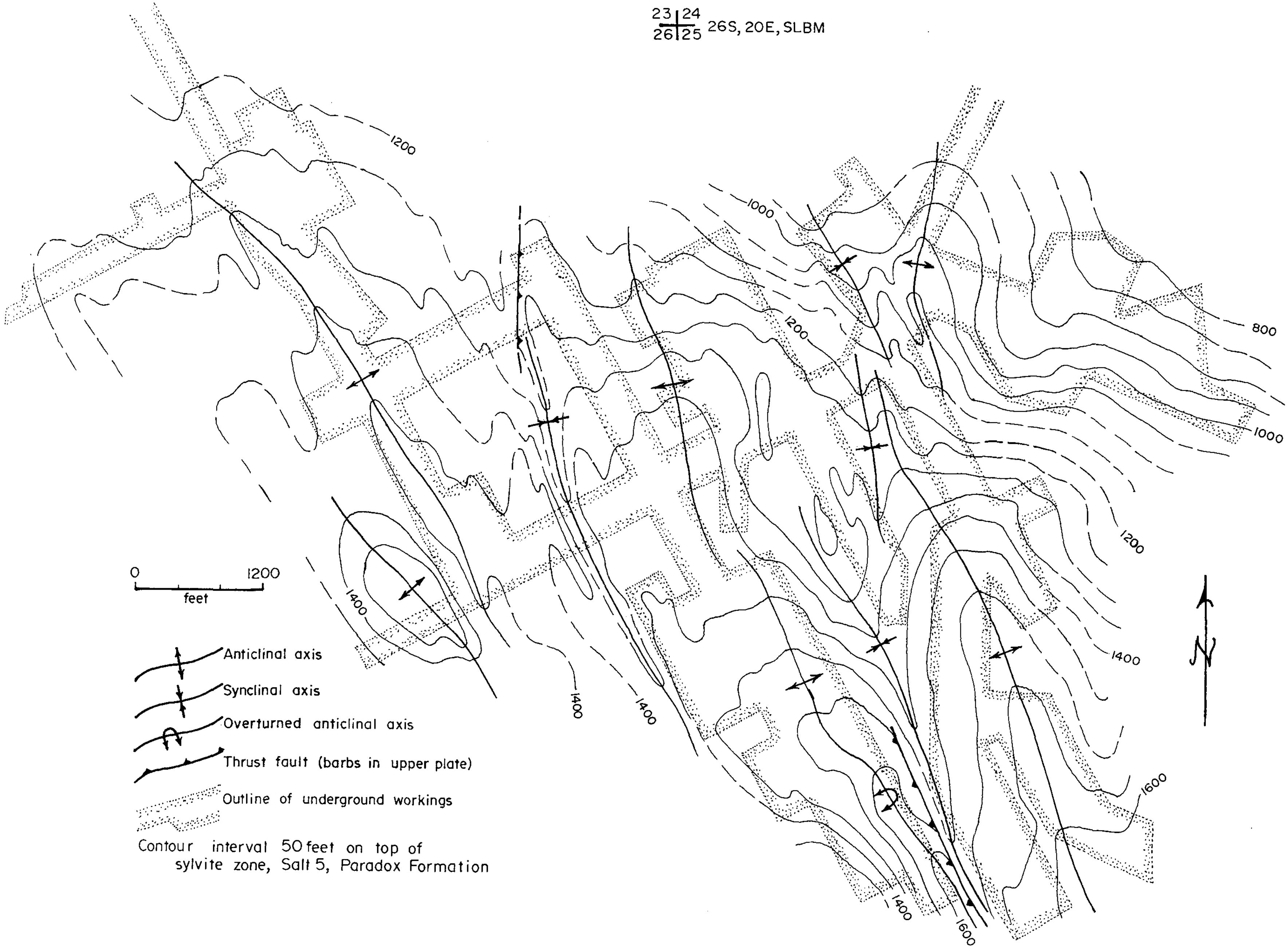


Figure 4. *Minor folds and faults in salt 5 of the Paradox Formation as mapped in the Moab Salt Company Cane Creek mine at Potash. Contours are in feet above sea level (modified from Evans and Linn, 1970; Huntoon, 1985).*

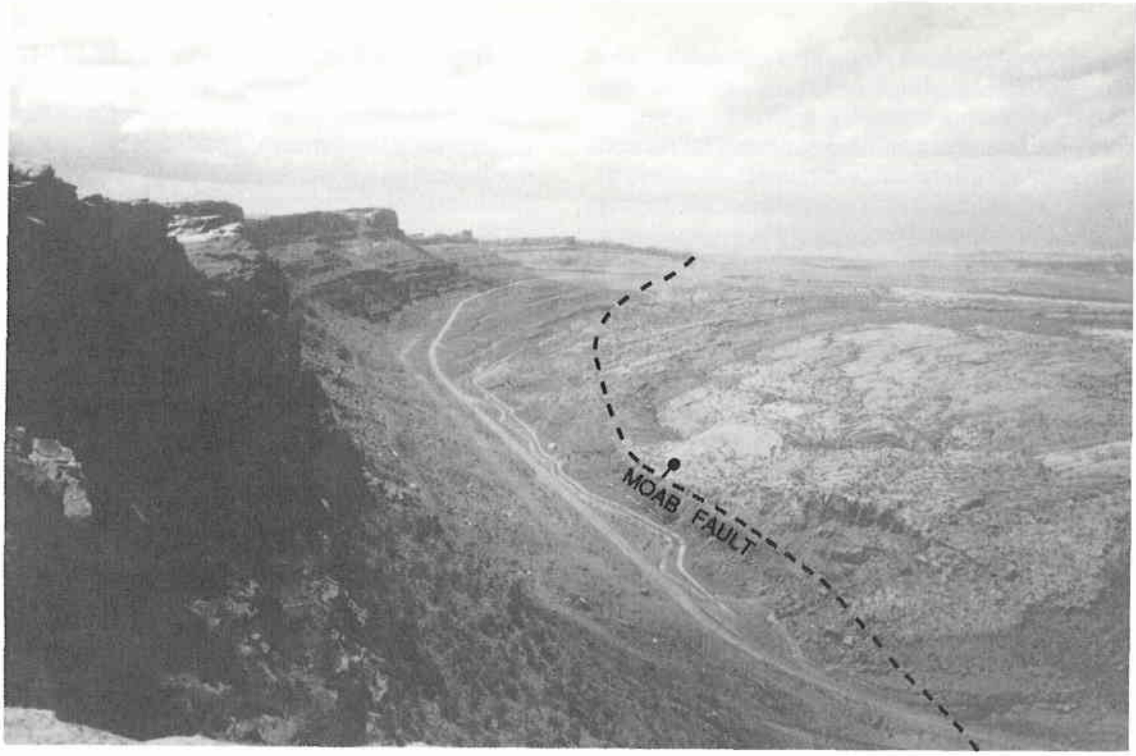


Figure 5. *Northwesterly view of Moab Canyon and U.S. Highway 191 from the top of the Wingate Sandstone Cliff opposite the Arches National Park visitor center. The trace of the Moab fault is to the right of and parallels the highway. The strata dip southwesterly from the axis of the Moab anticline, which subparallels the highway and fault to the right.*

faults are normal faults with downthrown northeast blocks. The fault juxtaposes gently dipping beds of the Salt Wash Member of the Morrison Formation and the Moab Tongue of the Entrada Sandstone in the hanging wall against the base of the Permian Cutler Formation in the footwall. Stratigraphic separation across the fault is about 3,000 feet (914 m) using thicknesses estimated from nearby surface measurements. A thin wedge of Moenkopi Formation bounded by fault branches is present in the southeast half of the zone.

Locally, drag is evident along the principal splay of the Moab fault. The Cutler Formation in the footwall dips about 12 to 15 degrees southwestward, except locally where it dips as much as 15 degrees northeastward toward the fault. The zone of dip reversal reaches a maximum width of about 50 feet (15 m), too narrow to show on cross section A-A′. The Salt Wash Member of the Morrison Formation and the Entrada Sandstone dip as much as 20 to 25 degrees southwestward on the southwest limb of the Moab anticline, but generally flatten out along the principal splay of the fault. Dips in the slice of Moenkopi Formation range from nearly horizontal to as much as 25 degrees easterly. A thickness of at least 150 feet (46 m) of Moenkopi Formation is exposed in the fault slice.

The Moab fault cuts Cretaceous rocks northwest of the Gold Bar Canyon quadrangle (figure 1). No Quaternary sediments have been cut by the fault in the quadrangle. Salt dissolution structures are clearly evident in Moab and Spanish Valleys paralleling the Moab fault, but only minor dissolution of salt is apparent along the fault in the Gold Bar Canyon quadrangle and the area to the northwest. Oviatt (1988, p. 43) believed that movement on the Moab fault beheaded Little Canyon, just north of the quadrangle, in late Tertiary to early Quaternary time.

High-Angle Faults in Potash Amphitheater

A series of high-angle normal faults, arranged to form grabens, cut rocks of the Permian Cutler and Pennsylvanian Honaker Trail Formations near the crest of the Cane Creek anticline in the Potash amphitheater. The faults strike N. 40 to 50° W., subparallel to the dominant joint set in the area, and have dips greater than 70 degrees. Stratigraphic separation across mapped faults varies from less than 10 feet (3 m) to a maximum of 50 feet (15 m). Slickensides were not observed, and net slip is uncertain. Some faults and adjacent joints display bleaching. Most of the faults are grouped in pairs as grabens with down-dropped blocks 100 to 200 feet (30-61 m) wide. Some faults display consistent left-stepping enechelon patterns. The subsurface extent of the faults is uncertain, but they do not continue down into the Paradox Formation (Huntoon, 1985). The faults may have accommodated minor extension along the outer arc of the Cane Creek anticline, but the age of the faulting is uncertain.

Fracture Zone

A northeast-striking, steeply dipping fracture zone cuts the Wingate and Kayenta Formations in the Bull Canyon area. This zone represents part of the northeast-striking lineament called the Roberts rift by Hite (1975). The zone consists of several discrete fractures, with a locally developed breccia zone as much as 15 feet (5 m) wide. Clasts in the breccia are as much 3 feet (1 m) in diameter, vary from angular to subrounded, and consist mostly of sandstone derived locally from the Wingate Sandstone. Some sandstone clasts, however, may be derived from the underlying Chinle Formation, and Hite (1975) described limestone clasts that were derived from underlying Pennsylvanian strata and transported upward into the zone a minimum of 2,000 feet (600 m). Secondary minerals in the breccia include barite, calcite, and rare sulfides. Sandstone is bleached white to yellow in a zone extending up to 50 feet (15 m) outward from the main fractures. The fracture zone displays less than 1 foot (0.3 m) of separation of bedding, and does not offset the trough of the Kings Bottom syncline, precluding significant slip along the zone. Discontinuous fractures with limited bleaching are aligned along the northeast projection of the fracture zone near Little Canyon. The fracture zone may reflect failure due to high fluid pressure created by fault movement beneath the salt. Hite (1975, p. 221) postulated wrench-faulting in rocks older than the Paradox Formation that did not involve younger rocks. This supposes that the competent rocks beneath the Paradox Formation moved independently of the competent strata overlying the salt. He indicated that the age of the structure is unknown.

Joint Systems

A dominant set of joints strikes northwestward to west-northwestward over much of the quadrangle (plate 1 and figure 6). The joints tend to parallel the trends of major fold hinge lines. Spacing between joints is on the order of 1 to 10 feet (0.3-3 m) in many areas, but spacing depends partly on lithology and bedding thickness. Spacing between joints is expected to be greater in more indurated and thicker beds. A less well-developed set of northeast-striking joints is locally present. North-striking joint sets were observed along Little Canyon.

GEOMORPHOLOGY

Landforms in the quadrangle include a tectonically warped tableland or plateau, canyons and valleys formed by ephemeral streams, the Potash amphitheater, and the canyon of the Colorado River.

The warped tablelands are underlain by resistant bedrock ledges and gentle dip slopes of the Glen Canyon Group, and may represent relatively old surfaces developed before major downcutting of the Colorado River. Young eolian sand deposits, variably modified by sheetwash and shallow-channel flow, cover large parts of the warped tableland. Lag deposits of alluvial gravel are locally preserved in bedrock hollows on Amasa Back about 550 feet (168 m) above the current level of the Colorado River. The gravel consists of subrounded to rounded, trachyte to trachyandesite clasts with well-developed desert varnish. The clasts were probably derived from the La Sal Mountains. The lag deposits may represent part of a regional gravel, preserved near the La Sal Mountains, that was deposited during late Pliocene to early Pleistocene time before collapse of

Figure 6. *Northwest-trending joints in outcrops of Wingate Sandstone along Dry Fork of Bull Canyon, NW 1/4 SE 1/4, section 3, T. 26 S., R. 20 E.*

the Moab salt-cored anticline (Michael L. Ross, Utah Geological Survey, personal communication, 1991).

The Colorado River flows across the southeastern part of the quadrangle through a deeply incised (as much as 2,000 feet [610 m]) canyon. Strath terraces are locally preserved at elevations as much as 450 feet (137 m) above the modern floodplain, and record a protracted history of downcutting by the river. The maximum incision rate of the Colorado River in the Gold Bar Canyon quadrangle during late Tertiary to Quaternary time is estimated to have been 0.8 ft/1,000 years (24 cm/1,000 years)(Woodward Clyde Consultants, 1980, p. 43, table 4-2), giving an age of 562,000 years for the highest terraces. Alluvium covers the modern floodplain of the river.

Canyons and valleys with small ephemeral streams form an integrated network that drains the uplands into the Colorado River. With the exception of the Colorado River, the drainages in the Gold Bar Canyon quadrangle exhibit a parallel pattern controlled by structure. Little Canyon is beheaded along the escarpment that parallels Moab Canyon in the adjacent Merrimac Butte quadrangle. The ephemeral stream is underfit and the canyon is separated from a relatively larger paleodrainage no longer evident to the northeast (Oviatt, 1988, p. 68).

ECONOMIC GEOLOGY

Most of the mineral value derived in this quadrangle has come from potash and other evaporites, petroleum, sand and gravel, uranium, and gold. Small amounts of other metals are associated with the uranium ore and some potential may exist for decorative stone.

Potash, Salt and Magnesium

The Gold Bar Canyon quadrangle is underlain by the Paradox Formation which is an estimated 3,300 to 7,000 feet (1,005-2,134 m) thick. The thicker sections may be due to complex flowage and folding of salt layers. In the deepest parts of the Paradox basin, 29 cycles of halite (common salt) precipitation and associated clastic deposition have been identified (Hite, 1960). Thickness of individual cycles was controlled by the supply of water from the sea, evaporation rates, climatic changes, position in the basin, and tectonic activity. A cycle began with a rise in sea level and a freshening of water in the basin (Peterson and Hite, 1969, p. 894-895). The depositional sequence commenced with the precipitation of anhydrite followed by dolomite and finally deposition of calcareous black shale. Thereafter, the gradual return to restricted conditions deposited anhydrite again with black shale and salt. The end of the cycle was marked by a disconformity produced at the beginning of the next cycle as the water again freshened. The 29 cycles, which are numbered in descending order, are rarely all present in one geographic area and generally individual cycles are incomplete. In the Gold Bar Canyon quadrangle about 65 to 75 percent of the Paradox Formation consists of salt deposits, which in addition to halite contain potentially commercial quantities of potash, magnesium, bromine, boron, and lithium (Ritzma, 1969, p. 17). Individual salt layers range in thickness to nearly 1,000 feet (305 m). Carbonate, anhydrite, and black shale layers are commonly lumped together and identified as marker beds. Potentially commercial brines are present in some of these marker beds.

The most common salt minerals are halite, carnallite, and sylvite (Ritzma, 1969, p. 26). Carnallite ($KCl.MgCl_2.6H_2O$) is most abundant after halite and contains 38.3 percent chlorine, 14.1 percent potassium (equivalent 16.9 percent K_2O), 8.7 percent magnesium, and 39 percent water. Because of its low potash content, carnallite is presently not considered commercial, but it remains a potentially valuable source of magnesium. Sylvite (KCl) is the commercial potash mineral composed of 52.4 percent potassium (equivalent to 63.1 percent K_2O) and 47.6 percent chlorine.

Seventeen of the 29 cycles contain potash salts, but only 10 are rich or thick enough to be potentially commercial. Of greatest interest are cycles 5, 6, 9, 13, 16, 18, and 19 (plate 2). A brine-bearing marker bed between salt 15 and 16 is also of interest. Salt 5 is currently mined at the Moab Salt Company's Cane Creek mine at Potash, SE ¼ section 24, T. 26 S., R. 20 E. The sylvite horizon near the top of salt 5 ranges from 0 to 25 feet (7.6 m) thick across the quadrangle and contains 25 to 30 percent equivalent K_2O. The horizon is not pure sylvite, but is a mixture of sylvite and halite known in the industry as sylvinite. Variations in grade occur vertically and laterally (Gwynn, 1984).

The sylvite layer at the top of salt 6 is less well known, but is believed to reach a maximum thickness of 20 feet (6 m) in the quadrangle area. Equivalent K_2O content is generally not as high as that of salt 5. Some insoluble interlayers, amounting to as much as 2 percent in volume, are present in the salt. Salt 6 also contains a thick carnallite zone in the lower third of the horizon. The sylvite layer at the top of salt 9 usually contains in excess of 35 percent equivalent K_2O and is 0 to 25 feet (0-7.6 m) thick. The unusual high quality could be due to secondary enrichment caused by a local reconcentration of an earlier, more widespread lower-grade deposit prior to the deposition of the overlying marker bed (written communication, R. R. Norman, Buttes Gas and Oil Co., 1970). The layer may be missing under parts of the quadrangle.

Less is known about the deeper potash-bearing zones. Sylvite in salt 13 may be very thick but contains considerable insoluble material and carnallite (Hite, 1960). Sylvite in salt 16 is thought to be similar in quality and thickness to that in salt 5. In a test well drilled in section 9, T. 26 S., R. 20 E., brine containing in excess of 7 percent equivalent K_2O was encountered with a potential flow rate of 50,000 barrels per day (written communication, R. R. Norman, 1970). The potash zones at the tops of salts 18 and 19 are identified as sylvite-carnallite zones. These zones may be as thick as 100 feet (30 m) or more and contain 10 to 16 percent equivalent K_2O. The grade varies locally.

Including only salt 5, the quadrangle contains a resource of 1.1 billion tons (998 million metric tons) of sylvinite in place. Exploitation of potash and halite is presently (1993) occurring in the Moab Salt Company Cane Creek mine at Potash. Mining began in 1961 with construction of a 2,789-foot (850-m) shaft and an incline that extended to the salt 5 ore zone. Mining was done by the room and pillar method at a depth of 2,700 to 3,200 feet (823-975 m) and between 1965 and 1970 about 150 miles (241 km) of underground workings were driven (Gwynn, 1984, p. 4). Problems were encountered because of intense secondary folding and faulting in the salt (figure 4), mine-roof maintenance, and salt movement. The temperature of the mine workings was reported to be in the middle 90 degrees Fahrenheit (35°C). Crude oil, natural gas, and pockets of brine were encountered in the marker bed above; none were found in the salt (Gwynn, 1984, p. 7). The mining method was converted to solution mining in 1971 (Huntoon, 1986, p. 644). In the current operation, water from the Colorado River is pumped into the mine through injection wells, recovered from the mine as brine, and concentrated in evaporation ponds located south of the quadrangle.

Petroleum

The area within and immediately surrounding the Gold Bar Canyon quadrangle has been the site of widespread exploration, with local production of oil and gas from the Long Canyon, Cane Creek, Big Flat, and Bartlett Flat fields (figure 7). Production in these fields has been from the Cane Creek zone of the Paradox Formation and from the Mississippian Leadville Formation. Oil shows have also been encountered in other intervals of dolomite, shale, and anhydrite within the Paradox Formation (plate 2). Tops of formations within drill holes in the quadrangle, identified using geophysical logs and well cuttings, are summarized in figure 8.

The Long Canyon field, located in the west-central part of the quadrangle, had produced over 948,000 barrels of oil and over 1 million cubic feet of gas as of December 1992 (figure 9). Production is from fractured dolomite, shale, and anhydrite of the Cane Creek zone of the Paradox Formation, and inert gas has been recovered from the Mississippian Leadville Formation. The discovery well, the Southern Natural Gas Long Canyon #1, was completed in 1962. Pressure in this well was about 5,000 psi at a depth of 7,075 feet (2,156 m), indicating significant overpressuring (Fassett and Thomaidis, 1978).

The Cane Creek field borders the southern part of the quadrangle along the Colorado River. Wells in this field have encountered several oil shows in the Paradox Formation, including oil from the Cane Creek zone. Although no wells have been

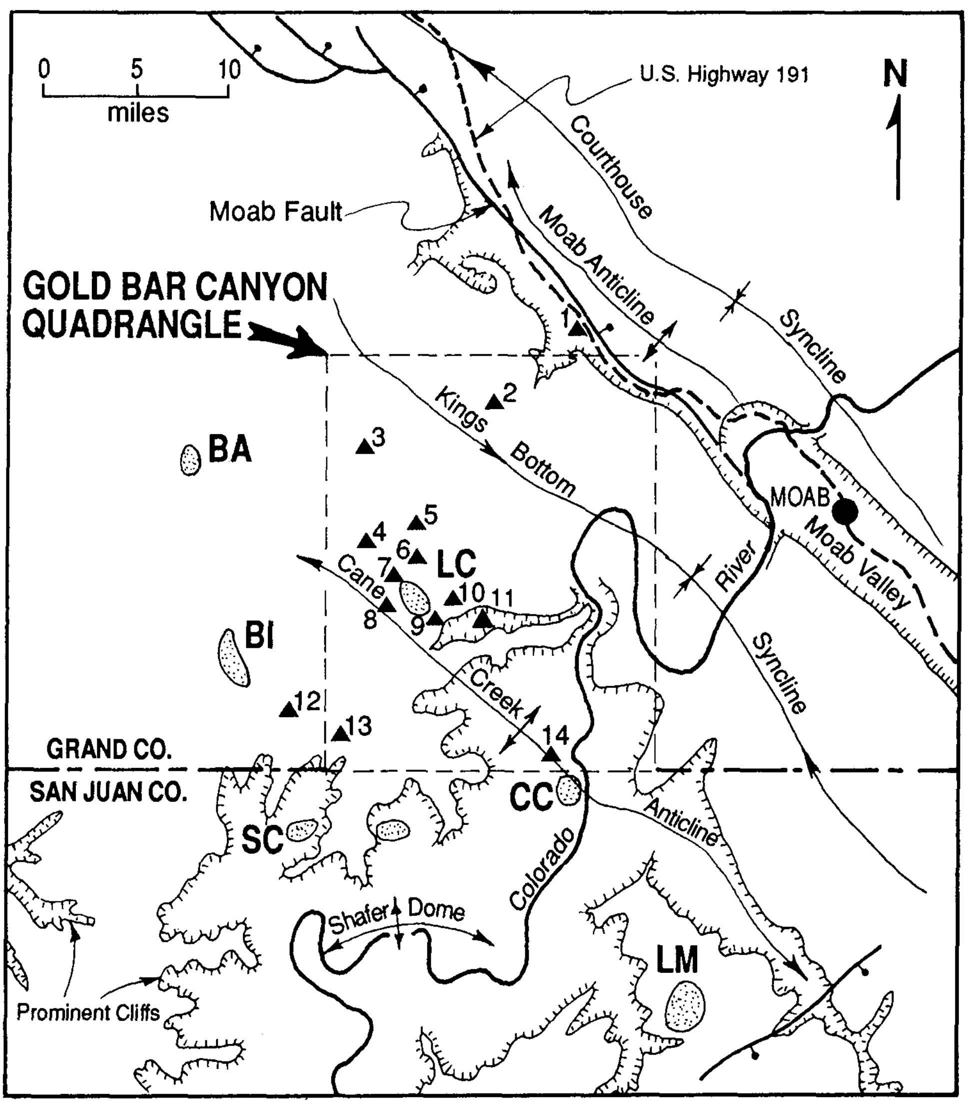
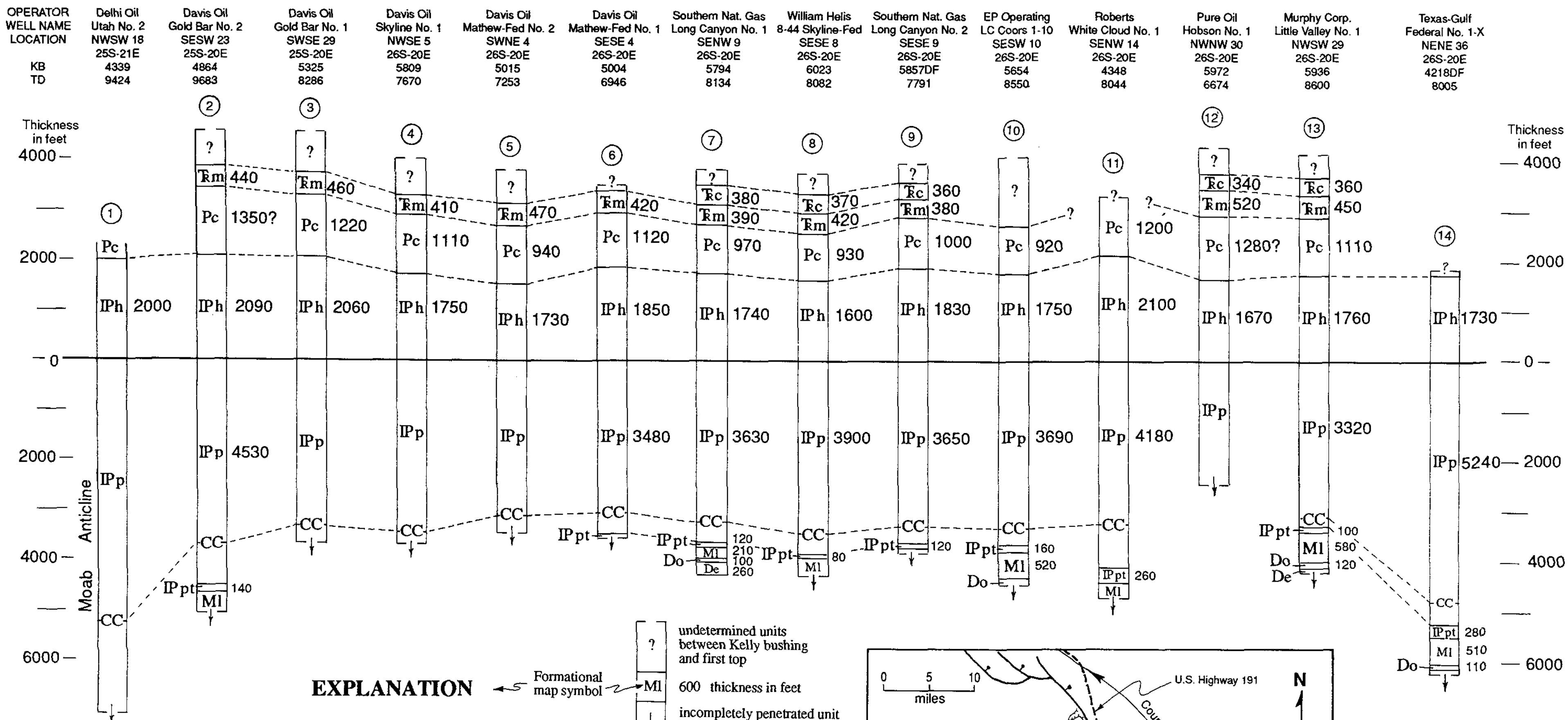


Figure 7. Oil and gas fields in and around Gold Bar Canyon quadrangle. Bartlett Flat (BA), Long Canyon (LC), Shafer Canyon (SC), Cane Creek (CC), and Lion Mesa (LM) all exploited Pennsylvanian reservoirs. The Big Flat field (BI) exploited Mississippian reservoir rock. Drill holes (▲) are on figure 8.



EXPLANATION

Formational map symbol — Ml

? undetermined units between Kelly bushing and first top

600 thickness in feet

incompletely penetrated unit

datum is base of Honaker Trail Formation

Ꞧc – Chinle Formation
Ꞧm – Moenkopi Formation
Pc – Cutler Formation
IPh – Honaker Trail Formation
IPp – Paradox Formation
CC – Cane Creek marker
IPpt – Pinkerton Trail Formation
Ml – Leadville Formation
Do – Ouray Limestone
De – Elbert Formation

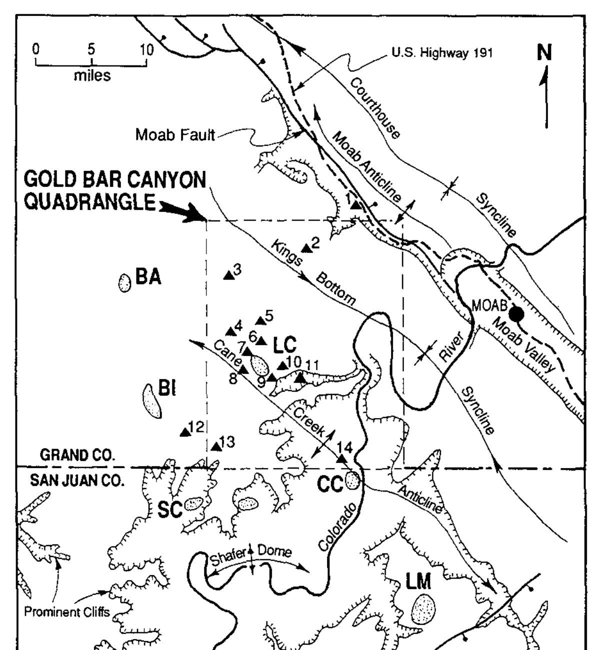


Figure 8. Formation tops encountered in drill holes in and around the Gold Bar Canyon quadrangle as interpreted by the authors. All measurements are in feet.

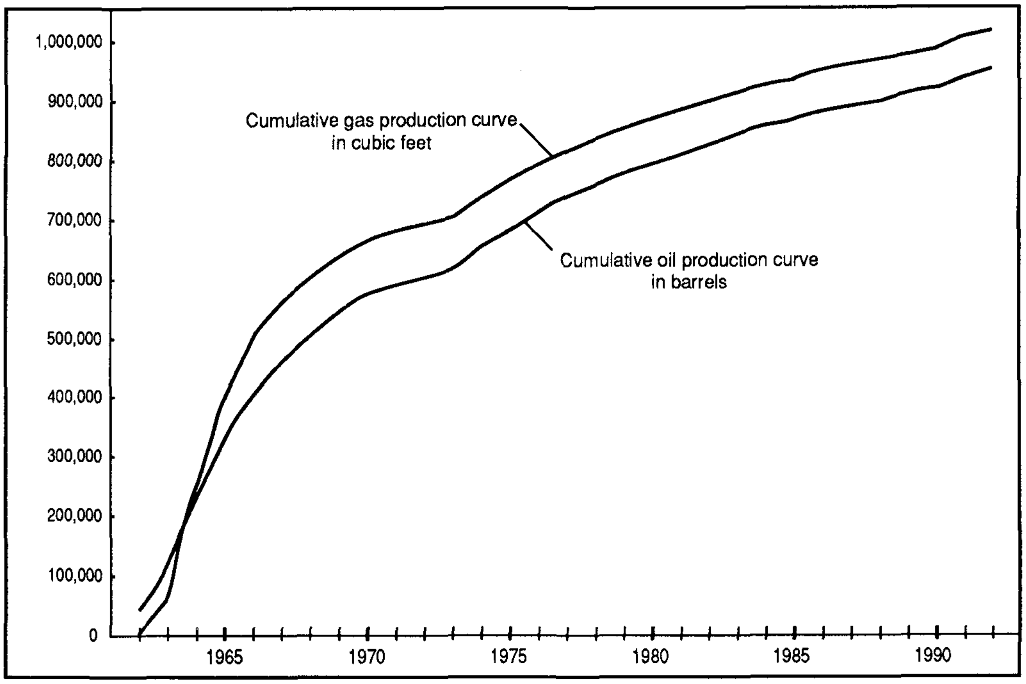


Figure 9. Annual oil and gas production and cumulative oil and gas production curves (inset), Long Canyon field, 1962-1990. Other oil and gas production in the Gold Bar Canyon quadrangle consists of 675 barrels of oil and 1,430 thousand cubic feet (MCF) of gas from the Davis Oil Skyline No. 1 well completed in 1982, 1,343 barrels of oil from the Davis Oil Mathew Fed. No. 1 well completed in 1981, 507 barrels of oil from William Helis 8-44 Skyline Fed. well completed in 1976, and 13,125 barrels of oil and 14,800 MCF of gas from the Davis Oil Gold Bar No. 1 well completed in 1982. All four of these wells are presently shut in. Data are from Utah Division of Oil Gas and Mining records.

successfully completed in this field as of 1993, a total of 1,887 barrels of oil have been produced during testing. The initial well in the field was spudded in 1924, but had a blowout and was destroyed by fire. Intermittent drilling continued until 1958. Exploration for potash in this area began in 1956, and in 1960, 9,445 acres (3,822 hectares) of land were withdrawn from oil and gas leasing to encourage development of potash mining. In 1992 the Utah Division of State Lands and Forestry opened some of the acreage for leasing – the remainder will be available in 1994.

The Big Flat field, located west of the quadrangle, was abandoned in 1988 after production of over 92,000 barrels of oil and 50,000 MCF of gas from the Mississippian Leadville Formation.

The Bartlett Flat field, located northwest of the quadrangle, was abandoned in 1965 after production of 39,400 barrels of oil and 22,000 MCF of gas from the Cane Creek zone of the Paradox Formation. The successful completion of the Kane Springs Federal 27-1 well in the Bartlett Flat field, by Columbia Gas Development Corporation in April, 1991, renewed interest in oil and gas development in the area. This well was drilled horizontally into fractured Cane Creek zone rock and had produced 163,800 barrels of oil and 169,000 cubic feet of gas by December 1992. Permeability of 32 millidarcies in the Cane Creek zone appears to be largely caused by fracturing (Morgan and others, 1991). In November, 1991, the Kane Springs Federal 19-1A was completed (undesignated field), also horizontally into the Cane Creek, and had produced 76,000 barrels of oil and 68,300 cubic feet of gas by December 1992.

Uranium, Vanadium, and Copper

Uranium mineralization in the Gold Bar Canyon quadrangle is localized at the base of sandstone and conglomerate lenses that fill broad, ill-defined channels in the top of the Moenkopi Formation and at the top of mottled or reddish siltstone beds within the Chinle Formation. The uranium mineralization is associated with finely divided carbonaceous plant debris disseminated in the sandstones or conglomerates. The reduction of ferric oxides (bleaching) is the principal form of alteration, which affects no more than 8 feet (2.4 m) of rock at the base of the Chinle Formation nor extends more than 3 feet (1 m) into the Moenkopi Formation. Uranium mineralization is usually enhanced in areas of intense alteration or bleaching.

The principal and primary ore mineral is uraninite (mixture of UO_2 and UO_3; 50-85 percent U_3O_8). Associated with the uraninite are small quantities of chalcopyrite, pyrite, rare marcasite, galena, vanadium clays, and montroseite. The sulfides (primary ore minerals) are very fine grained and disseminated in the sandstone and conglomerate hosts. The oxides (secondary ore minerals) include schroeckingerite, autunite, chalcocite, malachite, and azurite. A small amount of barite has been identified and fluffy white coatings of thenardite appear on the walls of the mine workings. The secondary minerals tend to coat fractures and bedding planes, as well as ore body contacts.

All uranium mines and prospects in the Gold Bar Canyon quadrangle are currently inactive (1993). Because uranium mineralization was discovered over much of the region during the uranium boom (Doelling, 1969, p. 9), the Colorado Plateau was divided into uranium areas and districts. Uranium area and district boundaries cross the Gold Bar Canyon quadrangle and workings have been assigned to two areas of the Green River district and one area of the Moab district (Doelling, 1982).

The Sevenmile Canyon uranium area of the Green River district includes Little Canyon in the northern part of the quadrangle. Although mines of the Sevenmile Canyon area in the Merrimac Butte quadrangle have produced much ore, the workings in Little Canyon are limited to exploratory rim stripping and short adits. Assays of materials yielding higher counts on a radiation counter average 0.03 percent U_3O_8 and 0.01 percent V_2O_5.

Most of the quadrangle area west of the Colorado River is assigned to the Interriver area of the Green River district. Sporadic mineralization occurs in the vicinity of Bull Canyon and around the rim of the Potash amphitheater. Mines or prospects opened in this area include the Bull Canyon prospect, Shamrock mine, You All prospect, Gray Fault mine, and Big Chief mine (plate 1).

Dozer cuts and channel trenches mark the Bull Canyon prospect in the SW 1/4 SW 1/4 SW 1/4, section 34, T. 25 S., R. 20 E. Specks of sparse microscopic to fine-grained uraninite are present in sandstone and conglomerate immediately above and 30 feet (9 m) above the Chinle-Moenkopi contact. No ore has been produced and no assays are available. The mineralized zone is less than a foot (0.3 m) thick and presumed to be low grade.

The Shamrock mine is located in the SW 1/4 NW 1/4 SE 1/4, section 4, T. 26 S., R. 20 E. on the south side of the unnamed middle tributary of Bull Canyon (plate 1). The mine consists of two adits, about 100 feet (30 m) and 150 feet (46 m) long with a few crosscuts. Little, if any, ore was produced from the mine. Host rocks at the base of the Black Ledge of the Chinle Formation consist of light-gray to buff, fine-grained to conglomeratic sandstone interbedded with dark-gray to green, thin-bedded shales, and are bleached. Mineralized zones are thin and of short lateral extent.

The You All prospect is located in the SE 1/4 section 14, T. 26 S., R. 20 E. (plate 1). A pod-like bleached and mineralized body of small lateral extent is present averaging 1 foot (0.3 m) thick. The mineralization is presumed to be low grade.

The Gray Fault mine (D. W., Golden West claims) consists of four short adits that follow mineralization in from the rim of the Potash amphitheater (plate 1). The total extent of these workings probably does not exceed 300 feet (91 m). The mineralized bodies consist of seams and pods of uranium minerals contained in sandstone and conglomerate beds that fill channels scoured into the top of the Moenkopi Formation. The average thickness of the mineralized rock is 2 feet (0.6 m). Production from this mine has totaled 1,314 pounds (597 kg) of U_3O_8.

The Big Chief or Mile High group of workings is located in the W 1/2 section 27, T. 26 S., R. 20 E. (plate 1). There is little apparent channeling at this location and the strongest mineralization is in rock with the greatest amount of carbonaceous plant debris located within 8 feet (2.4 m) of the Moenkopi contact. Grab samples have yielded as much as 0.15 percent U_3O_8. The workings consist of several adits and dogholes totaling about 800 feet (244 m) in length. The known production is 291 pounds (132 kg) of U_3O_8.

The most impressive show of uranium mineralization occurs in the extreme southeast corner of the quadrangle (section 32, T. 26 S., R. 21 E.) in the Utah School Section 32 mine (plate 1). The mine workings are extensive (many thousands of feet) and extend into the Shafer Basin and Through Springs Canyon quadrangles. The property is located in the Lower Cane Creek area of the Moab uranium district (Doelling, 1982). Individual ore bodies ranged to 200 x 300 x 6 feet (61 x 91 x 1.8 m). Records indicate that 197,000 pounds (89,000 kg) of U_3O_8 and 94,000 pounds (43,000 kg) of V_2O_5 have been recovered from the larger mine area (includes production from neighboring quadrangles) from more than 27,000 tons (25,000 metric tons) of ore assaying 0.36 percent U_3O_8 and 0.17 percent V_2O_5 through 1965 (US Atomic Energy Commission unpublished records through 1965).

All of the surface occurrences of uranium mineralization have probably been found in the quadrangle. The uranium mineralization pattern at the base of the Chinle Formation recognized in the Interriver area indicates that new ore bodies will be difficult to find and will be small and low grade.

Sand and Gravel

Colorado River alluvium (Qa) and terrace alluvium (Qat) contain sand and gravel suitable for construction of highways. The Utah Department of Transportation conducted tests on deposits at two localities, Gold Bar and Jackson Bottom, and found them suitable for use as base and surfacing gravel (table 1). The quality of the sand and gravel in the terraces and alluvium along the river is not expected to vary. No attempt was made to calculate the reserves, but they are large. Such sand and gravel was put to use in the construction of Utah Highway 279 that connects Moab with Potash.

Gold

The gravels of the Colorado River (Qa) and the terrace alluvium (Qat) contain "flour" gold and rare flakes and small nuggets. A small, but unknown quantity of gold was recovered in the quadrangle from past operations carried out adjacent to the Gold Bar, sections 5 and 6, T. 26 S., R. 21 E., and Jackson Bottom, sections 19 and 30, T. 26 S., R. 21 E. The gold occurs in black, magnetite-bearing, coarse sandy lenses in the river gravels. The gold content is generally uniform vertically in individual gravel bars. The upstream ends of bars and higher-level terraces may be slightly richer (Butler, 1920, p. 638). Some of the gravels disturbed in the process of gold extraction have subsequently been exploited for sand and gravel.

Decorative Stone

Although no decorative stone has been produced from the quadrangle, interesting rocks found in neighboring quadrangles have been put to use as facing, pavement, and garden stone in Moab. Ripple-marked sandstone from the Moenkopi Formation, rounded metamorphic and igneous cobbles from the higher-level terraces (Qat), and flat slabs of fossiliferous limestone from the Honaker Trail Formation have been collected for such purposes.

GEOLOGIC HAZARDS

Earthquakes

The northern Paradox basin shows little natural earthquake activity (Smith and Sbar, 1974). Historical seismicity in the Gold Bar Canyon quadrangle includes low-level, small- to moderate-magnitude activity with diffusely distributed epicenters (Wong, 1984). Two events have been felt at Green River. The first occurred on July 30, 1953 and had a Modified Mercalli Intensity (MMI) of V, the second on March 31, 1954 was a MMI IV event. These earthquakes are attributed to induced seismicity related to coal-mining in the Book Cliffs. Induced seismicity is defined as man-related earthquakes usually triggered by mine excavation, reservoir impoundment, fluid injection, failure of underground workings.

Wong (1984) and Wong and Humphrey (1989), studied seismicity in the Paradox basin from 1979 to 1987 in connection with nuclear waste-disposal investigations. Very low-level earthquake activity was noted along the Colorado River from its confluence with the Green River northward to Amasa Back. The strongest recorded event occurred on February 1, 1967 (Richter magnitude 3.8) with its epicenter near Upheaval Dome (Woodward-Clyde Consultants, 1980, table 7-4). Most of the events occurring in the region are microearthquakes having Richter magnitudes less than 1.0. During the period of Wong and Humphrey's 1989 study, 421 events occurred within 2.5 miles (4 km) of the original underground potash mine workings. The old workings are generally flooded with water, which hydrostatically supports the roof. The mine is periodically dewatered (about once a year) for brine extraction, during which time earthquake events increase. However, slightly stronger events have been recorded along the river to the south. Microseismic activity is not felt and has little potential for causing damage.

Rock Fall

Rock falls occur sporadically along the cliff walls of the Gold Bar Canyon quadrangle as a natural process of erosional cliff retreat. In most cases, blocks of sandstone fall from the rims and break up harmlessly on the slope below, but damage to highways and railroad tracks has occurred.

Large blocks fell from a Wingate Sandstone cliff above Utah Highway 279 (Potash highway) and the Denver and Rio Grande Western Railroad near Jug Handle Arch in the early morning on February 12, 1986. The rock fall crossed the railroad tracks and debris fell to the far edge of the roadway. The maximum block size was described as being as big as a house, and the railroad tracks and highway were damaged (William F. Case, Utah Geological Survey, written communication, 1991; Moab Times-Independent, February 13, 1986).

One large and two or three small blocks separated from the southwest cliff wall of Moab Canyon along a parallel joint surface about 2 p.m., July 1, 1988 (figure 10). There were at least three runout paths from the source. The large block made 20 impact craters before disintegrating and coming to rest on the slope below the cliff. The cumulative volume of the larger intact clasts that broke from the larger block amounted to at least 145 cubic yards (111 m^3). The only damage was to the Denver and Rio Grande Western Railroad tracks at the base of the cliff. A large clast hit the rails directly, produced a 6-foot-deep (2 m) crater in the railroad bed, and twisted the rails. Traffic on U.S. Highway 191 was stopped for about 15 minutes because of poor visibility due to dust. When the cloud dissipated there was an inch or two (2.5-5 cm) of dust on the highway (William F. Case, Utah Geological Survey, written communication, 1991; Moab Times-Independent, July 7, 1988).

Evidence for recent rock-fall events includes the lack of desert varnish on cliff faces where blocks have detached and fresh rubble on the slopes below the cliff face. Rock falls occur more regularly where joints parallel the cliff faces. Generally, soft underlying units, which provide support for the hard rocks of the cliff, are eroded back under the cliff faces by ground water moving laterally to the cliff edge above the less permeable slope formers. The undercutting removes support from beneath the massive sandstone cliffs and promotes rock falls.

Flooding

Torrential summer rains occasionally fill washes with runoff (figure 11). Rock and earth debris that has collected in the washes for many seasons is then transported toward the Colorado River. Floodwaters in washes have been observed to move boulders larger than automobiles. Damage occurs where floods cross roads and trails. Motorists should not attempt to cross washes in flood and hikers should stay out of narrow canyons when thunderstorms are imminent.

Landslides

Landsliding is not considered a serious hazard on the Gold Bar Canyon quadrangle and should not be unless a long series of wet years occurs.

Only two significant landslide deposits are present in the Gold Bar Canyon quadrangle. One is located in the NE ¼ NW ¼ NE ¼, section 19, T. 25 S., R. 21 E., on the northeast side of Moab Canyon. A block of the Salt Wash Member of the Morrison Formation detached along a clayey red interbed and moved across the trace of the Moab fault and over the top of the Cutler Formation. The landslide is old, eroded, and currently inactive.

The other landslide is located in the SW ¼, SW ¼, SE ¼, section 13, T. 25 S., R. 20 E., in a tributary of Little Canyon. A jumbled mass of ledgy sandstone and fine-grained clayey horizons from the Chinle Formation has oozed over the Moenkopi Formation like a viscous debris flow. This landslide is also thought to be old and presently stable.

Other Geologic Hazards

Building houses or constructing roadways over clay-bearing units of the Chinle and Morrison Formations should be avoided if possible, due to the presence of expanding and shrinking clay. Rocks of the Chinle and Morrison Formations crop out in only small areas in the quadrangle. Sand blowing across and accumulating on roads occasionally causes problems. More commonly, motorists using the back roads should be cautious when proceeding into areas of sheet or dune sands. Loss of traction in sandy areas becomes more pronounced during the hot summer months when even gentle slopes of sand cannot be traversed in a motor vehicle.

Table 1.
Sand and gravel tests run by the Utah Department of Transportation on Colorado River alluvium (Qa) (Utah Department of Transportation, approximately 1967).

	TEST DATA - REPRESENTATIVE SAMPLE																					
						SIEVE ANALYSIS																
						BEFORE CRUSHING		PERCENT PASSING AFTER CRUSHING TO 1" MAX. SIZE										IMMERSION COMPRESSION AVG. P.S.L.			SODIUM SULFATE LOSS	
																		LIME				
	THICKNESS OF MATERIAL	DEPTH OF OVERBURDEN	DATE SAMPLED *	TYPE OF SAMPLE	DEPTH OF SAMPLE	> 3"	> 1"	1"	1/2"	No. 4	No.* 10	No.* 40	No. 200	LIQUID LIMIT	PLASTICITY INDEX	SWELL	A. A. S. H. O. CLASSIFICATION	WO/	W/	ABRASION 500 REV.	+ 4	- 4
Gold Bar	6	0	1962	Test Hole		2.6	39.8	100	57.5	34.8	30.6	27.0	2.3	18.1	NP	.016	A-1-a			21.2		
Jackson Bottom	10	0-2	1962			2.5	49.7	100	58.7	32.1	26.8	21.3	3.0	17.1	NP		A-1-a			21.6		

Figure 10. *Cliff on southwest side of Moab Canyon one mile north of the Arches National Park visitor center. Light-hued rock debris under the cliff represents rockfall of July 1, 1988. The cliff from which the debris fell exhibits no desert varnish.*

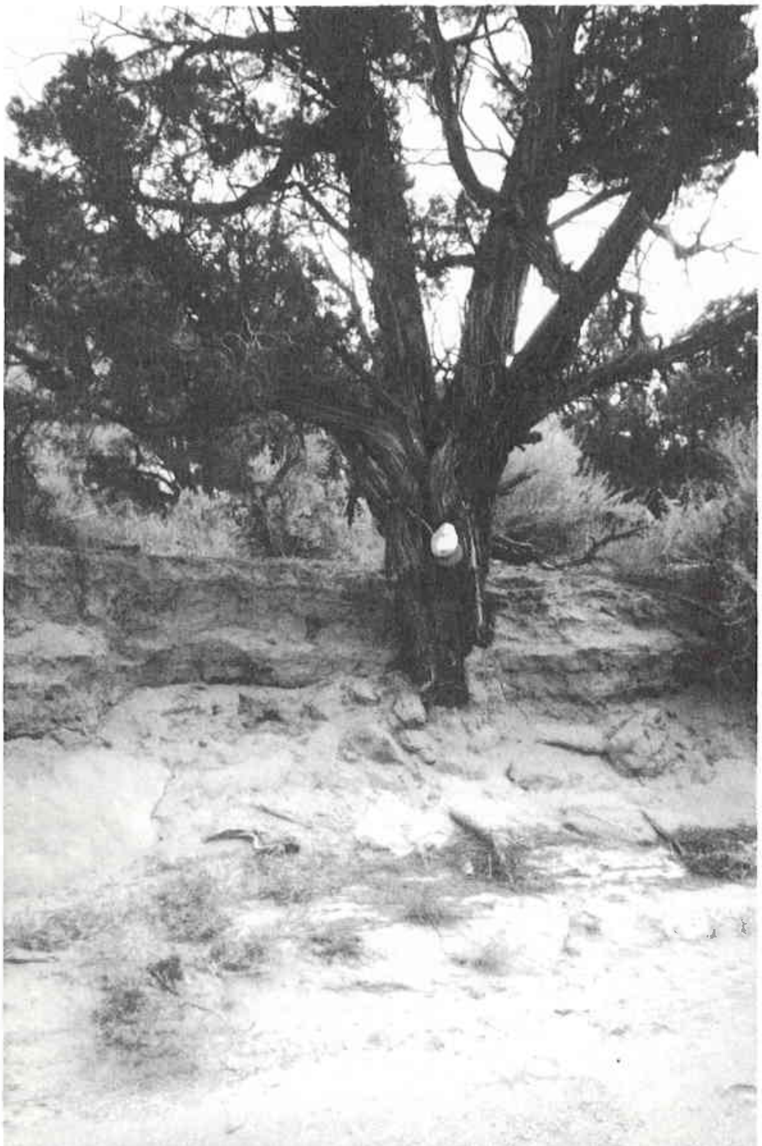


Figure 11. Partly buried tree in Little Canyon, SE 1/4 NE 1/4 SE 1/4, section 23, T. 25 S., R. 20 E. About 3 feet (1 m) of sand partially buried the trunk during a flash flood.

GROUND-WATER GEOLOGY

Three ground-water regimes are present in the Gold Bar Canyon quadrangle. The first involves bedrock aquifers and aquicludes above the level of the Moenkopi Formation, the second involves those below or the deep ground-water regime. The third involves the unconsolidated units of the quadrangle.

Bedrock Aquifers Above the Moenkopi Formation

Aquifers of the first regime are isolated from significant recharge by the deep canyons of the Colorado and Green Rivers. Even though excellent aquifers are present, discharge from springs is small and wells are expected to have small yields due to the low recharge. Snow accumulating and melting on the warped tableland provides the only significant, but limited, recharge to the upper aquifers. Precipitation varies annually, but averages only 8 to 10 inches (20-25 cm) per year.

The Navajo Sandstone is the best aquifer in the region, with a uniform regional transmissivity of 6.1 (Jobin, 1956), but only remnants of the formation remain on plateau tops in the quadrangle. The Kayenta Formation has a regional transmissivity of 2.1. Because of the Kayenta's heterogeneous lithology, ground-water reservoirs tend to be small and not connected. The Wingate Sandstone, although uniform in lithology, is better cemented than the Navajo and has a regional transmissivity of only 3.6. The Chinle and Moenkopi Formations are fine-grained aquicludes with approximately 0 transmissivities.

Deep Ground-Water Regime

The deep ground-water regime may be subdivided into three hydrostratigraphic units (U.S. Department of Energy, 1984). The upper unit consists of Permian rocks and the upper two-thirds of the Pennsylvanian 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 units below the Paradox Formation. The recharge area for the upper unit probably includes the La Sal and Abajo Mountains. The transmissivity of the upper hydrostratigraphic unit is largely unknown and untested, but permeabilities of Permian strata are low and largely controlled by the presence of local faults and joints (Huntoon, 1985). The amount of water is expected to be small and probably not as good in quality as that in the Kayenta Formation. Known seeps in the Permian Cutler Formation are from perched waters and are largely salty and unpotable (Huntoon, 1977). Permian and Pennsylvanian strata below the level of the Colorado River are generally saturated with sodium chloride brines in the Potash amphitheater area. The middle unit consists of horizons acting as aquicludes alternating with others of variable water-bearing capacity. Where water is found it is generally very salty.

The lower hydrostratigraphic unit consists of carbonates with good porosity and permeability. Oil-well data generally indicate large quantities of salty, connate water. The saltiness may reflect original seawater or mixing with the middle hydrostratigraphic unit salines. Factors that control permeabilities , listed in order of decreasing importance, include faults, joints and bedding planes, intergranular porosity, and intracrystalline porosity (Huntoon, 1977). For example permeabilities are much higher along the faulted crest of the Cane Creek anticline where fluid flow is focused parallel to the faults.

Unconsolidated Aquifers

The larger, unconsolidated sand patches (Qea and Qae) that fill the hollows on the plateau offer opportunity for ground-water development above the cliffs. Yields are expected to be small, but possibly enough for watering stock. Springs from Qa, Qea, and Qae aquifers yield good-quality calcium bicarbonate or sodium bicarbonate type water. Dissolved solid content is usually less than 500 ppm (Doelling, 1969). Wells with larger yields might be developed in the Colorado River alluvium.

SCENIC GEOLOGY

The Gold Bar Canyon quadrangle displays magnificent red-rock canyonland vistas. The Colorado River has incised a large meander loop in the southwest quarter of the quadrangle and the high canyon walls are lined with the scenic cliffs of the Glen Canyon Group. Utah Highway 279 is a beautiful river drive extending 15 miles (24 km) westward from Moab. Dead Horse Point State Park is partly located on the quadrangle. The major vista of the park into the canyonlands country is located a few miles south in the Shafer Basin quadrangle. However, many undeveloped vistas of the Potash amphitheater and the Cane Creek anticline are present that may be just as spectacular or as interesting from a geologic point of view. The cliff tops are generally 2,000 feet (610 m) above river level. A steeply inclined gravel road extends through Long Canyon, connecting Utah Highway 279 along the Colorado River with Utah Highway 313 on the warped tableland, and offering interesting views of canyonlands scenery from many vantage points.

Alcoves are common along the cliffs, and where joint spacing is narrow, several arches have formed including Gemini Arch, Jug Handle Arch, Gold Bar Arch, and Pinto Arch. Gemini Arch is located in the NW 1/4 NW 1/4 SW 1/4, section 34, T. 25 S., R. 20 E., and is in reality two large arches standing side by side. Gemini is an expanded crevice arch formed along joints in the Wingate Sandstone. It probably began as a pothole over an alcove.

Jug Handle Arch is at the mouth of Long Canyon in NW 1/4 NE 1/4 NW 1/4, section 18, T. 26 S., R. 21 E., located along Utah Highway 279, the arch formed in the Wingate Sandstone and is the classic type for a jug-handle arch. The span and opening of a jug-handle arch occur parallel to the cliffs so that the larger dimension of the opening is vertical rather than horizontal.

Gold Bar Arch is a free-standing arch cut in the Navajo Sandstone in the SW 1/4 NE 1/4 SE 1/4, section 30, T. 25 S., R. 21 E. (figure 12). A free-standing arch is distinguished by its relative isolation from surrounding rock masses (Stevens and

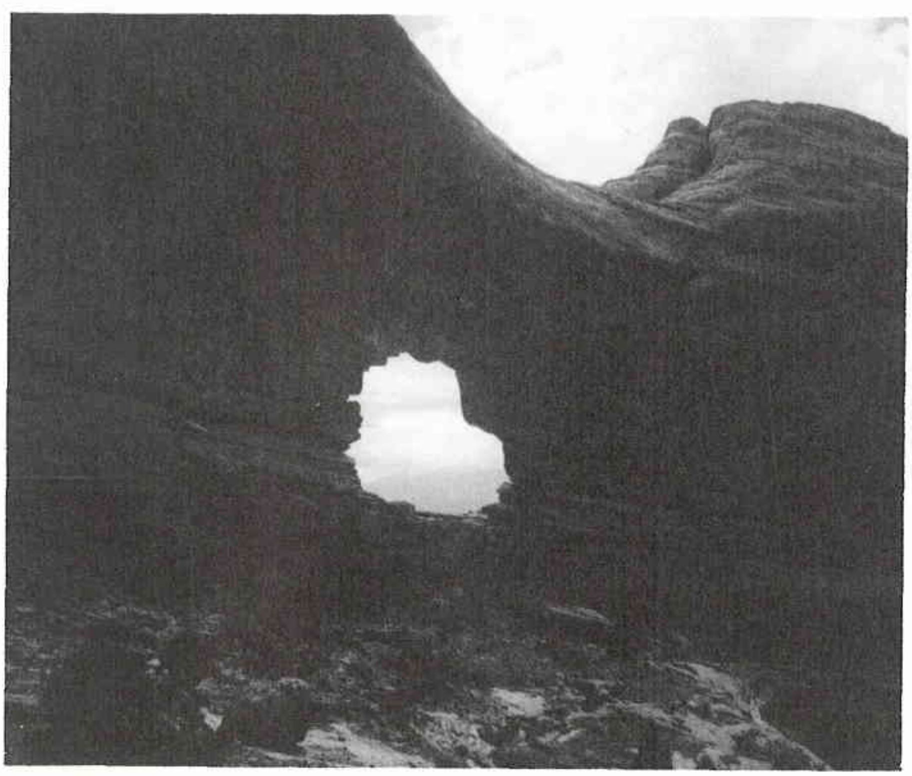


Figure 12. *Gold Bar Arch, cut into the base of the Navajo Sandstone, section 30, T. 25 S., R. 21 E.*

McCarrick, 1988, p. 18). Gold Bar Arch has a maximum horizontal span of 75 feet (23 m), is 35 feet (11 m) high, and has a width of 10 to 12 feet (3-4 m). Its sides are controlled by joint planes.

Pinto Arch is a pothole arch located in the NE¼ SE ¼ SW ¼, section 32, T. 25 S., R. 21 E., and is cut in the Navajo Sandstone. This particular arch is the result of "potholing" over the top of an alcove.

Several smaller arches are present on the quadrangle, many in Little Canyon and its tributaries. One, located in the SE ¼ NW ¼ SW ¼, section 24, T. 25 S., R. 20 E., is a spanned-alcove arch. Two adjacent alcoves have developed an opening between them. The arch in the NW ¼ NE ¼ SE ¼, section 26, T. 25 S., R. 20 E., is another expanded crevice arch based on a joint. The joint is developed at right angles to the cliff front; the opening is 10 x 25 feet (3 x 8 m) with the long dimension along the joint. About 2 to 3 feet (0.6-0.9 m) of rock is found between the crevice opening and the cliff front. Another free-standing arch is located in the NW ¼ NW ¼ SE ¼, section 24, T. 25 S., R. 20 E.

The Wingate and Navajo Sandstones locally erode into monuments and erosional forms that look like parrots, eagles, and spires. The spires and monuments commonly exceed 100 feet (30 m) in height. With a little imagination, exploring and rediscovering these scenic features can bring a great deal of enjoyment to the visitor.

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