GEOLOGIC MAPS OF THE KLONDIKE BLUFFS, MOLLIE HOGANS, AND THE WINDOWS SECTION 7.5' QUADRANGLES, GRAND COUNTY, UTAH

by Hellmut H. Doelling and Paul A. Kuehne

MAP 258DM, MAP 259DM, MAP 260DM
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2013

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NOTE: This booklet is intended for three quadrangle geologic maps, published and purchased separately: Klondike Bluffs, Mollie Hogans, and The Windows Section. Not all map units are present in each quadrangle.

Cover photo: *(top left) View looking northwest across the Salt Valley Anticline in Arches National Park. The rounded sandstone slickrock in the foreground is the Slick Rock Member of Entrada Sandstone and the Dewey Bridge Member of the Carmel Formation, and the background shows mostly Cretaceous strata (Photo by Jim Kirkland).*

(top right) View of Wall Arch before it collapsed in 2008. Wall Arch was made of the Slick Rock Member of Entrada Sandstone, and collapsed sometime in the night of August 4, 2008 (Photo by Grant Willis).

(bottom) View of South Window Arch. The Arch is composed of the Dewey Bridge Member of Carmel Formation, and the Slickrock Member of Entrada Sandstone (Photo by Gregg Buekelman).

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GEOLOGIC MAPS OF THE KLONDIKE BLUFFS, MOLLIE HOGANS, AND THE WINDOWS SECTION 7.5' QUADRANGLES, GRAND COUNTY, UTAH

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ABSTRACT

The Mollie Hogans, Klondike Bluffs, and The Windows Section quadrangles are located in east-central Utah and cover a large part of Arches National Park. They encompass colorful bedrock strata ranging in age from Pennsylvanian to Cretaceous, plus a variety of Quaternary deposits. The Salt-Cache Valley salt structure, consisting of a salt wall (a linear salt diapir), a salt anticline, and a central graben, is the most prominent structure in the quadrangles. The Moab Valley salt structure is also present under one corner of The Windows Section quadrangle. Early Tertiary deformation created anticlines that are superimposed on the Salt-Cache Valley and Moab Valley salt walls. Intervening folds include the Salt Wash and Courthouse synclines. Most structures trend northwesterly. Additional structures, such as the Elephant Butte folds, are attributed to salt dissolution, which also led to the formation of grabens above the salt diapirs.

Scenic resources are and will continue to be the most valuable asset of these three quadrangles, which contain the greatest concentration of arches in the world. Arches in The Windows Section and Devils Garden were the basis for designation of the original national monument. The area is also a showcase for joints, fins, grabens above salt walls, and colorfully displayed rock formations, and has been enjoyed by millions of visitors.

Energy and mineral resources include vanadium-uranium ore, copper, potash and magnesium salts, and petroleum. The quadrangles include part of the Yellow Cat uranium district. Potash and magnesium salts are present in great quantity in the salt walls, but are either too deep or too deformed to mine economically with today's technology. Petroleum shows have been reported in many area drill holes, especially in the marker beds of the Paradox Formation, but no wells within the quadrangle have produced economically, though several productive fields are in the area.

Potential geologic hazards in the three-quadrangle area include landslides, especially debris flows, mud flows, collapsible soils, rock falls, and flooding, and erosion. Water resources are increasingly important in the area; the Glen Canyon Group is considered the best bedrock aquifer in the Paradox Basin.

INTRODUCTION

The Mollie Hogans, Klondike Bluffs, and The Windows Section quadrangles are located north of the town of Moab in east-central Utah and cover most of Arches National Park (figures 1 and 2). The three quadrangles are located within a crude triangle formed by Interstate Highway 70, U.S. Highway 191, and Utah State Road 128, which parallels the Colorado River. Access within the three-quadrangle area is provided by national park roads, county roads, and unimproved four-wheel-drive roads extending from the three highways.

Elevations above sea level range from about 4000 to a little over 5560 feet (1200–1690 m), from the Colorado River to the top of Elephant Butte. Intermittent streams cross the area, generally from north to south, and empty into the Colorado River. Climatically, the area is a mid-latitude steppe and desert, receiving from 7 to 10 inches (18–25 cm) of rainfall per year (Iorns and others, 1965; Western Climate Center, 2012).

Dane (1935) first mapped the three quadrangles at a scale of 1:63,500. Other geologic maps covering all or parts of the three quadrangles include Williams (1964), Dyer (1983), and Doelling (1985, 2001). Several surrounding quadrangles have also been mapped (figure 2). Selected additional literature covering the geology of the three quadrangles includes reports by Lohman (1975), Doelling (1988, 2010), and Stevens and McCarrick (1988).

The three quadrangles are located in the Paradox fold and fault belt, a region of large scale salt flow and dissolution (figure 3). The main structures found in the quadrangle, Salt and Cache Valleys, owe their origin to diapiric salt flowage that formed a salt wall. Salt walls are linear salt diapirs in which salt flowed toward a linear subsurface structure, such as a fault, and then upward to form a subsurface "wall" of salt. This wall later collapsed due to salt dissolution forming linking grabens that form Salt and Cache Valleys. In southeast Utah salt walls are up to about 2 miles (3 km) high and 20 miles (30 km) long, and formed mostly in the Late Pennsylvanian to Early Triassic, with minor continued flow since that time. The rising salt typically forms an anticline in overlying strata.

Exposed strata in the three-quadrangle area are Middle

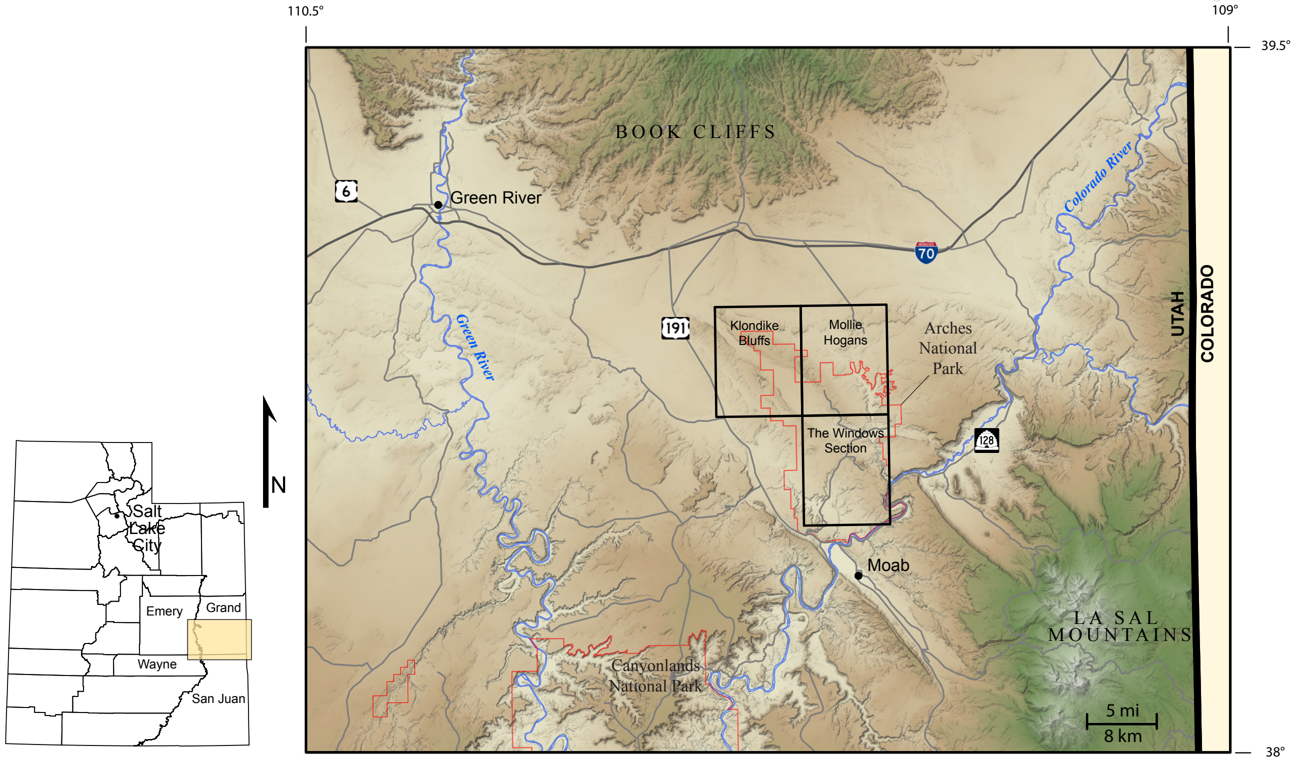

__Figure 1__. Index map showing location of Klondike Bluffs, Mollie Hogans, and The Windows Section quadrangles in east-central Utah.

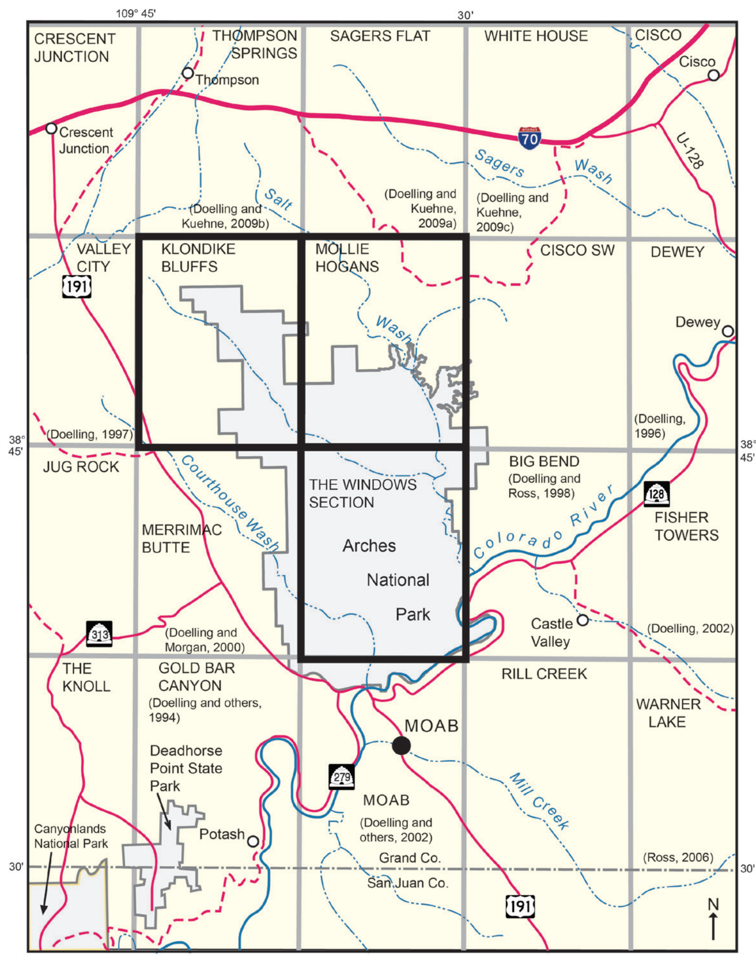

__Figure 2__. Map showing area in and around Arches National Park and the location of Klondike Bluffs, Mollie Hogans, and The Windows Section quadrangles. Geologic quadrangle maps previously published by the Utah Geological Survey are indicated by author and year in parentheses in the quadrangle, and are listed in the References section.

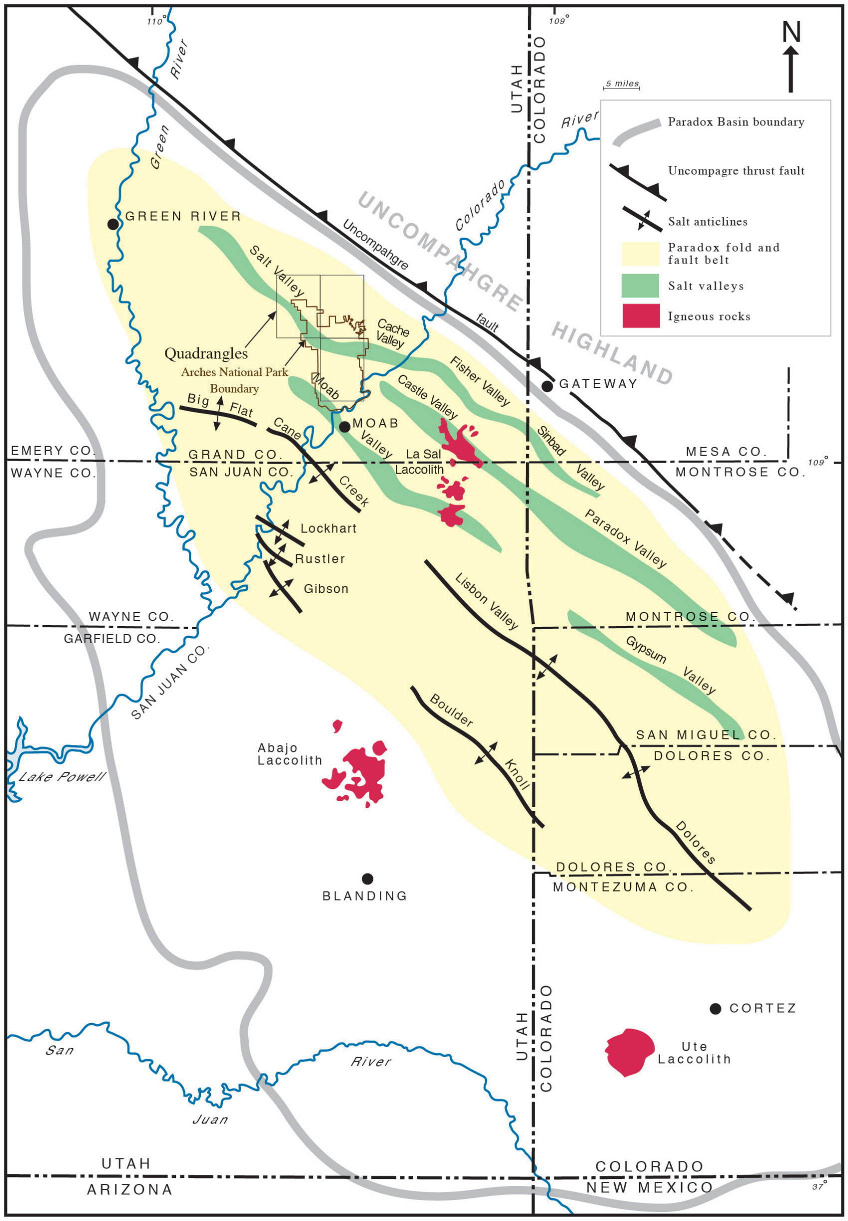

***Figure 3**. Major structural features, salt valleys, and igneous intrusive centers within the Paradox fold and fault belt of the Paradox Basin.*

Pennsylvanian to Late Cretaceous (300 to 90 Ma) in age. Due to movement of underlying salt, most Middle Pennsylvanian to Early Jurassic formations vary considerably in thickness. Where rising salt created structural and topographic highs, Late Pennsylvanian through Late Triassic rocks are very thin or missing, but on the subsiding flanks of the salt structures in rim synclines these strata are unusually thick (see cross sections). Some formations are not exposed or have few surface exposures because they pinched out against the rising structures. Only the uppermost parts of two Paleozoic formations are exposed at the surface. Most of the Mesozoic section, which averages about 6000 feet (1800 m) in total thickness, is at least locally exposed. Late Cretaceous strata are preserved only as small blocks in grabens above collapsed Pennsylvanian-Triassic salt diapirs, and north of the Salt Valley graben. Clasts derived from younger Cretaceous and early Tertiary strata to the north are common in alluvial surficial deposits. Surficial deposits, including middle Quaternary basin fill, are locally abundant.

DESCRIPTION OF MAP UNITS

Quaternary Deposits

Qa, Qa1, Qa2, Qa3 **Alluvial stream and wash deposits (Holocene)** – Moderately to poorly sorted sand, silt, and clay, with local lenses of mostly pebble-sized fragments of sandstone, in ephemeral stream channels and alluvial fans; locally includes poorly sorted, angular to subrounded cobbles and boulders; older deposits commonly mantled by thin eolian sand; along the Colorado River, consists of mostly moderately well rounded and moderately to well sorted cobbles and pebbles; Qa1 are deposits in active washes and up to about 10 feet (3 m) above the wash bottom; Qa2 and Qa3 form low surfaces 10 to 20 feet (3–6 m), and 30 or more feet (9+ m), respectively, above active channels; mapped as Qa (undifferentiated) where levels are too small or indistinct to map separately; mostly less than 15 feet (4 m) thick, but locally more than 30 feet (9 m). Alluvium, assumed to be Holocene in age, is common along the major streams and washes of the three-quadrangle area. In the graben areas, young (Holocene) alluvium may locally grade downward into basin fill that is much thicker and older. The basin fill exposed in the graben areas is discussed under mixed eolian and alluvial deposits (Qea).

Qat **Terrace deposits (late Pleistocene)** – Older alluvial deposits capping relatively high surfaces above active channels (40+ feet [12+ m]); same general composition as Qa deposits; cobbles and pebbles are generally rounded to subrounded; locally derived boulders may be subangular; mostly 5 to 20 feet (1.5–4.6 m) thick. Terrace deposits cap many surfaces above channels and washes. They are mostly aligned with the active channels, and they generally are similar in composition to Qa deposits. Though terraces are common along the Colorado River in nearby areas, no river terraces are large enough to show at map scale in The Windows Section quadrangle. Terraces mapped along Salt Wash and some of its tributaries in the northern part of the Mollie Hogans quadrangle contain detritus brought down from the Book Cliffs; some of the cobbles contain bivalve coquinas of early Tertiary age. Terrace deposits mapped along Klondike Wash in the Klondike Bluffs quadrangle were principally derived from local conglomerate of the Dakota Sandstone. These cobbles were rounded during the Cretaceous and have been reworked by alluvial processes for at least the second time. Colluvium on slopes flanking terraces is commonly mapped with the terrace deposit. The deposits are probably late Pleistocene in age.

Qaf **Alluvial-fan deposits (Holocene)** – Poorly sorted, generally unstratified, muddy sand, silt, angular sandstone fragments, and reworked pebbles derived from local bedrock outcrops; mostly along the north or northeast flank of Salt Valley in the Klondike Bluffs and Mollie Hogans quadrangles; rarely more than 10 feet (3 m) thick. Low-slope alluvial fans have developed at the bases of steeper slopes north of Salt Valley in the Klondike Bluffs and Mollie Hogans quadrangles. They consist mostly of detritus derived from the bedrock unit on which they have formed. They are probably Holocene in age.

Qap **Pediment-mantle deposits (late to middle Pleistocene)** – Mostly poorly sorted alluvial sand and small fragments of sandstone with thick calcic soil (caliche) on south rim of Salt Valley in The Windows Section quadrangle; less than 20 feet (6 m) thick. Pediments are incised erosional surfaces that are commonly veneered with gravel-rich alluvial deposits. Pediment-mantle deposits are only mapped in The Windows Section quadrangle where they form remnants of larger surfaces. The surface of these exposures slopes slightly south, away from the south rim of Salt Valley. Caliche forms rubble along the edges and at the top of part of these deposits, indicating that locally the upper soil developed on the deposits has been removed by erosion. The deposits are probably late to middle Pleistocene in age.

Qafb **Older basin-fill deposit in the Windows Section (middle Pleistocene)** – Moderate- to well-sorted sand, muddy sand, silt, and gravel with beds partially lithified to sandstone, mudstone, siltstone, and a basal conglomerate; contains marly beds with poorly preserved root structures, diatoms, and ostracods; contains two ash beds; present in The Windows Section quadrangle; 30 feet (10 m) thick. The older basin-fill deposit is found in one location in The Windows Section quadrangle west of the turnoff for Delicate Arch. The ash beds have been identified as the Bishop ash (0.74 Ma) and the Lava Creek B ash (0.62 Ma; Izett, 1982; Oviatt, 1988; Barbara Nash, University of Utah, written communication, 2012). Faults and folds have deformed ash beds in the unit. They are thicker in the center of the syncline and thinner at the center of the anticline, implying that deposition and deformation were taking place at the same time (Oviatt, 1988).

Qag **Gravel deposits (early (?) Pleistocene)** – Moderately sorted cobble and pebble gravel; generally forms thin erosional remnants; partially mantles and flanks caprock in Salt Valley; similar in composition to terrace deposits derived from the Book Cliffs; thickness indeterminate, local exposures 5 to 15 feet (1.5–4 m) thick. Gravel deposits mapped as Qag in Salt Valley are believed to be remnants of a broad gravel mantle deposited by streams that flowed down the collapsed salt structures, covering collapsed formations and Paradox Formation caprock. Exposures are generally adjacent to prominences of caprock that emerge through the fill in Salt Valley. Dyer (1983) included these gravel deposits as a basal conglomerate or gravel of his basin-fill deposits that unconformably overlie the Pennsylvanian Hermosa Group, the Triassic Chinle Formation, and the Cretaceous Mancos Shale in Salt Valley. He postulated that the gravel was carried into the Salt Valley graben by ancestral drainages originating in the Book Cliffs because it is similar in composition to terrace deposits derived from the Book Cliffs and it contains cobbles of early Tertiary bivalve coquinas. A few such deposits are present on the high flanks of the Salt Valley anticline (Doelling and Morgan, 2000), indicating that the graben has undergone considerable dissolution and collapse since gravel deposition. These gravel deposits are probably early Pleistocene in age, but age control is weak.

Qes **Eolian sand deposits (Holocene to late Pleistocene)** – Fine- to medium-grained quartzose sand as sheets and small dunes in bedrock hollows on the lee (northeast) sides of ledges, cliffs, rim rocks, and small escarpments; grains are commonly well sorted and subrounded to rounded; locally cover older, mixed eolian and alluvial deposits, especially in the Salt Valley graben; maximum thickness is about 20 feet (6 m). The deposits are prevalent on sandstone bedrock of the Navajo Sandstone, Slick Rock Member of the Entrada Sandstone, and Salt Wash Member of the Morrison Formation. Sand from the latter formations commonly drapes over the Tidwell Member of the Morrison Formation. The deposits occur as sheets and small dunes and are in part active. Locally they cover older, mixed eolian and alluvial deposits, especially in Salt and Cache Valleys.

Qea **Mixed eolian and alluvial deposits (Holocene to middle Pleistocene)** – Mostly fine- to medium-grained sand with lesser quantities of silt and sand-sized fragments and granules; mostly wind deposited, and reworked by fluvial processes. Generally as much as 20 feet (6 m) thick, but more than 300 feet (90 m) thick in the Cache-Salt Valley graben.

Qeag **Mixed gypsiferous eolian and alluvial deposits (Holocene to middle Pleistocene)** – Like Qea but with significant quantities of reworked gypsum as a gypcrete or gypsiferous soil; mostly pale gray; as much as 25 feet (8 m) thick; found only in the Salt-Cache Valley graben. Mixed eolian and alluvial deposits (Qea) and mixed gypsiferous eolian and alluvial deposits (Qeag) are mostly fine- to medium-grained sand deposited on broad surfaces protected from frequent erosion. Much of the sand was likely deposited by wind, and locally reworked and added to by alluvial processes such as sheet wash and ephemeral stream activity. In the Salt-Cache Valley graben, deposits are thicker due to subsidence during deposition. Because subsidence was unequal, these mixed deposits are more complex than similar deposits outside of the valleys. In the grabens, the deposits are dominated by fluvial materials, some are lacustrine (deposited in shallow ponds), and some parts are interlayered with gypsiferous soil adjacent to caprock exposures. Local mixed eolian and alluvial deposits that are highly gypsiferous have been mapped separately (Qeag) in The Windows Section quadrangle. The thickness of the Qea/Qeag deposits in Salt Valley is irregular because the collapsed surface on which they were deposited (mostly Paradox caprock) was hilly caprock and other bedrock that projected above the Qea/Qeag surfaces as mounds. The Department of Energy #3 well, drilled in the northwest corner of the Klondike Bluffs quadrangle in section 5, T. 23 S., R. 20 E., passed through approximately 180 feet (55 m) of Qea before reaching caprock (table 1, no. 48). At least that amount of Qea, which is deformed into graben-parallel anticlines and synclines, is exposed along the Arches National Park highway where it crosses the graben. Thicknesses are greatest where salt dissolution is favored, such as where established streams and washes (such as Salt Wash) cross the grabens. For example, in the Moab 7.5' quadrangle more than 300 feet (90 m) of valley fill overlies more than 500 feet (152 m) of caprock near the river (Doelling and others, 2002). Deposits in the grabens are Holocene to middle Pleistocene, and possibly even early Pleistocene, in age.

Qer **Mixed eolian and rubble deposits (Holocene to Late Pleistocene)** – Eolian sand and silt with angular limestone rubble derived from underlying bedrock and calcic soil (caliche) that have broken up and been incorporated into the sand and silt; as much as 3 feet (1 m) thick. These deposits are sheets of wind-blown sand and silt with rubble of weathered bedrock on small exposures of the Tidwell Member of the Morrison Formation along the west edge of The Windows Section quadrangle. Color is similar to the source bedrock. Weak calcic soils developed on some of these deposits, and the carbonate was later broken up and incorporated into the rubbly part of the deposit.

Qmt **Talus and colluvial deposits (Holocene to late Pleistocene)** – Poorly sorted angular boulders, cobbles, and smaller rock fragments in a matrix of sand, silt, and clay that fringe canyons and slopes as cones and sheets; includes rock fall deposits, creep deposits, and slope wash; thin veneer to about 15 feet (5 m) thick. Cones and sheets of talus and colluvium are common on steep to moderate slopes below cliffs and in canyons. These deposits are common in the area, but only the more prominent deposits are mapped. Most de-

Table 1. *Oil and gas exploration drill hole data for the Mollie Hogans, Klondike Bluffs, and The Windows Section quadrangles and nearby areas, Utah (from Utah Division of Oil, Gas, and Mining, undated).*

No.	Well Name	Location	Surface Elevation (feet)	Total Depth (feet)	Formation at Surface	Formation at Total Depth	Year complete	Remarks
1	Crescent Syndicate #1	SWSW 27-21S-23E	4916	2171	Mancos Shale	Dakota Sandstone	1930	Oil test
2	PCA #2 Wright	SESW 33-21S-19E	4865	5012	Mancos Shale	Paradox Formation	1943	k test. Lt O show Jgc 1896-1901; G show Paradox Formation 4865
3	Western States #1 McCarthy	--NW 34-21S-19E	4900	2200	Mancos Shale	?	1930	No data
4	Texaco #T-1 Govt	SENW 35-21S-20E	5066	5203	Mancos Shale	Cutler Formation	1970	O&G test.
5	Woodworth #1 Hawkins	SENW 36-21S-20E	4941	1952	Mancos Shale	Morrison Formation	1970	O&G test
6	Endrex #1-30 Franklin	--NE 30-21S-21E	4878	1550	Mancos Shale	Entrada Sandstone	1981	O&G test
7	Equity #1	NWSW 33-21S-21E	4798	13766	Mancos Shale	Paradox Formation	1949	O&G test
8	Supron #13-21-22 Mobil	SESW 13-21S-22E	4547	2360	Mancos Shale	Entrada Sandstone	1979	O&G test
9	Mobil #1-30 Elba Flats	SWNE 30-21S-22E	4637	18450	Mancos Shale	?	1982	O&G test
10	Utah Oil Refining #1	SWNW 03-22S-19E	4920	80	Mancos Shale	Mancos Shale	1924	O&G test
11	Crescent Eagle #1	SWSE 04-22S-19E	4780	4009	Mancos Shale	Paradox Formation	1941	O&G test, O&G shows in Mancos Shale, Dakota Sandstone 1981; strong flow+
12	Defense Plant #1 Reeder	SWSE 04-22S-19E	4787	10350	Mancos Shale	Paradox Formation	1949	k & Mg test to 4210; then O&G test;no O&G shows+
13	PCA #1 Wright	SWSW 04-22S-19E	4780	5005	Mancos Shale	Paradox Formation	1943	k test, saturated 2051-2053(Morrison Formations); O show 2565±
14	Walker #1 Govt	SWNE 08-22S-19E	4743	1820	Mancos Shale	Morrison Formation	1948	O&G test, oil show at total depth (Morrison Formation)
15	W.S.L. Main #1	NENE 09-22S-19E	4785	4125	Mancos Shale	Paradox Formation	1932	O&G test, no data or tops
16	Brendel Oil & Gas #1	NENE 09-22S-19E	4770	4125	Mancos Shale	Paradox Formation	1932	O&G test, gas show 3400 (Paradox Formation)
17	Maddox #1 Govt	SESW 09-22S-19E	4724	1830	Mancos Shale	Kayenta Formation	1950	O&G test, tops unreliable--faults?
18	Armstrong #1	SESE 09-22S-19E	4760	1223	Mancos Shale	Summerville Formation	1927	O&G test, hvy O base 710(Dakota Sandstone); O show 1210-1217
19	PCA #1 Woods	NWNW 10-22S-19E	4766	5013	Mancos Shale	Paradox Formation	1943	Potash test
20	Big Six Oil #1	NESE 10-22S-19E	4745	1710	Mancos Shale	Navajo Sandstone	1928	O&G test, Gas 460; oil 795; no tops
21	Black Dome #15-1 State	SESW 15-22S-19E	4686	1205	Mancos Shale	Morrison Formation	1980	O&G test
22	PCA #1 McCarthy	NWNE 16-22S-19E	4731	5250	Mancos Shale	Paradox Formation	1943	Potash test, produced 130 bbls Oil @ 1603
23	Beeman #1 Beeman State	NWNE 16-22S-19E	4722	1083	Mancos Shale	Summerville Formation	1984	O&G test
24	kimball #1 State	NWNE 16-22S-19E	4722	1202	Mancos Shale	Morrison Formation	1954	O&G test; pumped 20 BO in 16 hours
25	Grand Pyramid #1 Govt	SESW 20-22S-19E	4630	1480	Mancos Shale	Dakota Sandstone	1953	O&G test; no data
26	Menor Aubrey #1 Govt	SESW 21-22S-19E	4654	4910	Mancos Shale	Moenkopi Formation	1957	O&G test
27	Continental #1	NENW 22-22S-19E	4685	13223	Mancos Shale	Paradox Formation	1962	O&G test; did not reach base of salt
28	Black Dome #22-1 State	NENW 22-22S-19E	4681	1196	Mancos Shale	Morrison Formation	1980	O&G test
29	Big Six Oil #1 Salt Valley	NWSE 23-22S-19E	4670	1130	Mancos Shale	Morrison Formation	1941	O&G test; no data
30	San Jacinto Salt Valley #1	---- 25-22S-19E	4710	4060	Mancos Shale	Paradox Formation	1961	Potash test, cored continuously through salt
31	Beeman #1 Solitude Wash	SESW 26-22S-19E	4690	2385	Tidwell Member	Honaker Trail Formation	1979	O&G test
32	Raddatz-Vogel-Travis #1	SESE 09-22S-20E	4830	1415	Mancos Shale	Morrison Formation	1925	O&G test; no data
33	Continental #1 Crescent	NWSW 17-22S-20E	4780	14994	Mancos Shale	Mississippian	1973	O&G test
34	Hope Syndicate #1	NWNE 21-22S-20E	4772	1400	Mancos Shale	Morrison Formation	1925	O&G test; no data
35	Stellar #1 Stellar Fed	SWSE 30-22S-20E	4695	1260	Mancos Shale	?	1969	O&G test; no data, no tops
36	Oil Securities & Uranium #1	---- 31-22S-20E	4780	2690	Cretaceous Rocks	Paradox Formation	1956	k test; salt top may be at 220; HC blowouts in +
37	Carmack #2 Toledo Red	SWSW 03-22S-21E	4733	1518	Mancos Shale	?	1979	O&G test; no data
38	Carmack #1 Toledo Fed	-CSE 10-22S-21E	4719	1271	Mancos Shale	Summerville Formation	1979	O&G test
39	Pure #1 Govt	SESE 10-22S-21E	4697	1439	Mancos Shale	Entrada Sandstone	1956	O&G test; assume Curtis Formation included with Entrada Sandstone
40	G.k. Industries #1 Govt	NWNE 11-22S-22E	4460	1120	Mancos Shale	Morrison Formation	1954	O&G test
41	Utah Southern Oil #1	NWNW 33-22S-22E	4785	6715	Morrison Formation	Honaker Trail Formation	1937	O&G test; water at 4000 ft is 107? , no tops
42	Texaco #1 Mckinnon	SWSW 15-23S-19E	4574	12083	Mancos Shale	Mississippian	1966	O&G test
43	Moab Oil #1	NWSW 26-23S-19E	4800	700	Mancos Shale	Mancos Shale	1912	O&G test; no data
44	Equity #1 State	NESE 36-23S-19E	4588	6769	Mancos Shale	Cutler Formation	1954	O&G test
45	Pure Oil #1	SENW 02-23S-20E	5241	3036	Curtis Formation	Paradox Formation	1950	O&G test
46	Oil Securities #1 Peterson	NWNW 05-23S-20E	4773	2690	Quaternary Basin Fill	Paradox Formation	1956	O&G test; no data
47	k. Levi, Western Allies	SESE 05-23S-20E	4835	1258	Quaternary Basin Fill	Paradox Formation	1931	Potash and O&G test; O&G show 775-825
48	Dept of Energy #3	NENW 05-23S-20E	4820	4074	Quaternary Basin Fill	Paradox Formation	1979	High-level nuclear waste disposal probe
49	Continental #1 Hall	SWSW 06-23S-20E	4826	3100	Morrison Formation	Paradox Formation	1956	O&G test
50	Utah Southern Oil #1 king	NENE 13-23S-20E	5180	3829	Kayenta Formation	Paradox Formation	1929	O&G test
51	U.S. Govt Potash #24	---- 13-23S-20E	5010	1731	Quaternary Basin Fill	Paradox Formation	1931	Potash test; no potash present
52	Union #1-P-2 State	SESE 02-23S-21E	4617	3988	Morrison Formation	Cutler Formation	1970	O&G test
53	Union #1 Devils Garden	SWSE 05-23S-21E	4720	9265	Morrison Formation	Paradox Formation	1967	O&G test
54	San Jacinto #2 Salt Valley	---- 29-23S-21E	4827	4002	Quaternary Basin Fill	Paradox Formation	1961	Potash test; no potash present
55	Charles Howell-Fritz #1	NENE 31-23S-21E	4880	400	Quaternary Basin Fill	Paradox Formation	1960	O&G test; no data
56	Utah Southern Oil#1 Balsley	NWNW 32-23S-21E	4880	6120	Quaternary Basin Fill	Paradox Formation	1932	O&G test; oil show 3387-3436
57	king #1 king	NWNW 32-23S-21E	4882	3550	Quaternary Basin Fill	Paradox Formation	1953	O&G test; no data
58	Endrex #23-8 Tumbleweed	NESW 08-23S-22E	4804	2304	Morrison Formation	Cutler Formation	1981	O&G test
59	Quintana #1-9 Yellow Cat	SENW 09-23S-21E	4868	11748	Morrison Formation	Honaker Trail Formation	1970	O&G test
60	Mtn Fuel Supply #2 klondike	NESE 22-24S-19E	4779	7830	Carmel Formation	Paradox Formation	1976	O&G test
61	Tiger #12-11 State	SWNW 11-24S-20E	4927	12357	Cedar Mountain Formation	Devonian	1978	O&G test
62	Shell #1 Leggett	SWNE 12-24S-20E	4648	5600	Summerville Formation	Cutler Formation	1964	O&G test
63	Ladd #1 Salt Valley	NENW 16-24S-20E	4456	11330	Morrison Formation	Mississippian	1984	O&G test
64	Union #1 State	SWSE 36-24S-20E	4446	7534	Curtis Formation	Paradox Formation	1969	O&G test
65	San Jacinto #1 Salt Valley	---- 05-24S-21E	4840	4003	Quaternary Basin Fill	Paradox Formation	1961	Potash test; k present, cored through salt
66	Ferguson & Bosworth #1	NENE 07-24S-21E	4855	4964	Curtis Formation	Cutler Formation	1973	O&G test
67	G.C. #1 Big Rock Bartlett	NENE 26-25S-19E	5454	8875	Kayenta Formation	Mississippian	1970	O&G test
68	Pure #5 Big Flat	NWSE 27-25S-19E	5757	7253	Kayenta Formation	Mississippian	1962	O&G test; produced from Paradox Formation
69	Columbia #28-1 kane Springs	NWSE 28-25S-19E	5602	7233	Kayenta Formation	Paradox Formation	1992	O&G test; produces from Paradox Formation, horizontal well
70	Columbia #25-19-34-1 kS	NWNE 34-25S-19E	5821	7377	Kayenta Formation	Paradox Formation	1993	O&G test; produces from Paradox Formation, horizontal well
71	Chandler #16-9 Federal	SESE 09-25S-20E	4996	9968	Kayenta Formation	Devonian	1982	O&G test
72	Columbia #1 Sevenmile	SWSE 12-25S-20E	4700	4243	Cutler Formation	Paradox Formation	1938	O&G test; shows from 2130-2133, probably in IPh
73	Davis #2 Gold Bar	SESW 23-25S-20E	4852	9683	Kayenta Formation	Mississippian	1982	O&G test
74	Davis #1 Gold Bar	SWSE 19-25S-20E	5325	8386	Moenkopi Formation	Paradox Formation	1982	O&G test; Paradox Formation 53 BOPD
75	Ari-Mex #1-7 Skip Federal	NWSW 07-25S-21E	4743	2300	Curtis Formation	Moenkopi Formation	1978	O&G test
76	Delhi #2 Utah	NWSW 18-25S-21E	4337	9424	Cutler Formation	Paradox Formation	1955	O&G test; several oil shows, potash
77	Samson #1 Arches Federal	NWSW 18-25S-21E	4339	8000	Cutler Formation	Paradox Formation	1983	O&G test
78	Empire Petroleum #1	NESW 20-25S-21E	4400	235	Curtis Formation	?	1926	O&G test; no data
79	Buckeye Gas #2 Buckeye	SESW 26-25S-21E	3964	1544	Quaternary Basin Fill	Paradox Formation	1979	LPG storage well
80	Embar Big Six #1	SENW 34-25S-21E	4000	5345	Honaker Trail Formation	Paradox Formation	1926	O&G shows at var. elevs. from 2380-4880
81	Suburban #1 LPG storage	SWNE 35-25S-21E	3958	2050	Quaternary Basin Fill	Paradox Formation	1960	LPG storage well
82	Great Lakes Carbon #1	NENW 35-25S-21E	3960	3367	Quaternary Basin Fill	Paradox Formation	1943	Potash test, then brine disposal well
83	Enserch #1-3 Mineral Canyon	SENE 03-26S-19E	5858	8184	Kayenta Formation	Devonian	1984	O&G test
84	Tidewater #74-11	SENW 11-26S-19E	6132	8338	Kayenta Formation	Paradox Formation	1949	O&G test
85	Davis #1 Matthew	SESE 04-26S-20E	5004	6946	Moenkopi Formation	Mississippian	1981	O&G test
86	Davis #2 Matthew	SWNE 04-26S-20E	5015	7253	Chinle Formation	Paradox Formation	1981	O&G test
87	Davis #1 Skyline	NWSE 05-26S-20E	5809	7670	Kayenta Formation	Paradox Formation	1982	O&G test; Cane Creek production
88	Calvert Western #7 Big Flat	SENW 06-26S-20E	5846	7797	Kayenta Formation	Paradox Formation	1964	O&G test
89	Mayhew #1 Dougan-Voorhies	SWSW 01-26S-21E	4000	2027	Quaternary Basin Fill	Paradox Formation	1943	O&G test; then used as a brine well
90	Western Allied #1	NWNE 12-26S-21E	4000	2458	Quaternary Basin Fill	Paradox Formation	1920	O&G test; O shows @ 1380 & 1420; G show @ 2055
91	Union #1-G-1 Burkholder	SWNE 01-26S-22E	5300	11223	Kayenta Formation	Devonian	1972	O&G test

posits are structureless. Talus deposits are probably all Holocene to late Pleistocene in age.

Qms **Landslide deposits (late to early? Pleistocene)** – Masses of muddy siltstone with large, angular, coherent to chaotic blocks of sandstone, conglomerate, and conglomeratic sandstone; mostly involve the Dakota, Cedar Mountain, and Morrison Formations; thicknesses vary. Landslides are not common in the map area; a few deposits are located on the steep slopes of the Brushy Basin Member of the Morrison Formation and are probably late Pleistocene in age. Exposed deposits generally are composed of Dakota, Cedar Mountain, and Morrison Formation debris. Unusual small landslide remnants are common in a syncline of the Elephant Butte folds on the south flank of Salt Valley in The Windows Section quadrangle (see figure 4). The landslide blocks are made up of the Entrada and Navajo Sandstone, and are more resistant than surrounding alluvium and bedrock so they form mounds. These landslide blocks and debris lie 1 to 2 miles (1.6–3.2 km) east of the present Cedar Mountain–Brushy Basin cliff, suggesting that they are pre-Holocene, and probably early Pleistocene in age (figure 4). Additional landslides are likely concealed in valley fill below Qea in Salt and Cache Valleys.

Cretaceous Rocks

Mancos Shale The Mancos Shale is the youngest bedrock formation in the three quadrangles. Regionally, it is 3300 to 3600 feet (1000–1100 m) thick (Willis, 1994; Doelling, 2001), but only about the lower 1000 feet (300 m) is exposed in collapsed or down-dropped fault blocks in Cache and Salt Valleys in the Klondike Bluffs and The Windows Section quadrangles.

Kmb **Blue Gate Shale Member (Upper Cretaceous, lower Campanian to Santonian)** – Light- to medium-gray, fissile marine shale that is intermittently sandy; sand is generally very fine grained; weathers into low hills; 500+ feet (150 m) thick in Cache-Salt Valley graben. The Blue Gate Shale Member is similar to the Tununk Shale Member in most of its lithologic characteristics, but weathers into low, pale- to medium-gray hills. Only the lowermost about 500 feet (150 m) of the member is preserved in collapsed fault blocks in Cache and Salt Valleys.

Kmj, Kmju, Kmjl **Juana Lopez Member (Upper Cretaceous, upper to middle Turonian)** – Mostly brown-gray, platy or thin-bedded, very fine grained sandstone interbedded with mudstone and shale; forms two cuestas and mapped as upper (Kmju) and lower (Kmjl) sandstone units separated by a soft swale underlain by dark-gray and black fissile carbonaceous shale that is included in the lower map unit; broken fossils (mostly bivalves) commonly litter the surface at the top of the upper cuesta (Kmju) and locally at the top of the lower cuesta (Kmjl); cephalopod Prionocyclus wyomingensis (Turonian) and pelecypod (Inoceramus) fossils are locally identifiable in hash (Molenaar and Cobban, 1991); upper cuesta (Kmju) is 40 to 60 feet (10–20 m) thick, middle black shale is 20 to 30 feet (6–9 m) thick and lower cuesta is 25 to 30 feet (8–9 m) thick; member is 85 to 120 feet (26–37 m) thick.

The Juana Lopez Member is the most resistant part of the otherwise soft Mancos Shale in the three quadrangles due to the sand content, which also gives it a brown-gray color. It forms a double

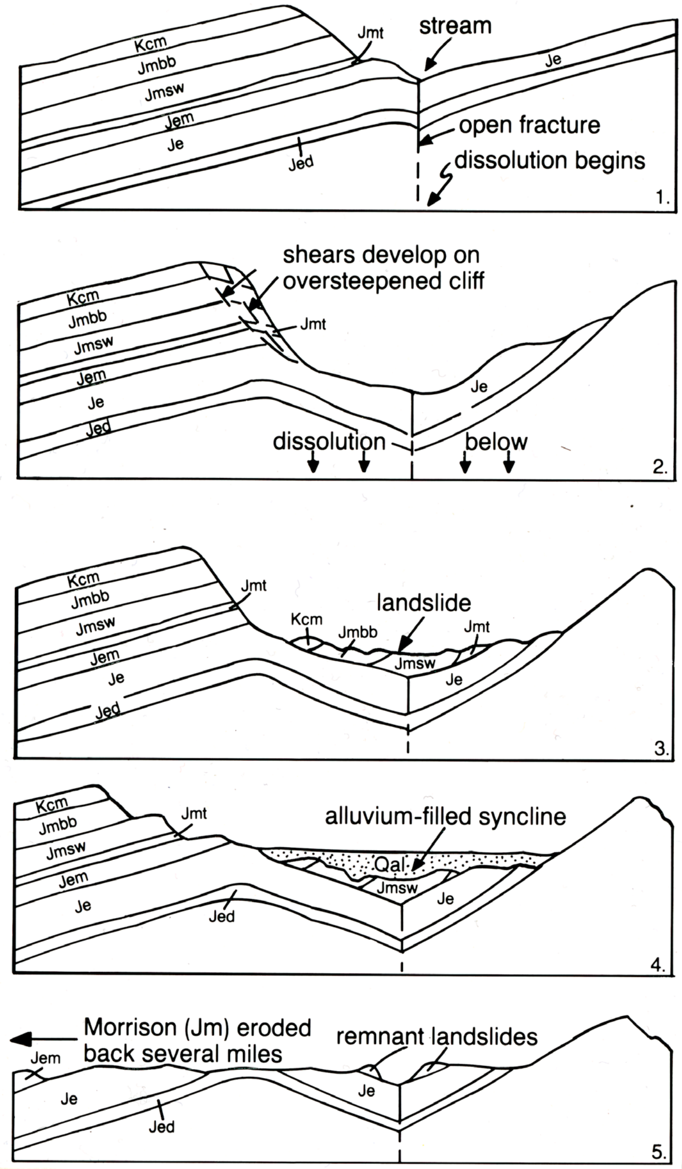

Figure 4. Development of the Elephant Butte folds landslides (from Doelling, 1988, p. 38).

cuesta along the northern margin of the Klondike Bluffs quadrangle, and is also exposed in downfaulted blocks in Salt Valley in the northwest corner of the Klondike Bluffs quadrangle, and in collapsed blocks near Salt Wash in Cache and Salt Valleys in The Windows Section quadrangle. The double-cuesta feature is not as pronounced in Salt and Cache Valleys, but the two sandy shale horizons and dark carbonaceous shale horizon are present. The Juana Lopez Member was deposited in a shallow shoaling sea, and the upper contact is gradational over a short interval. The Juana Lopez Member is Late Cretaceous in age (Molenaar and Cobban, 1991). This unit is called the Ferron Sandstone on older maps, but workers have shown that this interval is more closely related to the Juana Lopez Member to the east (Gardner, 1995).

Kmt **Tununk Shale Member (Upper Cretaceous, middle Turonian to upper Cenomanian)** – Gray fissile shale that is intermittently silty or sandy; sand is generally very fine grained; contains Coon Spring Sandstone Bed (not mapped) 45 to 50 feet (14–15 m) below the base of the overlying Juana Lopez Member; Coon Spring bed is characterized by scattered gray-brown, fine-grained, calcareous sandstone concretions up to 2.5 feet (0.7 m) in diameter that are locally fossiliferous and septarian with cracks filled with sparry siderite or calcite; 200 to 400 feet (60–120 m) thick, averaging 250 feet (75 m).

The Tununk Shale Member of the Mancos is exposed along the north margin of the Mollie Hogans quadrangle, in a fault block in Salt Valley in the northwest corner of the Klondike Bluffs quadrangle, in the southwest corner of the Klondike Bluffs quadrangle, and in collapsed blocks in Salt and Cache Valleys in The Windows Section quadrangle. It normally forms a soft, light- to medium-gray-banded slope between the Dakota Sandstone and the lower cuesta of the Juana Lopez Member of the Mancos Shale and supports little vegetation; slopes are steeper where capped by gravel or the Juana Lopez Member. The Tununk is fissile shale that is intermittently silty or sandy; sandy beds are very subtle in outcrop. Sand becomes more prevalent near the top of the unit below its contact with the Juana Lopez Member. The pelecypods *Exogyra levis* and *Pycnodonte newberryi* (late Cenomanian) are abundant near the base of the Tununk, about 20 feet (6 m) above the Dakota contact (Dane, 1935; Peterson and others, 1980). The Coon Spring Sandstone Bed (Molenaar and Cobban, 1991) is not well displayed in the map area and is not mapped. The upper contact with the Juana Lopez Member appears gradational, but is an erosional sequence boundary (Van Wagoner and others, 1990; Molenaar and Cobban, 1991). The Tununk Shale was deposited in an epicontinental sea that covered the central part of the North American continent in Late Cretaceous time (Molenaar and Cobban, 1991).

Kd **Dakota Sandstone (Upper Cretaceous, middle Turonian to upper Cenomanian)** – Mostly yellow-brown weathering, resistant sandstone, conglomeratic sandstone, and conglomerate interbedded with subordinate, slope-forming, gray to yellow-gray mudstone and thin, dark, carbonaceous shale; conglomeratic sandstone dominates the upper part, and shale dominates the lower; cementation is generally calcareous and lenses are cross-stratified; 45 to 110 feet (15–35 m) thick.

The Dakota Sandstone crops out on the flanks of the Salt Valley anticline and in steeply tilted beds within Salt and Cache Valleys. Rare fossil wood and leaf impressions are present in the more resistant beds. A lower slope-forming unit of yellow-gray to white mudstone commonly rests on the drab green-gray mudstone of the Cedar Mountain Formation in the southern part of the Klondike Bluffs quadrangle. The upper contact of the Dakota Sandstone with the Mancos Shale is gradational over a few feet. The Dakota was deposited on a broad coastal plain in front of an advancing epicontinental sea (Mancos Sea) in the Late Cretaceous (Molenaar and Cobban, 1991).

Kcm **Cedar Mountain Formation** – Members after Kirkland and others (1997, 1999). The Cedar Mountain Formation is exposed on the flanks of Salt Valley and in tilted blocks within Salt and Cache Valleys. It forms a cap on the steep slopes of the Brushy Basin Member of the Morrison Formation. This formation is marked by an unconformity at the base that is represented by an interval of chert pebbles floating in mudstone, and is also marked by a change in color from the variegated slope of the Brushy Basin Member of the Morrison Formation to the drab green-gray slope of the Yellow Cat Member of the Cedar Mountain. There are no smectitic mudstones at the base of the Yellow Cat Member. Various dinosaur fauna have been discovered in the Cedar Mountain Formation in this area. Members are still being studied, and contacts between members will likely change as more discoveries are made.

Kcmr **Ruby Ranch Member (Lower Cretaceous, Albian to Aptian)** – Drab-green and pale-gray-purple (lavender), variegated mudstone, ribbon sandstone, dolostone, and limestone; mudstone has abundant irregular carbonate nodules that form a desert pavement; contains dinosaur bone fragments; along west side of Arches National

Park includes a thick and laterally extensive lacustrine interval; Ruby Ranch Member is Early Cretaceous (Albian-Aptian) in age according to fossil evidence and radiometric and stratigraphic relations (Kirkland and others, 1999; Kirkland and Madsen, 2007); approximately 100 feet (30 m) thick.

Kcmp **Poison Strip Sandstone Member (Lower Cretaceous, Aptian)** – Fine- to medium-grained sandstone with chert pebbles, trough cross-bedding, minor conglomerate lenses, and mudstone partings; forms one to four resistant sandstone ledges that usually make a prominent escarpment (Stikes, 2007); contains dinosaur bone fragments and petrified wood; shown as a line on maps where thin; from 12 to 24 feet (4–8 m) thick.

Kcmy **Yellow Cat Member (Lower Cretaceous, Aptian)** – Pale-gray-purple (lavender) to pale-green mudstone (non-smectitic) with thin sandstone and limestone beds; the base of the Yellow Cat Member is an unconformity that is locally marked by a change from a brightly color-banded slope to a drab pale-green slope (Kirkland and others, 1997, 1999); a medial calcrete divides slope into upper and lower intervals; includes fish, reptile, and dinosaur bone fragments; about 50 feet (15 m) thick.

Jurassic Rocks

Upper, Middle, and Lower Jurassic rocks are all present in the map area. Upper Jurassic rocks consist of the Morrison, Summerville, and Curtis Formations (Baker and others, 1936). Middle Jurassic rocks are assigned to the San Rafael Group and include the Curtis, Entrada, and Carmel Formations (Gilluly and Reeside, 1928). Lower Jurassic rocks are assigned to the Glen Canyon Group and include the Navajo, Kayenta, and Wingate Formations (Gregory and Moore, 1931).

Morrison Formation

Jmb **Brushy Basin Member (Upper Jurassic, Tithonian)** – Clayey and silty mudstone, and muddy sandstone with a few conglomeratic sandstone lenses; variegated red-brown, bright-green, greenish-gray, purple-gray, and gray slopes; overall greenish-gray color in Cache Valley, elsewhere is mostly red brown; indistinctly bedded and sandstone is commonly cross-bedded; forms steep slopes above the resistant Salt Wash Member bench; beds dip steeply in Salt and Cache Valleys; 250 to 450 (76–140 m) feet thick.

The Brushy Basin Member of the Morrison Formation was partly deposited on a broad floodplain dotted with small lakes and partly in a larger lake known as Lake To'odichi (Peterson and Turner-Peterson, 1987). Peterson and Turner-Peterson (1987) thought that the bright green Brushy Basin sediments were deposited subaqueously and that the variegated strata was deposited as overbank and floodplain deposits. Many of the mudstones are probably decomposed reworked volcanic ash, and have high clay content as is evident from "popcorn" weathered surfaces. About 75 percent of the Brushy Basin is mudstone. The sandstone and conglomerate lenses are generally present near the base of the unit. Dinosaur bone and petrified wood are locally present. The Brushy Basin is Late Jurassic in age (Kowallis and others, 1991; Demko and others, 2004).

Jms **Salt Wash Member (Upper Jurassic, Kimmeridgian)** – Light-gray sandstone lenses 2 to 20 feet (0.6–6 m) thick (25 to 40%) interbedded with red-brown, green-gray, and lavender muddy siltstone (60 to 75%); sandstone lenses are cross-bedded, poorly sorted, have dominantly quartz grains, increase upwards, and break apart and litter the outcrop; bench and cliff-forming; upper sandstone lenses are commonly mineralized with vanadium and uranium in the Mollie Hogans quadrangle in the Yellow Cat area; muddy siltstones weather into recesses or earthy slopes; 130 to 300 feet (40–90 m) thick, averaging about 180 feet (55 m).

The Salt Wash Member is a fluvial deposit laid down as channel deposits in an anastomosing braided river system. The sandstone lenses represent ancient river channels with individual channels locally traceable for a few hundreds of feet. Sedimentary features, such as meanders, point bars, trough cross-stratification, and cut-and-fill are readily identifiable. The muddy siltstones are considered overbank deposits. The upper sandstone lenses of the Salt Wash Member are commonly mineralized with uranium and vanadium, especially in the Mollie Hogans quadrangle in the Yellow Cat area. Typically, the member consists of six or seven thick, vertically stacked sandstone lenses. Locally, dinosaur bone and fragments of petrified wood have been found in the member. The upper contact is placed at the top of the interval dominated by the light-gray sandstone channels of the Salt Wash Member, above which are the brightly variegated mudstone or dark-colored conglomeratic sandstone lenses of the Brushy Basin Member. The upper part of the Salt Wash Member generally forms a bench with the steep slope of the Brushy Basin Member above. Tilted Salt Wash outcrops are also present in fault slices in Salt and Cache Valleys. The age of the Salt Wash is Late Jurassic (Kowallis and Heaton, 1987; Demko and others, 2004).

Jmt **Tidwell Member (Upper Jurassic, Kimmeridgian)** – Red-brown, gray-brown, lavender, tan, or light-gray-weathering siltstone with discontinuous beds of light-gray limestone near base and top; contains mostly white chert concretions up to 6 feet (2 m) in diameter near the base in many areas; forms a red-brown slope with the underlying Summerville Formation; 20 to 50 feet (6–15 m) thick.

The Tidwell Member of the Morrison Formation generally forms a continuous slope or recess with the Summerville Formation between the Salt Wash Member sandstone and the Moab Member of the Curtis Formation. However, whereas the Summerville Formation is non-calcareous, the Tidwell is calcareous. The upper part of the Tidwell has a lavender hue, whereas the lower part is light-tan to gray-brown, similar to the Summerville Formation. Some of the chert concretions are as much as 6 feet (2 m) in diameter and a few contain irregular red and brown patches of jasper. The upper contact of the Tidwell Member is placed at the base of the first thick sandstone lens in the Salt Wash Member. The contact is gradational and locally intertonguing. The strata were probably deposited on a gently sloping floodplain or in shallow lakes on this floodplain. The Tidwell Member is Late Jurassic in age (Kowallis and Heaton, 1987; Demko and others, 2004).

Jsmt **Tidwell Member of Morrison Formation and Summerville Formation, undifferentiated (Upper Jurassic, Kimmeridgian and Oxfordian)** – *undivided in some areas on maps and cross sections.*

The Summerville Formation and Tidwell Member of the Morrison Formation form a reddish-brown interval between the light-hued Moab Member sandstone below and the Salt Wash Member of the Morrison Formation above. Where poorly exposed, the two units are difficult to differentiate. Both the Summerville and Tidwell are thin units, but are separated by a regional unconformity (J-5 unconformity of Pipiringos and O'Sullivan, 1978). With practice they can be divided in outcrop, but on aerial photography the contact is difficult to place. Therefore, we have left them undivided in some areas; and have mapped them separately elsewhere.

Js **Summerville Formation (Upper Jurassic, Oxfordian)** – Thin- to medium-bedded, light-tan to brown, ledgy sandstone and slope-forming red-brown sandy siltstone; fine to medium grained, well sorted, and quartzose; upper sandstone rippled; forms a steep slope capped by ledge of blocky to platy sandstone at top; has reworked yellow-gray sandstone at base that locally has dinosaur footprints; 6 to 40 feet (2–12 m) thick, averaging 25 feet (8 m) thinning southward.

The upper contact of the Summerville is placed at the base of a thin-gray limestone bed or maroon to lavender siltstone of the Tidwell Member of the Morrison Formation. McKnight (1940) interpreted the Summerville as delta deposits marginal to a shallow sea that lay to the west. The Summerville Formation is Late Jurassic in age (O'Sullivan, 1992; Wilcox and Currie, 2006).

Curtis Formation

Jctm **Moab Member (Upper Jurassic, Oxfordian)** – Pale-orange, gray-orange, pale-yellow-brown, or light-gray, fine- to medium-grained, calcareous, very thick bedded, cliff-forming, low-angle cross-stratified sandstone that weathers white or light gray; well indurated; generally highly jointed in outcrop; 25 feet (8 m) of brown, thin-bedded, silty, fine-grained, slope- or recess-forming sandstone underlies very thick bedded sandstone in the northwest part of the Klondike Bluffs quadrangle; 60 to 110 feet (20–34 m) thick.

The Curtis Formation consists only of the Moab Member in this area. It is a conspicuous, resistant sandstone that forms a capping surface on many of the Entrada Sandstone cliffs. This capping surface is usually highly jointed, which is quite evident from the air, especially along the flanks of the Salt Valley salt structure (Lorenz and Cooper, 2009). The Moab Member lies above the J-3 unconformity of Pipiringos and O'Sullivan (1978) and correlates with the main body of the Curtis Formation as exposed in the San Rafael Desert area west of the Green River (Doelling, 2001, 2002b). West of the map area the Moab Member thins abruptly, tonguing into the main Curtis Formation. As noted above, typical Curtis Formation lithology of areas to the west continues eastward under the Moab Member sandstone into the northwest corner of Arches National Park. Up to 25 feet (8 m) of silty, slope-forming sandstone of the main body of the Curtis Formation underlies the Moab Member in the northwest part of the Klondike Bluffs quadrangle (not mapped separately), but southeastward the main body of the Curtis thins to become a prominent parting or indentation. The Moab Member was formerly a member of the Entrada Sandstone (Wright and others, 1962; Williams, 1964; Doelling, 1985; Doelling and Morgan, 2000), but was moved into the Curtis Formation because it overlies the J-3 unconformity (Doelling, 2002a, 2010) and intertongues with the Curtis to the west (Doelling, 2001). The upper contact is sharp and is drawn where the light sandstone of the Moab Member is overlain by the red-brown sandstone of the Summerville Formation. The base of the Summerville consists of a few inches to a foot of reworked Moab Member sandstone. The source of the Moab Member was to the southeast (McKnight, 1940). The Moab Member was deposited in an eolian dune field downwind of the Curtis seaway (Peterson, 1994). The age of the Curtis Formation is Late Jurassic (Wilcox and Currie, 2006).

Entrada Sandstone

Jes **Slick Rock Member (Middle Jurassic, Callovian)** – Well-indurated, red-orange or brown, locally banded, very fine- to fine-grained eolian sandstone containing sparse and scattered medium to coarse grains, all cemented with calcite and iron-oxide cement; eolian cross-stratified and planar bedded; locally indented parallel to banding; forms smooth vertical cliffs, mesas, bare-rock slopes, and buttes; generally highly jointed; commonly contains small holes (tafoni) aligned along cross-bed laminae; most arches formed in this and in the immediately adjoining units; 180 to 400 feet (55–120 m) thick, mostly 230 to 300 feet (70–90 m) thick.

The Entrada Sandstone, which consists only of the Slick Rock Member in this area, generally forms vertical cliffs, and locally forms mesas and buttes. The Slick Rock Member is perhaps the most important geologic unit in Arches National Park. Most of the arches in the park are positioned along its lower and upper contacts and along the indentures in the middle of the unit. It makes up the vertical cliffs of The Courthouse Towers and The Great Wall, and the fins of the Fiery Furnace and the area northeast of Salt Valley where it is cut by numerous closely spaced joints. Where the Slick Rock is not exposed as a cliff, fin, or arch, the outcrop band is covered or partly covered by large irregular fields of self-derived wind-blown sand. The unconformable upper contact is mostly with eolian sandstone of the Moab Member of the Curtis Formation, or the underlying silty sandstone beds. This contact is sharp and easily mappable because the overlying Moab Member is not banded and does not have the small holes aligned along the cross-bed laminae. The Slick Rock Member was deposited in a dune field in a back-beach area and is Middle Jurassic in age (Wright and others, 1962; Peterson, 1994).

Carmel Formation

Jcd **Dewey Bridge Member (Middle Jurassic, Callovian and Bathonian)** – Lower part is yellow-gray, planar-bedded, medium- to thick-bedded, resistant, fine-grained sandstone 15 to 80 feet (5–24 m) thick; in some areas lower part is color-banded pink to red-brown; upper part is red-brown, muddy, soft, mostly fine-grained sandstone 60 to 150 feet (20–50 m) thick generally thickening northwestward, with irregular and local contorted bedding; forms a distinctive reddish recess or earthy slope between the Navajo and Entrada Sandstones; angular, white and gray chert fragments are commonly embedded in the lower sandstone immediately above the Navajo Sandstone contact; upper and lower parts not mapped separately; 90 to 190 feet (30–60 m) thick.

The Carmel Formation is exposed in all three quadrangles and in this area only consists of the Dewey Bridge Member. In the past, the Dewey Bridge Member was assigned to the Entrada Sandstone (Wright and others, 1962; Lohman, 1965; Doelling, 1985; Doelling and Morgan, 2000); however, recent workers have reassigned it to the Carmel Formation (O'Sullivan, 2000; Doelling, 2001, 2002b). It forms a relatively narrow outcrop band above the rims of Salt and Cache Valleys, and forms the base of Elephant Butte, the Great Wall, and the Courthouse Towers. The Dewey Bridge Member of the Carmel Formation erodes into arches and alcoves at many locations in the map area, notably at the Windows Section of Arches National Park (Doelling, 1996). The red-brown Dewey Bridge beds are overlain by orange-brown massive sandstone of the Entrada. The contact with the Entrada is conformable and sharp, but locally it can be irregular. In some cases the Dewey Bridge and Entrada intertongue. Thickness variations in the Dewey Bridge Member may partly be due to the relief on top of the Navajo Sandstone, the lower Dewey Bridge being thicker where hollows are present in the Navajo's upper surface. The Dewey Bridge Member of the Carmel Formation was deposited on broad tidal flats marginal to the shallow Carmel sea, located to the west (Wright and others, 1962; Peterson, 1994). It correlates with parts of the Winsor and Paria River Members of the Carmel Formation and Page and Temple Cap Formations in areas to the south and west (Sprinkel and others, 2011). The Dewey Bridge is Middle Jurassic in age (Wright and others, 1962; Sprinkel and others, 2011).

Glen Canyon Group

JTRgc **Navajo, Kayenta, and Wingate Formations, undivided (Lower Jurassic to Upper Triassic)**; *cross section only.*

Jn, Jnl **Navajo Sandstone (Lower Jurassic)** – Mostly light-red-brown, light-brown to light-gray, fine-grained, eolian quartz sandstone; generally friable and weakly cemented with silica or calcite; medium to coarse grains of sand are common along cross-bed laminae; sandstone is massive and divided into generally 15- to 25-foot-thick (5–8 m) cross-bed sets; cross-bed angles locally exceed 30 degrees; thin, gray, cherty limestone beds, which represent small playas ("oases") in the paleo-ergs, can cover several hundred acres, locally contain small nodules of authigenic jasper (red chert), form resistant benches, and are present in the upper third of the formation (Jnl); they are 1 to 4 feet (0.3–1.2 m) thick; thin, red, silty sandstone partings separate the limestone beds; 200 to 700 feet (60–210 m) thick, but mostly 200 to 400 feet (60–120 m) thick.

The Navajo Sandstone, with the Wingate and Kayenta Formations, make up the rim rocks of Salt and Cache Valleys. It also forms a large bench in The Windows Section quadrangle between the canyon of Salt Wash and the Great Wall. The surface of this bench area has irregular, dome-shaped, bare-rock sandstone outcrops, sometimes referred to as "petrified" sand dunes. The contact with the overlying Carmel Formation is unconformable and displays relief. Beds above and below the unconformity are generally parallel. In the Merrimac Butte quadrangle to the west, this unconformity displays relief up to 80 feet (25 m), and low areas on the upper surface of the Navajo are overlain by thicker Carmel strata (Doelling and Morgan, 2000). The relief may not be as great in these three quadrangles. Commonly, both the Navajo and the lower part of the Carmel Formation are fine-grained sandstone of the same color, and locally the contact may be difficult to identify. Angular white chert is common immediately above the contact in the Carmel Formation. Some of the variation in thickness of the Navajo Sandstone is due to relief on its upper surface; the variation might also be explained by local renewed movement of salt during Early Jurassic time. The Navajo Sandstone was deposited in an eolian environment (Peterson and Pipiringos, 1979; Blakey and others, 1988). The limestone represents deposition in oases, playas, or interdune lakes (Stokes, 1991; Peterson, 1994).

Jk **Kayenta Formation (Lower Jurassic)** – Mostly red-brown, stream-deposited, lenticular sandstone interbedded with intraformational conglomerate, siltstone, and shale with subordinate eolian sandstone; some thinner beds are purple, lavender, red, tan, orange, or white; sandstone is mostly moderate orange-pink and shale is mostly dark red-brown to gray-red; sandstone varies mostly from fine to coarse grained, and is mostly quartz; it exhibits both high- and low-angle cross-stratification, channeling, current-ripple marks, and rare slump features; forms ledgy and cliffy bare-rock surfaces; locally fractured and deformed; 220 to 340 feet (70–100 m) thick.

In the map area, the Kayenta Formation (with the Wingate and Navajo) forms the rim rock of the Salt Valley grabens. Along the canyons of the Colorado River and its tributaries, it forms the cap of a bench, and in some areas with the Wingate and Navajo, forms a single cliff locally up to 900 feet (300 m) high. Generally, however, the Kayenta outcrop is a ledge or step-like bench between the more massive and cliffy Wingate and Navajo Sandstones below and above. The contact with the overlying Navajo Sandstone is conformable and locally intertonguing. The uppermost Kayenta bed is generally a gray-pink, thick to very thick sandstone bed that is lighter in color than the beds above and below it, and has a sharp and nearly horizontal upper surface. The Kayenta Formation was deposited in a fluvial system and its source area was the Ancestral Rocky Mountains of eastern Utah and western Colorado (Luttrell, 1987). Eolian rocks near the top of the formation indicate a gradual change in climate (Blakey, 1994). The Kayenta is Early Jurassic in age (Padian, 1989).

Jurassic-Triassic Rocks

JTRw **Wingate Sandstone (Lower Jurassic to Upper Triassic)** – Light-orange-brown, moderate-orange-pink, moderate-red-orange, pink-gray, or pale-red-brown, fine-grained, well-sorted, cross-bedded, eolian sandstone; forms massive desert-varnished vertical cliffs except where deformed along Cache-Salt Valley graben; locally cliff is horizontally banded especially in the Klondike Bluffs quadrangle; sandstone is well sorted, subrounded to rounded, and commonly stained with iron oxide; 250 to 450 feet (80–140 m) thick, averaging 300 feet (90 m).

The Wingate Sandstone mostly forms a prominent cliff along canyons of the Colorado River and its tributaries. Along the rims of Salt and Cache Valleys it is commonly shattered, and the typical vertical cliff is replaced by a very ledgy and step-like, blocky outcrop. Outcrops are dominantly red-brown, but commonly streaked and stained to a darker brown or black by desert varnish. Sandstone is quartzose and subarkosic, and contains traces of chert and accessory minerals (Lohman, 1965; Cater, 1970). The contact with the overlying Kayenta Formation is an irregular, sharp surface that locally is erosional with scouring and cut-and-fill features. Nation (1990) and Blakey (1994) interpreted the contact as unconformable while Baker and others (1936) defined the contact as locally conformable and gradational. We have interpreted it as comformable in this area. The contact is mapped where the vertical cliff ends and is replaced by more red or pale-purple ledges of the Kayenta Formation. The Wingate Sandstone represents eolian dune and interdune sediments deposited in erg environments that covered a large part of the Colorado Plateau in the Early Jurassic to Late Triassic (Blakey and others, 1988; Nation, 1990; and Blakey, 1994; Jensen and Kowallis, 2005).

Triassic Rocks

ŧc, ŧcu, ŧcl **Chinle Formation (Upper Triassic)** – Divisible into mappable lower (ŧcl) and upper members (ŧcu) that are only mapped along canyons of the Colorado River and lower Salt Wash; lower member (ŧcl) is light-green-gray, orange-pink, and pale-red-brown, interbedded, quartzose, ledge-forming sandstone and conglomerate with subordinate siltstone and mudstone; sandstone exhibits small- to medium-scale cross-stratification; upper part of lower member is commonly mottled white, light gray, purple, yellow, orange, and red brown; mottling is associated with paleosols that contain networks of vertical tubes that may represent root traces and crayfish and lungfish burrows; upper member (ŧcu) is primarily moderate-red-brown and pale- or gray-red, fine-grained sandstone and siltstone; sandstone exhibits indistinct bedding and occurs as lenses or layers that interfinger with siltstone beds; fine-grained, calcareous sandstone consists of well-sorted, subangular to subrounded quartz grains and minor mica; primary sedimentary features include horizontal stratification, medium- to small-scale, low-angle, trough cross-stratification, and asymmetrical ripple laminations; siltstone is generally structureless and indistinctly bedded; the two members are separated by an unconformity; upper member (ŧcu) is 200 to 460 feet (60–140 m) thick in outcrops and lower member is 0 to more than 380 feet (0–120 m), but is generally less than 150 feet (45 m) thick in outcrops; the formation (ŧc) varies from less than 200 feet (60 m) to nearly 900 feet (270 m) thick in the subsurface across the three quadrangles.

Like the Moenkopi Formation, the Chinle is mostly a subsurface unit in the map area. It is exposed along the Colorado River at the Big Bend and downstream in The Windows Section quadrangle, and in scattered outcrops along the margins of Salt and Cache Valleys in all three quadrangles. It unconformably overlies the Moenkopi Formation in the central and east parts of The Windows Section quadrangle, and the Honaker Trail Formation in most of its Salt and Cache Valley exposures. Though formal members have been defined in southeastern Utah, in the Moab–Arches National Park area, members are difficult to map consistently and are generally not mapped or are lumped into two informal members due to rapid thickness and facies changes, indistinct contacts, and structural complications. The lower member (ŧcl) is generally much thinner than the upper, but is unusually thick in rim synclines. The thickest outcrops for both members are in rim synclines near Mat Martin Point in The Windows Section quadrangle. The thinnest sections are on top of the Salt-Cache Valley salt wall. The upper paleosol contains networks of vertical tubes that may represent crayfish burrows, root tracings, and lungfish burrows (R.F. Dubiel, verbal communication, 1993; Demko and others, 1998). A distinct angular unconformity exists between the lower and upper members of the Chinle Formation as seen in the Colorado River canyon in The Windows Section quadrangle. The upper member of the Chinle Formation may be divided into three parts (not mapped) based on resistance to erosion. Upper and lower parts are generally slope forming. The middle is ledge- and cliff-forming, mostly pale-red, red-brown, and red-gray, fine-grained sandstone interbedded with lenticular conglomeratic sandstone and thin siltstone and shale beds. The ledges and cliffs are commonly stained with desert varnish. The Chinle Formation unconformably overlies the Moenkopi Formation and is Late Triassic in age (Kirby, 1989; Lucas, 1993). It was deposited in alluvial channel and floodplain environments (Dubiel and others, 1989; Dubiel, 1994).

ŧm **Moenkopi Formation (Lower Triassic)** – Only exposed in The Windows Section quadrangle, but thick in subsurface in other quadrangles; consists of four members in area, but only the upper two, Pariott and Sewemup Members, are exposed, but not mapped separately due to small outcrops; Sewemup Member is mostly pale-red-orange to gray-red, slope-forming, micaceous, thinly laminated to thin-bedded siltstone and generally red-brown to light-brown, fine-grained, micaceous subordinate sandstone; thin to thick beds of pale-lavender, coarse-grained sandstone to conglomeratic sandstone are locally present; the Pariott Member caps the Sewemup and is red-brown to lavender, thin-bedded sandstone interbedded with chocolate-brown, orange-brown, and red-brown siltstone and mudstone and contains many ledge-forming beds; Pariott Member is 210 to 230 feet (64–70 m) thick in the Big Bend area; only a few tens of feet of the Sewemup Member are incompletely exposed; whole formation is 0 to 2200 feet (0–670 m) thick in the subsurface; it is not present over Salt Valley–Cache Valley diapir and thickens in adjacent rim synclines.

In the map area, the Moenkopi Formation consists of four members (ascending): Tenderfoot, Ali Baba, Sewemup, and Pariott (Shoemaker and Newman, 1959). Near the Big Bend of the Colorado River in The Windows Section quadrangle only the uppermost Pariott Member is exposed, but the other members are exposed in the Big Bend quadrangle to the east (Doelling and Ross, 1998). The Pariott and Sewemup Members are recognizable on the south margin of Cache and Salt Valleys in The Windows Section quadrangle; unidentified fault slivers of the other members may also be present. The Moenkopi is present in the subsurface of the map area on both sides of the Salt Valley salt diapir (see cross sections). The exposed partial sections of the Moenkopi Formation in Salt and Cache Valleys are all probably less than 300 feet (90 m) thick. The Moenkopi Formation is primarily intertonguing deltaic and coastal (tidal flat) deposits that represent the initial Mesozoic marine transgression in the Colorado Plateau region (Stewart and others, 1972). The Moenkopi is characterized by ubiquitous oscillation ripples and mudcracks. Its beds are dated as Early and possibly Middle Triassic by most workers (Dubiel, 1994).

Permian Rocks

Pℙc **Cutler Formation (Lower Permian-Upper Pennsylvanian, Wolfcampian Desmoinesian)** – In the three-map area, Permian rocks, represented by the Cutler Formation, are not exposed, but they are exposed just outside of the area where they consist primarily of interbedded, red-brown, arkosic and subarkosic sandstone and orange-brown, eolian quartz sandstone, interbedded with generally minor red-brown siltstone, mudstone, and conglomerate (Doelling, 2001). Apparently they were not deposited over the Salt Valley salt wall, which rose relatively rapidly during the Early Permian, but they were deposited in the adjacent rim synclines. In the subsurface northeast and southwest of the Salt Valley salt wall in the map area they may exceed 4000 feet (1200 m) in thickness (see cross sections). The Cutler may be as much as 3500 feet (1200 m) thick in the adjacent Valley City quadrangle (Doelling, 1997) and 4000 feet (1220 m) thick in the Merrimac Butte quadrangle (Doelling and Morgan, 2000). Even thicker sections may be present in the subsurface between the Salt Valley salt wall and the Uncompahgre fault (White and Jacobsen, 1983; Doelling and others, 1994; Dubiel and others, 2009). The Cutler Formation was deposited on coalescing alluvial fans shed southwestward off of the Uncompahgre uplift, located to the northeast. The formation fines to the southwest (distal end of the fan) and intertongues with thin marine limestone beds (exposed in the Merrimac Butte quadrangle; Doelling and Morgan, 2000). Near the Uncompahgre uplift to the east and in the subsurface, coarse alluvial lower Cutler beds are stratigraphically and chronologically older and interfinger with the Honaker Trail and even Paradox Formations (Dubiel and others, 2009; Kluth and Duchene, 2009). The Culter Formation is primarily Early Permian in age, but the basal part is Late Pennsylvanian in age (Condon, 1992, 1997; Dubiel and others, 2009; Baars, 2010).

Pennsylvanian Rocks

ℙh **Honaker Trail Formation (Pennsylvanian, Missourian-Virgilian)** – Chippy-weathering sandstone, limestone or dolomite, shale and shaly siltstone, arkosic sandstone, and conglomerate; sandstone is the most abundant and is gray-tan-yellow or light brown, fine to medium grained, locally pebbly and gritty, locally cross-stratified, calcareous, and becomes finer grained southward; shaly to thin, very fine grained sandstone beds weather to produce sandstone chips; most sandstone beds are up to 4 feet (1.3 m) thick; limestone is gray, thin-bedded to shaly, silty and sandy, and contains rare, poorly preserved crinoid fragments; shale and siltstone beds are well indurated, siliceous or calcareous, commonly distorted, and light gray to dark brown; outcrops consist of highly faulted and folded slivers 200 to 300 feet (60–90 m) thick on top of the Salt Valley salt wall; the formation in the rim synclines may be more than 2400 feet (730 m) thick; identity of some smaller outcrops is questioned because of poor exposures, shattered rock, and similar lithologies to parts of Paradox Formation caprock.

The Honaker Trail Formation is exposed in hills in Salt Valley and is generally adjacent to Paradox Formation caprock exposures. The relationship between the two formations is unclear except perhaps in section 33, T. 23 S., R. 21 E., in the Mollie Hogans quadrangle, where it appears that a thin sequence of Honaker Trail rocks overlie Paradox gypsum and is in turn overlain by the Triassic Chinle Formation. Like Paradox Formation caprock, rocks are folded and faulted, and in some outcrops difficult to distinguish from them. In an earlier publication, Doelling (1988) called these rocks "non-gypsiferous outcrops" in contrast to "gypsiferous outcrops" of Paradox caprock. Some previous investigators (Elston and others, 1962; Gard, 1976) called these rocks Paradox marker bed material or included them in the Paradox Formation. Dyer (1983) identified them as "tentative" Honaker Trail Formation. Sandstone beds in the sections caused us to assign these rocks to the Honaker Trail Formation because the exposures do not match well with Hite's (1977) description of marker beds in the Paradox cycles, even though a 200- to 300-foot (60–90 m) exposure may be similar in composition and appearance to some marker beds intercepted in wells. Based on drill-hole information, the Honaker Trail Formation in the subsurface of these quadrangles consists of fossiliferous limestone and dolomite, cherty limestone, siltstone, and sandstone (Doelling, 1997). Quartz sandstone and arkose are more prevalent in the Honaker Trail rocks northeast of the Salt Valley anticline. The thickness of the formation in the rim synclines north and south of the Salt Valley salt wall probably exceeds 2400 feet (730 m), especially in the eastern part of the map area (see cross sections). The upper 600 to 700 feet (180–210 m) of Honaker Trail is well exposed in the Moab 7.5' quadrangle opposite the Arches National Park visitor center on the upthrown block of the Moab fault (Doelling and others, 2002). There, the unit consists of interbedded sandstone, limestone, and siltstone. Sandstone beds are gray, gray-pink, lavender, and pale-brown to red-brown, and mostly fine grained, but a few medium-grained beds are present. Limestone beds are gray to light gray, variably argillaceous, weather hackly, and are fossiliferous. Siltstones are lavender, purple, or green, and are generally thin-bedded. In Salt Valley, in the Mollie Hogans and The Windows Section quadrangles, the Honaker Trail beds are directly overlain by the Upper Triassic Chinle Formation, and the Permian Cutler Formation is missing in the section. The contact is unconformable but sharp and is placed below the lowest red siltstone, sandstone, conglomerate, or shale of the fluvially deposited Chinle Formation. Commonly, the lower 15 feet (5 m) of the Chinle is mottled yellow, purple, white, and black (paleosol). In the Moab 7.5' quadrangle, Honaker Trail limestone is overlain by orange and white sandstone of the Permian Cutler Formation (Doelling and others, 2002). The Honaker Trail Formation was deposited in shallow-marine shelf and near-shore environments (Melton, 1972) as the Uncompahgre uplift rose to the northeast, shedding coarse clastics into the depositional basin (figure 3). The Honaker Trail Formation is Pennsylvanian (Missourian-Virgilian) in age (Condon, 1992, 1997; Nuccio and Condon, 1996; Baars, 2010).

IPp **Paradox Formation (Pennsylvanian; Desmoinesian-Atokan)** – Silty crystalline gypsum interbedded with thin gray and black shale and thin-bedded gray limestone (caprock); crops out as rounded hills that locally rise above unconsolidated basin-fill deposits in Salt Valley; exposures are commonly faulted, folded, and crenulated; up to 150 feet (50 m) exposed.

The Paradox Formation is the oldest formation exposed in the map area. Only caprock, the insoluble residual part of the formation from which the salt has been removed by dissolution, is exposed at the surface. Drill holes (table 1 and figure 4) show that the caprock-salt contact is sharp and is generally about 1000 feet (300 m) beneath the surface (Hite, 1977). They also show that the caprock overlies 9000- to 14,000-foot-thick (2700–4300 m) diapirs or salt walls of cyclically deposited salt, gypsum, shale, and limestone that make up the bulk of the Paradox Formation (Hite and Lohman, 1973; Nuccio and Condon, 1996; Rasmussen and Rasmussen, 2009). According to Hite (1977), the amount of salt in a salt diapir averages 70–90 percent by volume. Individual salt beds in the salt wall are 190 to 1300 feet (60–400 m) thick. Rocks between salt beds, known as marker beds, consist of materials typically found in surface caprock exposures. Individual marker beds are up to 600 feet (180 m) thick. Salt and marker beds are deformed and faulted in the subsurface because loading of overlying sediment induced salt flowage toward normal faults, which deflected the salt toward the surface (Trudgill and Paz, 2009). Drill holes adjacent to Salt Valley encounter a much thinner salt section. Evidence indicates that during the late Paleozoic and early Mesozoic, salt moved toward a northwest-trending fault zone and rose to form a salt wall or linear diapir more than 15 miles (24 km) long and 4 to 5 miles (6–8 km) wide (Hite and Lohman, 1973; Kluth and DuChene, 2009; Trudgill and Paz, 2009).

The overlying Honaker Trail Formation consists of non-cyclical limestone, arkose, sandstone, and siltstone. The nature of the Paradox/Honaker Trail contact is obscure in the map area. Interpretations from logs of hydrocarbon exploration wells generally show the top of the Paradox Formation at the top of the highest salt bed. Others workers show the contact well above the highest salt, presumably based on fossils or other indicators. The Paradox Formation was deposited in a basin intermittently restricted from an open ocean that subsided as normal faults moved in the basement (Baars, 1966; 2010; Blakey, 2009). A warm dry climate induced extensive evaporation, creating a constant inflow of seawater into the restricted basin, causing precipitation of thick beds of halite and other salts. The Paradox Formation is Pennsylvanian, Desmoinesian-Atokan in age (Molenaar, 1987; Huffman and Condon, 1993; Nuccio and Condon, 1996).

STRUCTURAL GEOLOGY

The three-quadrangle area is located in the fault and fold belt in the Paradox Basin and includes a large part of the Salt-Cache Valley salt structure, and small parts of other structures (figure 3). Mesozoic strata dip away from the salt structures at most locations. The Courthouse syncline and Moab Valley salt structure cross the southwest corner of The Windows Section quadrangle. The Salt Wash syncline axis snakes sinuously across the Mollie Hogans and north part of the The Windows Section quadrangles.

The quadrangle area consists of broad anticlines and synclines cut by prominent salt-dissolution grabens. The grabens formed over salt diapirs, salt walls, and salt-cored anticlines that are jointly referred to as salt structures. Other structures include rim synclines, rollovers, faults, and joints. The salt-cored anticlines are broad folds that formed over salt walls mostly in the Permian and Triassic as the salt bowed up overlying strata; most are overprinted by broader tectonic anticlines formed by early Tertiary compression. Rim synclines formed simultaneous with salt walls as the withdrawal of salt from areas between these salt structures produced broad sags. Broad synclines formed during Late Cretaceous to early Tertiary compression; some are superimposed over salt walls and rim synclines while others are not. Grabens formed during the late Tertiary and Quaternary as salt dissolution along the tops of breached salt structures caused overlying strata to subside. Rollovers formed locally along the margins of grabens where strata that used to dip away from the salt structures have subsided into the grabens such that dips "roll over" into the grabens. These strata are commonly faulted, with faulting increasing in intensity toward the grabens; most faults are normal with small offset. Large faults, commonly masked by dissolution, may be related to Tertiary extension. Faults also form the Yellow Cat graben in the Mollie Hogans quadrangle. Joints (parallel fracture sets) are probably related to Tertiary compression and extension, and were locally accentuated by collapse. Commonly, multiple structures are superposed, making interpretation difficult.

Salt Walls and Salt Anticlines

The Paradox Basin fold and fault belt is characterized by salt structures 30 to 75 miles (50–120 km) long and about 2 to 4 miles (3–6 km) wide (figure 3) that are typically a combination of salt walls, salt diapirs, and salt anticlines. Salt walls are linear salt diapirs in which salt flowed toward a linear subsurface structure, such as a fault, and then upward to form a “wall” of salt. In southeastern Utah salt walls are up to about 2 miles (3 km) high and 20 miles (30 km) long, and formed mostly in the Late Pennsylvanian to Early Triassic, with minor continued flow since that time. The rising salt typically forms an anticline in overlying strata, and most have a central graben formed by dissolution of salt.

The Salt Valley salt structure and a small part of the Moab Valley salt structure mostly trend northwesterly across the map area. The Cache Valley salt structure trends mostly east-west, but it is still physically continuous with the Salt Valley salt structure and the adjoining Fisher Valley–Sinbad Valley salt structure (Doelling, 2001) (figure 3). The names were derived from graben valleys that developed when the crests of the salt structures were breached and dissolved. Hite (1977), mapping the Salt Valley salt structure in the northwest end of the Klondike Bluffs quadrangle, estimated that the salt rises above underlying Mississippian rocks a little less than 12,000 feet (3700 m). The Moab Valley salt structure is near-vertical to slightly overhanging and in the Moab 7.5' quadrangle has a height of at least 9000 feet (3000 m) (Doelling and others, 2002), and is probably locally taller.

The sides of salt walls are near-vertical to overhanging and pierce overlying formations (Jackson and Talbot, 1991; Trudgill and Paz, 2009); Woodward-Clyde Consultants (1983) interpreted the southwest and northeast sides of the Salt Valley salt structure as a steep ramp from seismic data. Hite (1977) indicated that the crest of the mass is almost flat, but we tend to agree with Shoemaker and others (1958) that the upper surfaces of salt walls are rather hummocky.

Salt structures in the map area consist of contorted masses of halite, anhydrite, and other salts, silty dolomite, and organic-rich black shale. Hite (1977) grouped the anhydrite, dolomite, and shale into marker beds that can be recognized in drill hole logs and cuttings. These marker beds are thin relative to the salt intervals. The marker beds, together with the thick salt beds, form a series of evaporite cycles, which have been described in great detail (Hite, 1960, 1961; Rasmussen and Rasmussen, 2009, figure 2).

Evaporitic salts probably make up 70 to 90 percent of the salt structures (Shoemaker and others, 1958; Hite, 1977).

Not all salt flowage structures in the Paradox fold and fault belt are salt walls; salt in the southwest part of the belt does not cut through overlying strata. In those areas a nearly normal sequence and thickness of rocks overlies the thick salt and strata dip away from the linear salt "welt." Examples are the Big Flat, Cane Creek, and Lisbon Valley anticlines (figure 3) (Doelling, 2001).

Anticlines and Synclines

Salt-cored anticlines have developed on some salt structures such that sedimentary rocks are domed but not pierced and dip moderately to gently away from the structure. Broad synclines formed between adjacent salt walls and salt anticlines. The broad synclines may or may not coincide with rim synclines, which are narrower troughs that formed simultaneously with, and in response to, the evacuation of underlying salt as it flowed to the adjacent salt walls and salt anticlines. Not all structures are present in some areas. For example, the Cache Valley salt wall has rim synclines, but is not now a salt-cored anticline; this may indicate that salt dissolution and "roll over" modified an older anticline. The Salt Valley salt wall has a salt-cored anticline and rim synclines; the overlying beds, younger than Triassic in age, dip away from the anticline. Dips on the flanks of the Salt Valley anticline are up to about 15 degrees, but steeper dips are locally present and are generally attributed to salt dissolution. The Cache Valley structure formed by Pennsylvanian-Triassic salt movement, whereas the Salt Valley structure formed by both Pennsylvanian-Triassic salt tectonics and Laramide (Late Cretaceous and early Tertiary) folding.

Moab Valley Salt Structure

The Moab Valley salt structure trends roughly N. 35° W. and impinges onto the southwest corner of The Windows Section quadrangle. From there, it plunges to the northwest and is recognizable for another 6 miles (10 km) before flattening. Dips in the quadrangle along the northeast flank are gentle—mostly 4 to 6 degrees. Southwest-flank dips are much steeper—up to 35 degrees in the adjoining Merrimac Butte and Gold Bar Canyon quadrangles where the Moab Valley salt structure is a salt anticline (Doelling and others, 1994; Doelling and Morgan, 2000). To the south in the Moab 7.5' quadrangle the Moab Valley salt structure is a salt wall with a salt-cored anticline and a central graben (Doelling and others, 2002). It is shown as a salt anticline on the cross section for The Windows Section quadrangle.

Cache and Salt Valley Salt Structure

Four breached anticlinal salt structures are present in the Paradox Basin fold and fault belt (figure 3). Associated fracturing allowed salt dissolution, creating generally narrower grabens along parts of the crests of these elongate features. Fractures occurred during and following the Colorado Plateau uplift and Colorado River incision in the Tertiary and Quaternary. At this time erosion stripped off thousands of feet of strata, allowing fresh groundwater to reach the tops of the salt walls, dissolving the salt, and causing remaining overlying rocks to subside in grabens. Quaternary subsidence allowed accumulation of unique middle Quaternary deposits in the otherwise erosional regime of the Colorado Plateau. Dissolution has presumably been favored along some faults and fractures parallel to the structure, creating uneven collapse (Doelling, 1983, 1988), and as a result Quaternary deposits have been folded in zig-zag fashion along the anticlines and synclines that parallel the margins of the graben. Quaternary deposits cover much of the Cache and Salt Valley graben, partly burying mounds of Paradox caprock and strata that overlie the Paradox Formation.

Rollovers

Rollovers due to salt dissolution occur along graben margins. In rollovers, strata near the graben dip more steeply towards the graben with each succeeding fault or fracture. Locally, the most inward strata of the rollover are tilted to near-vertical. In the map area, rollovers typically occur on one margin of a salt structure. The Salt Valley graben in the Klondike Bluffs quadrangle is an example where the rollover is in rocks along the southwest margin, whereas in The Windows Section quadrangle, the rollover is on the north margin.

Although evidence for salt dissolution, such as caprock, is clearly evident in the grabens, some investigators believe that the rollovers are mostly due to extension along major normal faults that cut the salt structures (for example, Ge and others, 1996; Ferrill and Morris, 1997). We disagree with this interpretation—faults that cut salt are soon healed by salt recrystallization at depth and it is mechanically difficult to propagate a fault through two miles of salt. It appears that both mechanisms (dissolution of salt and extension) are important in the map area. Many questions involving the causes and timing of deformation remain to be answered. The presence of major faults that parallel and "cut" the Salt Valley salt structure are important to rollovers, and especially to the extensional fault model. These faults are indicated by "down-dropped" bedrock and locally adjacent caprock in the graben or along the valley margins. In The Windows Section quadrangle, fault traces cross the graben and caprock exposures are interspersed with Mesozoic strata, indicating that the diapir underlies the rollover and the normal fault would need to die out in the salt. Rollovers are expected to form on the hanging-wall side of faults that curve and become less steeply dipping at depth.

Elephant Butte Folds

The Elephant Butte folds are located south of the Cache-Salt Valley graben and Salt Valley fault in The Windows Section quadrangle. The fold axes are parallel to subparallel to the graben and fault. These anticlines and synclines are V-shaped in brittle rocks, and are smoothly curved in soft rocks. In places the fold axes become faults. Dips on fold limbs locally exceed 60 degrees, but average 10 to 20 degrees. These folds are assumed to be due to salt dissolution beneath parallel, penetrating fractures that reach the underlying salt structure. The upper surface of the Cache-Salt Valley salt structure is wider than the Cache-Salt Valley graben (see The Windows Section cross section), indicating that salt does extend under the folds.

Salt Wash Syncline

The Salt Wash syncline is a broad, north-northwest-trending fold on the northeast flank of the Salt Valley anticlinal salt structure in the Mollie Hogans quadrangle. The southeast flank of the syncline dips 4 to 7 degrees northeast and the northeast flank dips very gently, perhaps a degree or two, south from the Yellow Cat dome. The axis plunges gently northwestward. To the south in The Windows Section quadrangle, the existence of the Salt Wash syncline is obscure because its axis is perpendicular to the east-west-trending Cache Valley salt structure. Main evidence for the Salt Wash syncline south of the Cache Valley salt structure is that the Elephant Butte folds, which cross the Salt Wash synclinal axis perpendicularly, all plunge toward this syncline axis.

Courthouse Syncline

The Courthouse syncline is a broad northwest-trending fold with an axis parallel to Courthouse Wash and the Moab Valley salt structure. The axial trace trends N. 15° to 50° W., but averages N. 45° W., and plunges gently to the northwest. In the southwest corner of The Windows Section quadrangle, dips on either flank are gentle, mostly under 5 degrees.

Windows Anticline

The Windows anticline is located entirely in The Windows Section quadrangle and trends roughly N. 30° W. It is southeast of the bend in the Salt-Cache Valley salt structure, and continues the northwest-southeast trend of Salt Valley. The trends of the joints in the Entrada Sandstone in the Fiery Furnace area are the same as the trend of the Windows anticline. The Fiery Furnace joints are truncated by faults where the salt structure is aligned east-west. The Windows anticline is therefore believed to be the result of Laramide folding.

Moab Valley Faults and Joints

Several faults and closely spaced joints that parallel the Moab Valley salt structure cut the crest of the associated anticline in the southwest corner of The Windows Section quadrangle (see cross section). The faults, which are in a one-mile-wide zone (1.6 km), are all located northeast of the Moab fault and, in The Windows Section quadrangle, all have displacements of 15 feet (4.5 m) or less. The associated anticlinal axis trends N. 60° to 70° W. The joints are well displayed in the Entrada Sandstone. Since the joints display a conjugate pattern, downward displacements are on both the northeast and southwest sides of faults. Striations on slickensided surfaces are near-vertical. Most of these faults have been mapped on the southwest flank of the anticline because offset is most noticeable along the contact of the Moab Member of the Curtis Formation and the red marker of the Jsmt unit (Summerville Formation and Tidwell Member of the Morrison Formation). Some joints on the northeast flank may be displaced as well, but offset is less apparent in the Moab Member of the Entrada Sandstone.

The joints, deformation bands, and sheared joints associated with the Moab fault and the Salt Valley Anticline have been described by Davatzes and others (2005), and Lorenz and Cooper (2009). Fluid movement through the faults has generated iron and manganese deposits, which have been dated using $^{40}Ar/^{39}Ar$ at 20–25 Ma (Chan and others, 2001). The latest period of major fault motion of the Moab fault were dated at 60–63 Ma (Solum and others, 2005).

Yellow Cat Dome and Graben

The Yellow Cat Dome is a very gentle dome, anticline, or structural bench developed on regionally northward-dipping rocks northeast of the Salt Wash syncline. The dome reportedly has a closure of 100 feet (30 m) (Stokes, 1952). The Yellow Cat graben is about 1.25 miles (2 km) wide and located in the northeast part of the Mollie Hogans quadrangle. Its faults trend roughly N. 70° W. and have offset of mostly less than 100 feet (30 m).

Joints

The brittle sandstone formations of Arches National Park are generally highly jointed (parallel fracture sets) (Lorenz and Cooper, 2009). The joints mostly subparallel the northwest trends of the salt structures and major faults, but locally they do not. At the south end of the Fiery Furnace, joints are truncated by east-west-trending faults along which the rocks have collapsed toward the valley. The joints are closely spaced in the Moab Member of the Curtis Formation (Jctm) and Slick Rock Member of the Entrada Sandstone (Jes), favoring creation of arches in the formations.

GEOLOGIC HISTORY OF THE PARADOX BASIN

In Pennsylvanian time, the fault-generated and intermittently subsiding Paradox Basin formed on the southwest side of the ancestral Uncompahgre uplift (Baars, 1966; Cater, 1970; Stevenson and Baars, 1987; Trudgill and Paz, 2009; Baars, 2010). Clastic, carbonate, and evaporite sediments of the Paradox Formation were deposited across the basin. In the Middle Pennsylvanian, buried salt beds (mostly halite) in the deepest part of the basin began to flow horizontally toward discontinuities in the floor of the basin. These discontinuities were caused by normal faulting in pre-Paradox Formation rocks (basement faults) (Joesting and Case, 1960; Baars, 1966; Stevenson and Baars, 1987). Salt thickened and rose at these discontinuities to form elongate salt diapirs (salt walls) from the Late Pennsylvanian to at least the Late Triassic. Salt continued to move into the walls in response to intermittent movement of the basement faults.

Late Pennsylvanian through Triassic strata show local thinning, folding, brecciation, truncation, and omission of section. In some areas they were removed by erosion, or possibly never deposited, over the crests of the salt diapirs. Local basins, called rim synclines, developed next to salt diapirs as the underlying salt moved into the diapirs. These rim synclines filled with Late Pennsylvanian to Triassic strata that are thicker than elsewhere in the Paradox Basin. The transition zones between the thick strata in the rim synclines and the thin or missing strata overlying the salt walls are structurally deformed and locally faulted. Many angular unconformities are present in strata marginal to the salt diapirs, with dips increasing progressively downward.

Where not depleted, salt continued to move after Late Triassic time, causing lithofacies changes and thinning and thickening of Jurassic and Cretaceous strata over and next to some salt diapirs. Salt flowage was less than before, and therefore these strata do not have dramatic thickness variations and omissions typical in older strata. Depositional and structural events between the Late Cretaceous and Pliocene are difficult to interpret because time-constraining rocks from much of this interval are missing from the area. Tertiary structures are commonly superimposed on the earlier salt structures and in turn are masked by later salt-dissolution-induced structures, making interpretations difficult. Regionally, approximately west-southwest to east-northeast compression occurred during the Late Cretaceous to early Tertiary Laramide orogeny; during this time local strata may have been folded into broad northwest-trending anticlines and synclines (Cater, 1970; Doelling, 1985, 1988; Heyman and others, 1986).

Mostly northwest-striking normal faults, such as the Moab, Lisbon Valley, and Salt Valley faults, cut the assumed Tertiary folds (McKnight, 1940; Williams, 1964; Parker, 1981; Doelling, 1988), indicating that they post-date the Laramide episode of folding, however Solum and others (2005) showed latest movement on the Moab fault was in the Laramide. Some of these normal faults are superimposed over salt diapirs and grabens and are hard to recognize. The north and south walls of the Cache Valley graben near the east border of The Windows Section quadrangle have about 500 feet (150 m) of apparent displacement, which may have been produced by a normal fault. This Tertiary extension has been related to regional relaxation after Laramide compression (McKnight, 1940), possible reactivation of some subsurface faults in the pre-Paradox rocks (Doelling, 1988), regional extension during the Cenozoic (Ge and Jackson, 1994), and epeirogenic uplift of the Colorado Plateau during the late Tertiary (Parker, 1981).

The Colorado Plateau, which encompasses Arches National Park, was uplifted in early to late Tertiary time (Hunt and Waters, 1958; Lucchitta, 1979; Fleming, 1994; Davis, 1999). Subsequent erosion cut deeply into the strata and carved the extensive canyons of the Canyonlands region. This erosion allowed fresh groundwater to locally reach the upper parts of the salt diapirs through existing fractures (extensional faults and joints opened during folding, relaxation, and uplift). The ensuing salt dissolution caused subsidence with graben formation, tilting, and faulting during late Tertiary and Quaternary time (Shoemaker and others, 1958; Colman, 1983; Doelling, 1983, 1988; Harden and others, 1985; Oviatt, 1988). Pliocene to Holocene deposits filled depressions in the grabens, and are locally deformed by continued dissolution.

The three quadrangles contain the greater part of Arches National Park. Arch formation is a product of the Pleistocene and Holocene. Massive, moderately hard sandstones jointed by folding, resting on or containing soft layers or partings, and located near salt-cored anticlines undergoing dissolution, favor the formation of arches in this region (Willis, 2009, 2012). Rarely do all these phenomena occur in one place, but they do in Arches National Park and hence, in these three quadrangles. The joints are especially noticeable between the Devils Garden and the Fiery Furnace. In the park, rocks between the nearly vertical joint fractures are called fins. It is assumed that the joints formed in response to Laramide folding event(s) in Late Cretaceous-Early Tertiary time. Dyer (1983), Cruikshank (1993), Cruikshank and Aydin (1993), and Lorenz and Cooper (2009) provide discussions of the jointing in Arches National Park.

SUMMARY OF ECONOMIC RESOURCES

Vanadium and Uranium

In the Mollie Hogans quadrangle, the Yellow Cat area of the Thompson uranium district intermittently produced vanadium-uranium ores from 1911 to about 1980. The ore bodies are confined to the Salt Wash Member of the Morrison Formation in the thicker sandstone lenses. The ore was formed by selective mineralization of the sandstone, especially near fossil remains and through adsorption by certain types of clay minerals. Ore, as mined, was uniformly distributed through the sandstone, or occurred as irregular spots and blebs. In some places ore was aligned along bedding planes, in other areas mineralization crossed the bedding. The shape and size of individual deposits seemed to be governed by lithology, composition, and general arrangement of the sandstone host. The ore bodies ranged from thin, irregular layers less than 5 feet (1.5 m) across to bodies 200 feet (60 m) long and 12 feet (4 m) thick. Ore bodies were tabular or in the form of roll fronts—ore bodies having C or S shapes. Many ore bodies were single, richly mineralized logs (petrified wood) and their surrounding lower-grade aureoles.

The ore of the Yellow Cat area is vanadium-uranium type and referred to as carnotite deposits. The ore ranged in grade to 10 percent V_2O_5 and to 0.4 percent U_3O_8. The average vanadium-uranium ratio is unknown, but is estimated at 7:1 in the remaining reserve. The ore minerals coat the sand grains and partly or entirely fill the pore spaces. Ore minerals commonly replace finer sediments, thin clay films, and shale pebbles. The principal minerals are vanadium-bearing mica, carnotite, tyuyamunite, corvusite, and vanoxite.

About 45 mines and prospects were opened during the history of the Yellow Cat area (table 2). Only 11 have reported remaining reserves, none large. In a study conducted by the Utah Geological and Mineral Survey in 1974, about 12,000 pounds (5400 kg) of U_3O_8 and 86,000 pounds (39,000 kg) of V_2O_5 remained in measured, indicated, and inferred reserves. The principal mines include the Telluride, Little Eva, Blackstone Incline, Little Pittsburg, Yellow Bird, Johns Incline, Ringtail, and Parco (Utah Geological Survey, undated). All of these mines are located in the Mollie Hogans quadrangle and labeled on the base map.

Copper

Copper mineralization is evident along some faults marginal to Salt Valley. Several adits, prospects, and other diggings are found along the faults that bound the southwest margin of Salt Valley in the Klondike Bluffs quadrangle, and old diggings are present at many locations along the rim rocks of Cache Valley. Some of the mineralization is rich in silver. Merrell (1979) indicated that about 100,000 ounces (2800 kg) of silver was recovered from ore shipped from the Hoosier mine (section 5, T. 23 S., R. 20 E.) in the early 1900s as a by-product of ore that averaged 8 percent copper. Malachite, azurite, and copper pitch are the principal minerals and are present as disseminations or fracture coatings in Morrison and Cedar Mountain Formation sandstones. The copper minerals are generally accompanied by iron-oxide mineralization.

In section 6, T. 23 S., R. 20 E., in the Klondike Bluffs quadrangle, an open-pit mine was opened in the early 1970s to leach copper and possibly recover silver from the Salt Wash Member of the Morrison Formation. Gard (1976) reported that activity was short-lived and had stopped by 1975. Only 21,000 tons of ore was mined because of problems with the heap-leaching operation at the site (Woodward-Clyde Consultants, 1983). Merrell (1979) reported that as much as 10 million tons of low-grade ore had been blocked out.

Evaporites

Potash (sylvite), magnesium salts (carnallite), and rock salt (halite) occur in the Paradox Formation. Potash is solution mined from the Cane Creek anticline at Potash about 16 miles (26 km) west of Moab (Ritzma, 1969; Huntoon, 1986; Doelling and others, 1994). Several exploratory wells drilled in the Klondike Bluffs and Valley City quadrangles confirmed the presence of these evaporites in the Salt Valley salt wall (see figure 3 and table 1). The internal structure of the Salt Valley–Cache Valley salt wall is quite complex and may hinder extraction (Hite, 1977). However, some deposits are so thick that the structural complexities may not be insurmountable obstacles to economic extraction. The Paradox Formation is presumed too deep and thin for economical extraction under other areas in the quadrangles. Dyer (1945) reported that in 1924 at the north end of Salt Valley, potash was first discovered in the Paradox Basin. A few other exploratory wells were drilled between then and the advent of World War II. Critical wartime need for potash and magnesium led to the drilling of several more wells into the Salt Valley salt wall. The presence of unusually thick deposits of sylvite and carnallite were established, but continuity could not be confirmed because of internal structural complications. The last known exploration activity occurred in 1961.

Hite (1977) reported that voids and porous zones in the Paradox Formation caprock are commonly saturated with brine, and neutron logs support this. Impure gypsum is present in the caprock of the Paradox Formation and locally in unconsolidated mixed eolian and alluvial deposits that may be suitable for soil conditioner. The gypsum, badly fractured and mixed with gray shale, is too friable and impure for use in carving or sculpture.

Petroleum

Several petroleum exploration wells have been drilled in the area, especially in the Klondike Bluffs and Mollie Hogans quadrangles (Utah Division of Oil, Gas, and Mining, undated) (see figure 5 and table 1). No oil and gas has been

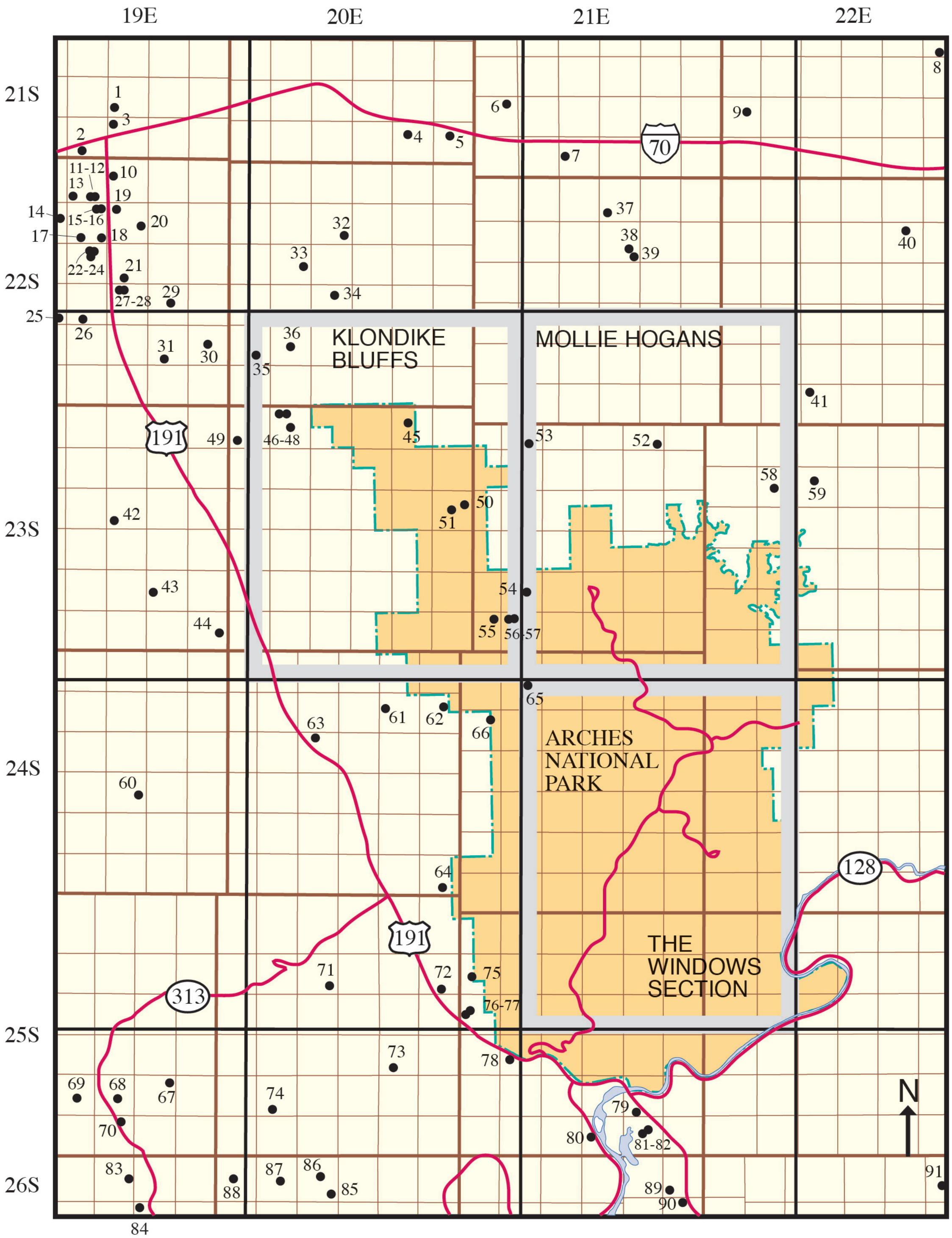

Figure 5. *Drill hole locations in and around Arches National Park and The Windows Section, Klondike Bluffs, and Mollie Hogans quadrangles. Well numbers correlate with those in table 1.*

Table 2. *Mine data for the Mollie Hogans, Klondike Bluffs, and The Windows Section quadrangles (from Utah Mineral Occurance System database 2011) .*

District	County	State	7.5' Quadrangle	Location (Utm Northing NAD27)	Location (Utm Easting NAD27)	Township	Range	Section	Site name	Commod	Ore material
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4301150	629085	022S	022E	32	SCHOOL SECTION # 32 MINE	U; V	CARNOTITE; VANADIUM MICA
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4300820	627760	022S	022E	31	BLACK JACK	U V	CARNOTITE; TYUYAMUNITE; PASCOITE; URANINITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4300650	626730	022S	021E	36	RINGTAIL	U V	CARNOTITE; URANINITE; TYUYAMUNITE; PASEOITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4300890	625640	022S	021E	35 36	M C GROUP	U V	CARNOTITE; TUYUYAMUNITE CORVUSITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4300540	628060	022S	022E	31	BLACKSTONE INCLINE	U V	CARNOTITE; URANINITE; TYUYAMUNITE; PASCOITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4300430	627820	022S	022E	31	UNKNOWN	U V	CARNOTITE; TYUYAMUNITE; PASCOITE; URANINITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4300230	627850	022S	021E	31	UNKNOWN	U V	CARNOTITE; URANINITE; TYUYAMUNITE; PASCOITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4300130	627590	022S	021E	31	UNKNOWN	U V	CARNOTITE; TYUYAMUNITE; URANINITE; PASCOITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4299900	627700	023S	022E	6	PARIS # 25	U V	CARNOTITE; VANADIUM MICA
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4299770	627240	023S	022E	6	UNKNOWN	U V	CARNOTITE; URANINITE; PASCOITE; TYUYAMUNITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4299520	627030	023S	022E	6	UNKNOWN	U V	CARNOTITE; URANINITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4299420	626950	023S	022E	6	UNKNOWN	U V	CARNOTITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4299500	627520	023S	022E	6	PARCO MINES	U V	CARNOTITE; TYUYAMUNITE; PASCOITE; COFFINITE; CORVUSITE; VANADIUM MICA
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4299630	627900	023S	022E	6	LITTLE EVA	U V	CARNOTITE; TYUYAMUNITE; URANINITE; PASCOITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4299620	628430	023S	022E	6	AEC GROUP 2	U V	CARNOTITE; TYUYAMUNITE; PASCOITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4299230	629050	023S	022E	5	LITTLE PITTSBURG MINE	U V	CARNOTITE; VANADIUM MICA; ROSCOELITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4299170	628070	023S	022E	6	AEC GROUP # 1	U V	CARNOTITE; VANADIUM MICA
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4299060	627770	023S	022E	6	AEC GROUP # 3	U V	CARNOTITE; VANADIUM MICA
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4299630	626110	023S	021E	1	JOHNS INCLINE	U V	CARNOTITE; URANANITE; TYUYAMUNITE; PASCOITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4299170	626360	023S	021E	1	UNKNOWN	U V	CARNOTITE; TYUYAMUNITE; VANADIUM MICA
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4298840	626300	023S	021E	12	CONSOLIDATION	U V	CARNOTITE; TYUYAMUNITE; GRAY VANADIUM MICA
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4298780	626550	023S 02	022E 02	06 1	RUBE MINE	U V	CARNOTITE; TYUYAMUNITE; PASCOITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4298560	626240	023S	021E	12	UNKNOWN	U V	CARNOTITE; PASCOITE; TYUYAMUNITE; URANINITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4298350	626180	023S	021E	12	UNKNOWN	U V	
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4298480	625730	023S	021E	12	UNKNOWN	U V	CARNOTITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4298400	625500	023S	021E	12	TELLURIDE MINES	U V	CARNOTITE; TYUYAMUNITE; CORVUSITE; PASCOITE; META ROSSITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4298060	626750	023S	022E	7	BLACK APE MINE	U V	CARNOTITE; TYUYAMUNITE; PASCOITE; GRAY VANADIUM MICA
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4298350	627210	023S	022E	6	UNKNOWN	U V	CARNOTITE; PASCOITE; TYUYAMUNITE; CORVUSITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4298200	627450	023S	022E	06 07	MEMPHIS MINES	U V	
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4299450	623850	023S	021E	2	SCHOOL SECTION 2	U V	CARNOTITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4298910	622740	023S	021E	3	FOOLS LUCK	U V	CARNOTITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4297950	623570	023S	021E	11	UNKNOWN	U V	CARNOTITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4297760	624300	023S	021E	11	SILVER MOON DEPOSIT	U V	CARNOTITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4296850	622020	023S	021E	15	UNKNOWN	U V	CARNOTITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4296300	625000	023S	021E	13 14	VIRGIN MARY # 1	U V	CARNOTITE; TYUYAMUNITE; CORVUSITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4295410	623850	023S	021E	23	JUANITA GROUP	U V	CARNOTITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4296430	626390	023S	021E	13	YELLOW BIRD MINE	U V	CARNOTITE; CORVUSITE; TYUYAMUNITE
THOMPSON (YELLOW CAT)	GRAND	UT	MOLLIE HOGANS	4290490	621825	024S	021E	4	UNKNOWN GRAVEL PIT	SDG	SANDS AND GRAVEL
CANE CREEK	GRAND	UT	THE WINDOWS SECTION	4288710	622950	024S	021E	3	UNKNOWN PROSPECT	U V	CARNOTITE; VANADIUM HYDROMICA
THOMPSON (YELLOW CAT)	GRAND	UT	KLONDIKE BLUFFS	4203180	610750	022S	020E	28 29	WEST LITTLE VALLEY MANGENESE	MN	PYROLUSITE
THOMPSON (YELLOW CAT)	GRAND	UT	KLONDIKE BLUFFS	4302530	611140	022S	020E	28 29	LITTLE VALLEY MANGANESE DEPO	MN	MANGANESE NODULES
THOMPSON (YELLOW CAT)	GRAND	UT	KLONDIKE BLUFFS	4302420	610550	022S	020E	29	CIE DOG	U V	CARNOTITE
THOMPSON (YELLOW CAT)	GRAND	UT	KLONDIKE BLUFFS	4301350	613500	022S	021E	33	EAST LITTLE VALLEY MANGENESE	MN	PROBABLY PYROLUSITE THOUGH NOT SPECIFIED
THOMPSON (YELLOW CAT)	GRAND	UT	KLONDIKE BLUFFS	4300705	614805	022S	020E	35	RIBBON RIDGE PROSPECT	U V	CARNOTITE; VANADIUM MICA
THOMPSON (YELLOW CAT)	GRAND	UT	KLONDIKE BLUFFS	4300320	616500	023S	020E	1	UNKNOWN	U V	CARNOTITE
THOMPSON (YELLOW CAT)	GRAND	UT	KLONDIKE BLUFFS	4299080	618700	023S	021E	5	BARE SPOT	U V	CARNOTITE
THOMPSON (YELLOW CAT)	GRAND	UT	KLONDIKE BLUFFS	4297430	611020	023S	020E	9	COBALT # 1	U CU MN	MALACHITE; AZURITE; AUTUNITE; METATOBERNITE
THOMPSON (YELLOW CAT)	GRAND	UT	KLONDIKE BLUFFS	4296710	612865	023S	020E	15	UNKNOWN	U V	
THOMPSON (YELLOW CAT)	GRAND	UT	KLONDIKE BLUFFS	4294030	617310	023S	020E	24	LENA #1 MINE	U V	CARNOTITE; VANOXITE
THOMPSON (YELLOW CAT)	GRAND	UT	KLONDIKE BLUFFS	4293695	612180	023S	020E	28	SLICK ROCK 1 ; 2 ; 3	U V	CARNOTITE
THOMPSON (YELLOW CAT)	GRAND	UT	KLONDIKE BLUFFS	4292060	613040	023S	020E	34	BERTHA # 5	U V	
MOAB AREA	GRAND	UT	KLONDIKE BLUFFS	4291120	610180	023S	020E	32	KLONDIKE LIMESTONE DEPOSIT	CER	LIMESTONE

produced from any of the wells in the three-quadrangle area, but shows were discovered in the Mississippian Paradox Formation. Nearby fields produce from the Leadville Formation, Paradox Formation, Entrada Sandstone, sandstones in the Morrison Formation, Cedar Mountain Formation, and Dakota Sandstone (Mahoney and Kunkel, 1963; Doelling and others, 1994; Morgan, 1994).

Exploration for oil and gas started about 1910 and continued intermittently until the late 1970s. During the 1920s and 1930s, wells were drilled into the Salt Valley anticline to test the Paradox Formation. Almost every well encountered numerous shows of oil and gas, but none proved capable of sustained production. These shows are most abundant in the non-evaporitic rocks of the formation. The formation averages 25 percent black shale and is buried deeply enough that hydrocarbon generation is complete (Hite, 1977). The petroleum is generally trapped in Paradox Formation carbonate "marker beds" under high pressure.

Sand and Gravel

Sand and gravel resources, which are needed for road building and maintenance, are not common in the three-quadrangle area. Terrace gravels (Qat) are present along Klondike Wash in the southwest corner of the Klondike Bluffs quadrangle and along Little Valley and Salt Wash in the very northern part of the Mollie Hogans quadrangle. Other surficial deposits in the three quadrangles are not of good quality or of limited extent. Gravel deposits (Qag) in Salt Valley are generally coarse and partly consolidated.

SUMMARY OF WATER RESOURCES

The map area is in the Green River desert and receives 7 to 10 inches (20–25 cm) of precipitation annually (Iorns and others, 1965; Western Climate Center, 2012). The Colorado River and Salt Wash (in normal to wet years) are the only perennial streams. Water flows in the other washes only when infrequent but intense summer storms strike the area.

The sandstone formations comprising the Glen Canyon Group are considered the most important bedrock aquifers of the Paradox Basin (Feltis, 1966; Blanchard, 1990). Water quality from the Glen Canyon Group in the region is generally good, with concentrations of total dissolved solids (TDS) averaging less than 220 mg/L. The water type is calcium bicarbonate or calcium magnesium bicarbonate and the water is moderately hard to hard (Blanchard, 1990).

Woodward-Clyde Consultants (1983) divided the groundwater resources in the Paradox Basin into several hydrostratigraphic units. These include a surface hydrostratigraphic unit, caprock hydrostratigraphic unit, upper hydrostratigraphic unit, middle hydrostratigraphic unit, and lower hydrostratigraphic unit.

The surface hydrostratigraphic unit includes all geologic units younger than the Triassic Moenkopi Formation. Aquifers in this unit include all the sandstone and coarse-grained Quaternary map units. Interconnection between the sandstone and alluvium is likely in all areas. The surface hydrostratigraphic unit is characterized by many small perched and local water tables with recharge by local precipitation. Recharge occurs when winter snows melt and during the infrequent summer and early fall thundershowers. Heavy thundershowers, when they occur, are generally restricted to small areas. The water percolates downward through fractures and weathered rock into the sandstones. Water generally moves a short distance through the aquifer and is then discharged through intermittently flowing springs and seeps. Discharge rates are low; many springs and seeps flow only during the spring and are dry during other seasons. Locally, along faults and at fault intersections, springs may discharge small amounts of water nearly perennially. Phreatophytes indicate that water is flowing above bedrock at the bottom of the alluvial cover in many of the washes. This water may locally appear as a spring, flow a short distance, and disappear again under the alluvium.

Caprock hydrostratigraphic unit characteristics were determined by U.S. Geological Survey drilling as reported in Rush and others (1980), Wollitz and others (1982), and Woodward-Clyde Consultants (1983). The thickness of caprock under Salt Valley ranges from about 490 to nearly 1000 feet (150–300 m). There is less than 60 feet (20 m) of relief along the caprock-salt interface. The caprock is somewhat cavernous in its makeup. The upper 330 feet (100 m) or more of the caprock is not water saturated. Apparently, water quality deteriorates toward the center of the valley and downward toward the caprock-salt interface. The quality varies from 2000 mg/L TDS $CaSO_4$ water adjacent to the southwest wall to 16,900 mg/L TDS NaCl water in the center of the valley. The salinity of the water is not a simple product of Paradox halite dissolution. Halite is dissolved, but dissolution of gypsum, sulfate reduction, calcite precipitation, and ion exchange complicate the hydrochemistry.

Water moves very slowly downward through the caprock and then toward the center of the valley just above the caprock-salt interface. Preliminary ^{14}C dating indicates that groundwater movement from the valley margin to the center takes more than 10,000 years (Woodward-Clyde Consultants, 1983). Hite (1977) noted that the saline water must escape the system in order for caprock to form. Investigators have not been able to determine whether the water flows out of the hydrostratigraphic unit northwesterly toward the Thompson Wash drainage (in the Valley City quadrangle), or southeasterly toward Salt Wash and the Colorado River, or both.

The upper hydrostratigraphic unit consists of the Cutler Formation and upper two-thirds of the Honaker Trail Formation. The middle hydrostratigraphic unit includes the remainder of the Honaker Trail Formation and the Paradox Formation. The lower unit includes the carbonate rock units below the Paradox Formation. The recharge area for the upper unit includes the La Sal Mountains. Water yields from the upper unit are expected to be small and of variable quality, tending to be saline. The middle unit consists of layers acting as aquicludes alternating with units of variable water-bearing capacity. Water in the middle unit is generally very saline. The lower hydrostratigraphic unit consists of carbonates having good porosity and permeability. Oil-well data generally indicate the presence of large quantities of salty water in the lower hydrostratigraphic unit (Hite, 1977).

SUMMARY OF GEOLOGIC HAZARDS

Geologic hazards are phenomena that can damage human-made features such as roads, buildings, and other developments, or that can put humans in danger. The three-quadrangle area contains few buildings and/or habitations, but is heavily visited for recreation. Roads and highways, pipelines, and similar transportation corridors are most likely to be affected.

Erosion, Debris Flows, Alluvial-Fan Flooding, and Stream Flooding

Landslides, including debris flows, mud flows, and rock falls, and flooding, and erosion are the most active and potentially damaging hazards in the three-quadrangle area. The sparsely vegetated, steep alluvial fan slopes and ephemeral stream channels are subject to these hazards from waters generated by cloudburst storms.

Debris flows, debris floods, and clear-water floods form a continuum of sediment-water mixtures. Debris flows and floods generally remain confined to stream channels, but may exit the channels and deposit debris where slope gradients and channel depths decrease on alluvial fans (Hylland and Mulvey, 2003). The heterogeneous lithologies and weathering characteristics of the bedrock are conducive to the accumulation of talus and colluvium on slopes, providing ample material for debris flows.

The paved roads found in the three-quadrangle area are well engineered to withstand these hazards and generally suffer minimal damage during flooding events. However, unpaved roads cross washes that are regularly deeply gullied by flash floods. Locally, debris flows have been deposited across the back roads.

Rock Falls

Rock falls occur sporadically throughout the rugged topography of southern Grand County. Steep cliff faces are present along the margins of Salt and Cache Valleys, and along the canyon of the Colorado River. Rock-fall debris may travel great distances down slope by rolling, bouncing, and sliding, as reflected by the extent of Qmt deposits.

Problem Soils and Windblown Sand

Clay in the Morrison, Cedar Mountain, and Mancos Shale strata, and in the soils derived from them, is capable of absorbing relatively large quantities of water (Schultz, 1963). As the moisture content of the clay changes, the clay minerals expand or contract producing as much as a 10 percent volume change (Shelton and Prouty, 1979). The "popcorn" surface of weathered outcrops of the Morrison and Cedar Mountain Formations is indicative of the shrinking and swelling nature of the clay within the formations. These formations and mostly non-gravelly surficial deposits are prone to piping. Piping is subsurface erosion by groundwater that flows into permeable, noncohesive layers, removes fine sediment, and exits at a spot where these layers intersect the surface. The removal of fine particles increases void space, producing a cylindrical void or "pipe" and enhancing erosion. Piping is common in arid and semi-arid climates where fine-grained, non-cemented, Holocene alluvium is incised by ephemeral stream channels. Generally, problem soils only create problems for the back roads of the area. The back roads can become impassable during and shortly after heavy rain or snowmelt and should be avoided. Also, areas of active windblown sand are common throughout the three-quadrangle area, and the shifting sand causes problems for roads and trails.

Earthquake Hazard

Seismicity in the Paradox Basin area, in which the three quadrangles are located, can be characterized as low; the region has experienced only a few historical small to moderate magnitude events (Wong and Humphrey, 1989). The closest area of concentrated seismic activity is associated with Cane Creek mine at Potash, about 15 to 30 miles (25–50 km) southwest of the quadrangles, where the seismicity is believed to be induced by underground solution-mining of potash salts in the Paradox Formation (Wong and Humphrey, 1989; Hylland and Mulvey, 2003). The strongest recorded earthquake near Arches National Park occurred in February 1967 (magnitude 3.8) near Upheaval Dome, about 30 miles (50 km) southwest of the three quadrangles (Wong and Humphrey, 1989).

NOTES ON SCENIC RESOURCES

The three quadrangles include most of the Arches National Park area, which attracts thousands of visitors daily. The exposed bedrock displays contrastingly beautiful colors and is eroded into sculpted and arranged forms. Notable are the rock arches; the area has the greatest concentration and some of the largest in the world (Stevens and McCarrick, 1988; Natural Arch and Bridge Society, 2012; Willis, 2012). Also wonderfully displayed are the geologic structures that accompany salt movement and dissolution (Doelling, 2010), which are mostly overlooked by visitors. Arches National Park began as a national monument in 1929 and included only two small areas, The Windows Section and Devils Garden, which are still the most attractive. Adjoining areas have been added since then, expanding the park from 4500 acres (18,000 ha) to more than 76,000 acres (31,000 ha).

The Windows Section

The most massive arches, called windows, are found in this part of Arches National Park. These are mostly free-standing arches formed in a wall of the Slick Rock Member of the Entrada Sandstone (Jes) underlain by the Dewey Bridge Member of the Carmel Formation (Jcd). The well-known arches in The Windows Section include the Parade of Elephants, North Window, South Window, and Turret Arch. This is also a good place to see alcoves (Cove of Caves) and the nature of the softer Dewey Bridge Member (Garden of Eden).

Courthouse Towers

Courthouse Towers (The Windows Section quadrangle) are monoliths of the Slick Rock Member of the Entrada Sandstone. The Park Avenue trail is about 0.8 mile (1.3 km) in length and affords the visitor most of the features present in this area of the park. The trail begins between two high monoliths of the Slick Rock Member underlain by the Dewey Bridge Member of the Carmel Formation. Along the way, the bust of Queen Nefretiri, Popsicle Rock, the Three Gossips, and the Organ can be seen. All this can be experienced by staying on the highway, but the hike includes many beautiful "nooks and crannies" that would be missed from the highway. At the end of the hike is an incipient arch known as Baby Arch.

The Great Wall

The Great Wall (The Windows Section quadrangle) is the massive Entrada Sandstone wall that parallels the highway from about one mile (1.6 km) north of the Tower of Babel to Balanced Rock. Several arches are hidden along this wall, especially pothole arches. The wall has a length of about 4 miles (6 km).

Devils Garden and the Fiery Furnace

This area of joints and fins (Klondike Bluffs quadrangle) extends from the Fiery Furnace northward to Dark Angel along the northeast rim of Salt Valley. Many arches have developed in this region, the more well-known being Sand Dune Arch, Broken Arch, Skyline Arch, Tunnel Arch, Pine Tree Arch, Landscape Arch, Navajo Arch, and Double O Arch. The longest maintained trail in the park gives access to many of them. The full trail is 7.2 miles (12 km) round trip. Stevens and McCarrick (1988) reported the presence of 123 arches in the Devils Garden area; most are free-standing and cliff-wall arches. Landscape Arch has the longest known span of any sandstone arch in the world, and the second or third largest span of any type of arch (Natural Arch and Bridge Society, 2012; Willis, 2012).

The Fiery Furnace is a maze-like labyrinth between Entrada Sandstone fins at the south end of Devils Garden. The maze is so complex that a trail guide is usually required. Some spaces between fins are so narrow that sunlight does not reach the bottom. The hike locally requires the use of hands and feet to scramble up and through narrow cracks and along narrow ledges above drop-offs. Also present are former arches that have collapsed.

Paleontological Resources

The paleontological resources in the map area are abundant, and include tracks, fish debris beds, petrified wood, plant remains, dinosaur skeletons, fusilinids, corals, bryozoans, brachiopods, gastropods, bivalves, crinoids, echinoids, and mammals (Arches National Park Paleontological Resources, Internal Report, 2012). These fossils range in age from Middle Pennsylvanian to Pleistocene. Several dinosaur quarries are in the mapping area where ankylosaurs, raptors, saurapods, crocodilian and iguanodonts were discovered. Most of the dinosaur remains are recovered from Cedar Mountain Formation.

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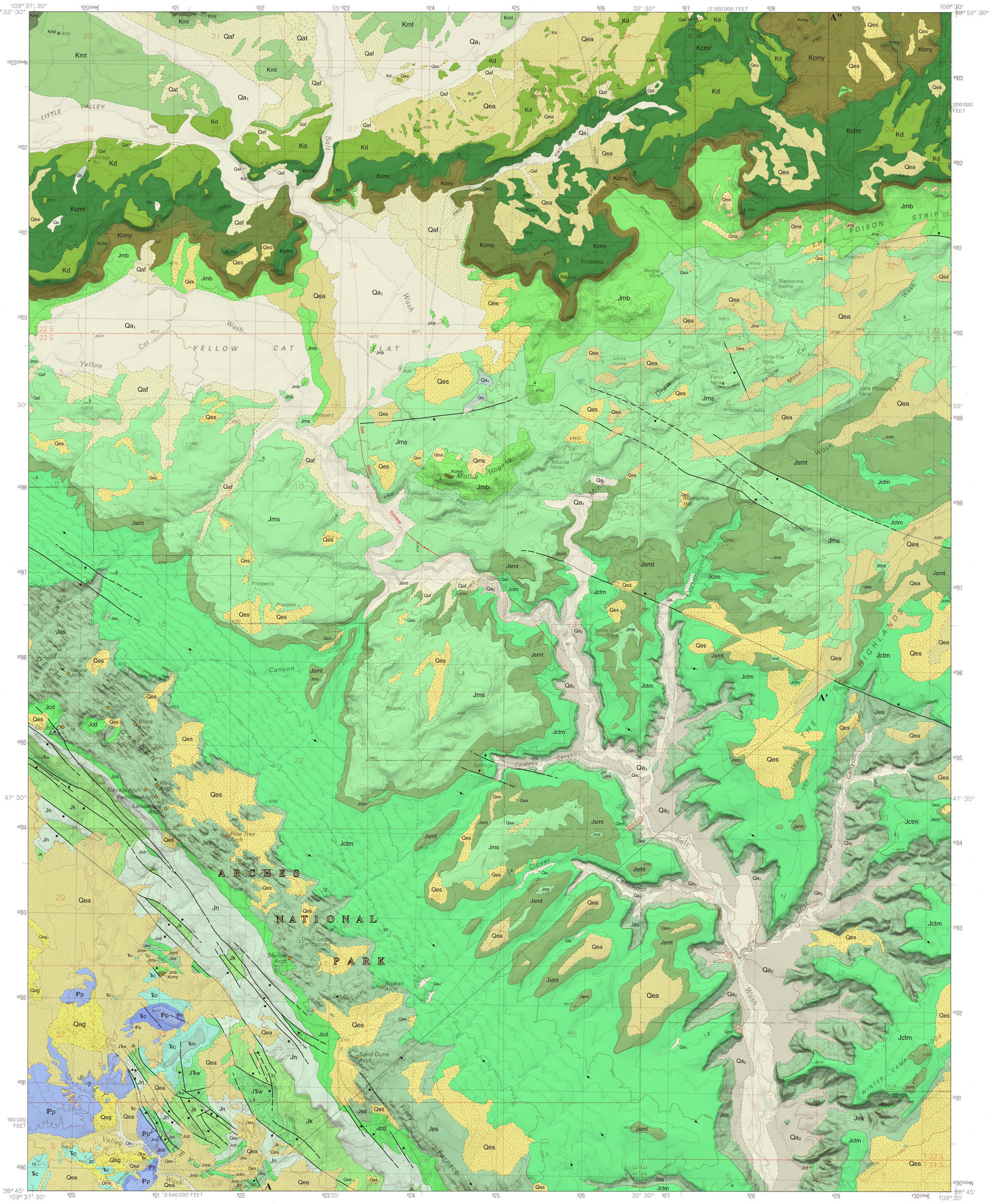


STRATIGRAPHIC COLUMN OF THE WINDOWS SECTION, KLONDIKE BLUFFS, AND MOLLIE HOGANS QUADRANGLES

SERIES	STAGE	SYSTEM	FORMATION / MEMBER		MAP SYMBOL		THICKNESS Feet (Meters)	LITHOLOGY
Upper	Coniacian to Santonian	CRETACEOUS	Mancos Shale	Blue Gate Shale Member	Kmb		500+ (150+)	
	Turonian			Juana Lopez Member, upper	Kmj	Kmju	85–120 (26–37); 40–60 (10–20)	
				Juana Lopez Member, lower		Kmjl	45–60 (15–20)	
	Cenomanian			Tununk Shale Member	Kmt		200–400 (60–120)	
			Dakota Sandstone		Kd		45–110 (15–35)	unconformity
Lower	Aptian-Albian		Cedar Mountain Formation	Ruby Ranch Member	Kcm	Kcmr	100 (30)	
				Poison Strip Member		Kcmp	12–24 (4–8)	
				Yellow Cat Member		Kcmy	50 (15)	unconformity
Upper	Tithonian	JURASSIC	Morrison Formation	Brushy Basin Member	Jmb		250–450 (76–140)	
	Kimmer-idgian			Salt Wash Member	Jms		130–300 (40–90)	
				Tidwell Member	Jsmt	Jmt	20–50 (6–15)	
	Oxfordian		Summerville Formation			Js	6–40 (2–12)	unconformity
			Curtis Formation	Moab Member	Jctm		60–110 (20–34)	unconformity
Middle	Callovian		Entrada Sandstone	Slick Rock Sandstone Member	Jes		180–400 (55–120)	
	Bathonian		Carmel Formation	Dewey Bridge Member	Jcd		90–190 (30–60)	unconformity
Lower	Toarcian		Glen Canyon Group	Navajo Sandstone	JƦgc	Jn (Jnl)	200–700 (60–210)	
	Pliensba-chian			Kayenta Formation		Jk	220–340 (70–100)	
	Sinemurian to Hettangian			Wingate Sandstone		JƦw	250–450 (80–140)	
	Rhaetian	TRIASSIC						unconformity
Upper	Carnian/Norian		Chinle Formation	upper member	Ʀc	Ʀcu	200–460 (60–140)	unconformity
				lower member		Ʀcl	0–380 (120)	unconformity
Lower	Spathian-Smithian		Moenkopi Formation		Ʀm		0–2200 (0–670)	unconformity
Lower	Leonardian	PERMIAN	Cutler Formation		Pℙc		0–4000 (0–1200)	not exposed
	Wolfcampian							
Upper	Virgilian	PENNSYLVANIAN	Honaker Trail Formation		ℙh		200–2400 (60–730)	partially exposed
	Mis-sourian							
Middle	Desmoinesian		Paradox Formation	caprock	ℙp		150 (50) exposed 1000+ (300+)	
							diapirs 9000–14,000 (2700–4300)	not exposed
	Atokan							

GEOLOGIC SYMBOLS

Contact – Dashed where approximately located

Normal Fault – Dashed where approximately located, dotted where concealed; bar and ball on the downthrown side; on cross section arrow shows relative movement

Synclinal axis – Dotted where concealed; arrow on line indicates plunge direction

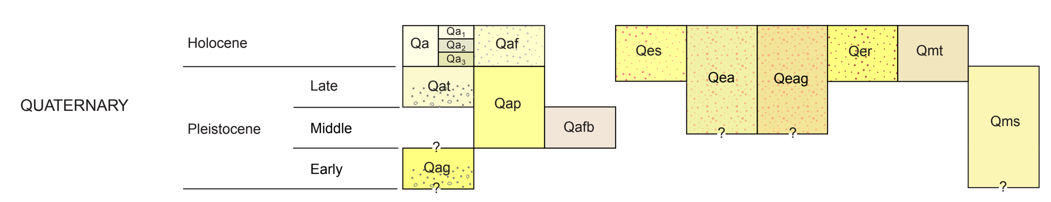
Strike and dip of strata

Strike of vertical and near-vertical joints

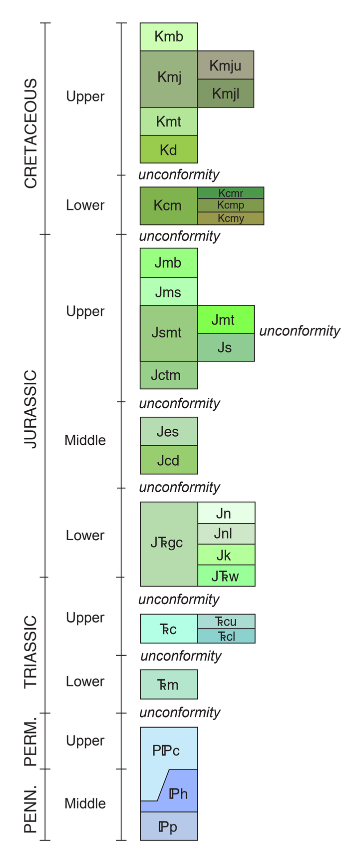
Major arch

CORRELATION OF MAP UNITS OF THREE QUADRANGLE AREA

QUATERNARY UNITS



BEDROCK UNITS



Unit descriptions in separate text booklet
Kmj, Kcm, JƦgc, and Pℙc are on cross section only
Not all map units present on this map

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CONTOUR INTERVAL 40 FEET

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QUADRANGLE LOCATION

GEOLOGIC MAP OF THE MOLLIE HOGANS QUADRANGLE, GRAND COUNTY, UTAH

by

Hellmut H. Doelling and Paul A. Kuehne

2013

APPROXIMATE MEAN DECLINATION, 2013

Base from USGS Mollie Hogans 7.5' Quadrangle (1991)
Projection: UTM Zone 12
Datum: NAD 1927
Spheroid: Clarke 1866

Project Manager: Grant C. Willis
GIS and Cartography: Paul A. Kuehne and Lori J. Steadman
Fieldwork: 1984 with minor revisions in 2009

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This map was created from Geographic Information System (GIS) data.

1. Thompson Springs
2. Sagers Flat
3. White House
4. Klondike Bluffs
5. Cisco SW
6. Merrimac Butte
7. The Windows Section
8. Big Bend

ADJOINING 7.5' QUADRANGLE NAMES