

# INTERIM GEOLOGIC MAP OF THE BIG BEND QUADRANGLE, GRAND COUNTY UTAH

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## ABSTRACT

The Big Bend quadrangle is located in east-central Utah in southern Grand County and is named for a deeply incised meander bend in the Colorado River. The quadrangle is in a scenic part of Utah's Red Rock country and includes a small part of Arches National Park with Delicate Arch, and parts of Cache, Castle, and Professor Valleys. It is in the fold and fault belt of the northern Paradox basin; a northwest-trending asymmetrical basin that formed adjacent to the ancestral Uncompahgre uplift during Pennsylvanian to Late Triassic time.

Exposed strata range from Pennsylvanian to Cretaceous age. These include less than 100 feet (30 m) of the Pennsylvanian Paradox Formation, 0 to 1,250 feet (0-381 m) of the Permian Cutler Formation, 0 to 1,370 feet (0-418 m) of the Triassic Moenkopi Formation, 200 to 840 feet (0-256 m) of the Triassic Chinle Formation, 240 to 350 feet (73-107 m) of the Lower Jurassic Wingate Sandstone, 240 to 300 feet (73-91 m) of the Lower Jurassic Kayenta Formation, 250 to 400 feet of the Lower Jurassic Navajo Sandstone, 380 to 520 feet (158 m) of the Middle Jurassic Entrada Sandstone, 590 to 650 feet (180-198 m) of the Cretaceous-Jurassic Morrison Formation, 200 to 240 feet (61-73 m) of the Cretaceous Cedar Mountain Formation, 40 to 50 feet (12-15 m) of the Cretaceous Dakota Sandstone, and about 1000 feet (305 m) of the Cretaceous Mancos Shale. The quadrangle is dominated by exposures of the Permian, Triassic, and Lower Jurassic formations; younger rocks are present only in and near Cache Valley in the north part of the quadrangle. Quaternary surficial deposits include those deposited by alluvial, eolian, and colluvial processes.

The quadrangle area contains thick deposits of evaporite salts of the Pennsylvanian Paradox Formation. These salt deposits were intermittently mobilized from Pennsylvanian to Late Triassic time to form elongate salt diapirs that cored northwest-trending anticlines. Well-developed salt diapirs are present under Cache and Castle Valleys. Permian and Triassic strata deposited adjacent to the growing salt diapirs are unusually thick in the peripheral synclines and thin or are cut out over the crests of the diapirs.

Regionally, gentle northwest-trending Tertiary-age synclines and anticlines are superimposed over a north-dipping homocline that plunges into the Uinta Basin. Late Tertiary and Quaternary uplift of the Colorado Plateau, followed by rigorous downcutting by the Colorado River and its tributaries, allowed ground-water circulation to reach the crests of the diapirs through pre-existing fracture networks. This resulted in Pliocene-Pleistocene salt-dissolution collapse of the crests of the salt-cored anticlines. The strata were tilted and offset along numerous faults to form grabens, v-synclines, and fractured drape zones. Alluvium filled Castle Valley as the graben deepened.

The quadrangle contains sand and gravel, petroleum and potash resources, and occurrences of gold, copper, uranium, barite, gypsum, and calcite. The principal geologic hazards include debris flows, mud flows, stream flooding, rock falls, indoor radon gas, and culinary water contamination.

## INTRODUCTION

The Big Bend quadrangle is named for a magnificent incised meander loop of the Colorado River in the heart of Utah's scenic Red Rock country. The quadrangle is centered on the point where the Colorado River leaves Professor Valley and the Richardson Amphitheater and enters a narrow canyon. It contains Cache Valley, an east-west trending salt-generated structure, and the nose of Castle Valley, a northwest-trending, alluvium-covered, salt-cored anticline. The area is one of the most scenic in Utah, and was the location for the filming of several Hollywood western movies and numerous television commercials. Utah Highway 128 (U-128), which parallels the Colorado River along its southeast bank, is a scenic byway of the state of Utah.

The Big Bend quadrangle is located in east-central Utah, approximately 12 miles (19 km) northeast of the Grand County seat of Moab (figure 1). The landscape consists of bench and canyonland morphology commonly associated with the Colorado Plateau physiographic province. The Colorado River flows across the quadrangle from the northeast to the southwest and cuts the Big Bend, a canyon more than 1,100 feet (335 m) deep, in the southwest corner. In the eastern part of the quadrangle mesas and valleys slope southwestward from the La Sal Mountains. In this area remnants of former high benches form picturesque buttes, ridges, and hills.

The Colorado River divides the quadrangle in half with respect to accessibility. The southeast half is reached from Moab along U-128 with adjoining roads providing access to Castle Valley and other places below the mesas. Access to Mat Martin Point and Porcupine

Rim from Moab is from the Sand Flats road (four-wheel drive road). Access to Cache Valley and Dry Mesa is from Arches National Park on a four-wheel drive road via the Delicate Arch turnoff. Access to the Dome Plateau is from Interstate Highway 70 (I-70) ranch exit 190, on a four-wheel drive road, extending through Yellow Cat Flat and the Poison Strip. These access roads are not shown on figure 1. The four-wheel drive roads have many branches and exact routes are accurately shown only on the U.S. Geological Survey (USGS) 1:100,000 scale, 30 x 60-minute Moab quadrangle map. Access to the right bank of the river is by boat only.

The tops of the mesas are bare sandstone or sandy soils with stands of pinyon and juniper trees dominating the higher elevations. At lower elevations desert shrubbery and grasses are common. Bitterbrush, blackbrush, Mormon tea, prickly pear cactus, rice grass, and scattered juniper trees are common in the canyons and below the cliffs.

Cattle are grazed both on the mesas and on level tracts below the cliffs and along the river. Orchards are present in the bottom land along the Colorado River. Hay fields, vineyards, and gardens are cultivated in lower Castle Valley. In recent years the community of Castle Valley has grown to accommodate those seeking homesites near recreational and scenic areas. A few larger ranches are also present along the river and in Castle Valley.

The Big Bend quadrangle area was first mapped by Dane (1935), at a scale of 1:63,500. It was later mapped by Williams (1964) at a scale of 1:250,000 (Moab 2 degree quadrangle). Doelling (1985) included half of the quadrangle in his 1:50,000-scale geologic map of Arches National Park. Other publications dealing with aspects of the geology in the

quadrangle are those of Cross (1907), Shoemaker and Newman (1959), Harper, 1960, and Doelling (1981, 1983).

Doelling mapped much of the western half of the quadrangle, including Dry Mesa, Mat Martin Point, and Cache Valley and Ross mapped the eastern half of the quadrangle including Castle Valley, Professor Valley, Ida Gulch, Dome Plateau, and the canyon of the Colorado River for this project. Doelling's field work was mostly conducted in 1982, 1983, 1989, and 1993. Ross' field work was mostly conducted in 1989 and 1990.

## STRATIGRAPHY

Rock formations exposed in the Big Bend quadrangle range in age from Middle Pennsylvanian to Late Cretaceous. In addition, there are several mappable unconsolidated Quaternary deposits. Precambrian, Cambrian, Devonian, and Mississippian rocks are present in the subsurface (Hintze, 1988).

Permian to Lower Jurassic formations are extensively exposed across the quadrangle. Pennsylvanian rocks (Paradox Formation caprock) are exposed at only two locations, one in Cache Valley and the other in Castle Valley. The Middle Jurassic to Late Cretaceous formations are preserved in the collapsed graben of Cache Valley and in the eastward extensions of the Elephant Butte folds on Dry Mesa (figure 1). As much as 10,000 feet (3,000 m) of strata make up the Permian to Lower Jurassic sequence, of which 4,500 feet (1,372 m) are exposed. The Permian and Triassic formations are highly variable in thickness. They are abnormally thin or completely missing over the salt-cored anticlines and are

exceptionally thick in peripheral zones (rim synclines or basins) adjacent to the salt-cored anticlines. The exposed post-Navajo Sandstone units are as much as 2,480 feet (756 m) thick.

### **Cambrian to Pennsylvanian (Subsurface) Rocks**

Permian to Cambrian-aged rocks were encountered in the No. 1 Conoco Federal 31 drill hole, located in the SE 1/4, NW 1/4, SE 1/4, section 31, T. 24 S., R. 23 E. Penetrated were 6,235 feet (1,900 m) of the Cutler Formation, 930 feet (283 m) of the Honaker Trail Formation, 3,060 feet (933 m) of the combined Paradox, Pinkerton Trail, and Molas Formations, 450 feet (137 m) of the Leadville Formation, 100 feet (30 m) of Ouray Formation, 150 feet (46 m) of the upper Elbert Formation, 90 feet (27 m) of the McCracken Sandstone Member of the Elbert Formation, and 80 feet (24 m) of Cambrian rocks at total depth.

Baars (1958), Lochman-Balk (1972), and Hintze (1988) indicated the Cambrian section to be 800-1,200 feet thick in isopach maps. Loleit (1963), in an isopach map, suggested the total thickness of Cambrian rocks in the Big Bend area may only be 400 feet (122 m). No drill holes have penetrated the complete Cambrian section in and around the Big Bend quadrangle. Cambrian rocks are unconformably overlain by Devonian rocks.

In the Paradox basin the Devonian is represented by the Aneth, Elbert and Ouray Formations (combined as Devonian rocks undivided on the lithologic column, plate 2), but the Aneth is missing in the quadrangle area (Parker and Roberts, 1966). The Elbert Formation is

divisible into the lower McCracken Sandstone Member and an upper unnamed member. According to Cooper (1955), the McCracken Sandstone Member consists predominantly of white, light gray to red sandstone, that is fine- to medium-grained, generally poorly sorted, commonly glauconitic, with a few streaks of sandy dolomites. The upper unnamed member of the Elbert consists of thin-bedded, commonly sandy dolomite, with thin interbeds and stringers of gray-green and red shale. The Ouray Formation consists of light to medium gray, finely crystalline dolomite and limestone, with very widely spaced, thin stringers of greenish shale. Parker and Roberts (1966) note that green waxy shale marker beds are commonly found at the top and bottom of the formation.

The name Leadville Formation is used for rocks of Mississippian age that underlie the region (Hintze, 1988), although some researchers prefer the name Redwall Formation (Parker and Roberts, 1963, Craig, 1972). Neff and Brown (1958) divided the Leadville into an upper limestone phase and a lower dolomite phase. The dolomite phase consists of coarsely crystalline to sucrosic, tan, brown, and gray, often cherty, massive dolomite. The limestone phase consists mostly of thick-bedded to massive limestone. Parker and Roberts (1966) indicated the lower dolomitic phase correlates with the Whitmore Wash and Thunder Springs Members and the upper limestone phase correlates with the Mooney Falls and Horseshoe Members, all of the Redwall Limestone of McKee (1963).

## Pennsylvanian Rocks

The contact between Mississippian and Pennsylvanian rocks in the area is an erosional unconformity (Hintze, 1988). The basal unit of the Pennsylvanian is the Molas Formation, which primarily consists of limestone clasts in a red muddy siltstone matrix (Wengerd, 1958).

The Molas Formation is overlain by the Hermosa Group, which consists of three formations, in ascending order, the Pinkerton Trail, Paradox, and Honaker Trail Formations. The Pinkerton Trail and Honaker Trail Formations both contain predominately shallow marine limestone and fine-grained clastic deposits (Wengerd, 1958). The Paradox Formation is a sequence of cyclically bedded halite, anhydrite, carbonate, siltstone, and shale. Following the terminology of Baars and others (1967), only sediments containing evaporites are included in the Paradox Formation. Along the northeastern edge of the Paradox basin, medium-grained, slightly arkosic clastics interfinger with the Paradox and Honaker Trail Formations (White and Jacobsen, 1983). Except for two small outcrops, the Pennsylvanian rocks of the Big Bend quadrangle are only found in the subsurface.

The thickness of the Paradox Formation in the area is extremely variable due to diapirism. Along the axial trace of the Castle Valley salt structure the formation is believed to be approximately 8,000 feet (2,438 m) thick based on gravity data (Case and others, 1963). The Grand River Oil and Gas Sid Pace No. 1 well, NE 1/4, SE 1/4, section 16, T. 25 S., R. 23 E., penetrated >5,400 feet (>1,646 m) on the flank of the salt anticline structure in the central part of Castle Valley. No. 1 Conoco Federal 31 drill hole, located in the SE 1/4, NW 1/4, SE 1/4, section 31, T. 24 S., R. 23 E., along the northeast flank of the structure

penetrated less than 3,000 feet (914 m) of salt-bearing strata and a total Pennsylvanian section of about 4,000 feet (1,219 m). The Union of California Burkholder No. 1 well, in SW 1/4, NE 1/4, section 1, T. 26 S., R. 22 E., southwest of Castle Valley and just off the quadrangle, drilled through approximately 2,900 feet (884 m) of Pennsylvanian rock, of which only 500 feet (152 m) contained salt-bearing strata. Elston and others (1962) estimated the original thickness of the Paradox Formation in the area of the Paradox Valley salt-cored anticline to have been at least 5,000 feet (1,524 m), based on the difference between the present thickness of the salt core and the minimum amplitude of the core.

The depositional history of the Hermosa Group may be summarized as follows (from Wengerd and Matheny, 1958, Woodward-Clyde Consultants, 1983, Baars, 1987). During Atokan (early Middle Pennsylvanian) time, silty shales and fossiliferous carbonates in the Pinkerton Trail Formation were deposited across the region in a shallow marine shelf environment. By Desmoinesian (Middle Pennsylvanian) time the Paradox basin began to subside and was periodically restricted from the open marine shelf that had shifted to the south-southwest. Halite, sylvite, carnallite, gypsum, and anhydrite were precipitated in the restricted hyper-saline environment that developed. This process was repeated up to 29 times, depositing as much as 8,200 feet (2,500 m) of evaporites, much of which is halite (Hite, 1960).

Open marine shallow-shelf conditions were re-established in upper Desmoinesian (late Middle Pennsylvanian) time and continued to Virgilian (Late Pennsylvanian) time, and marine carbonates and clastics of the Honaker Trail Formation were deposited.

## **Paradox Formation (IPp)**

The two small exposures of the Paradox Formation are resistant, rounded hills consisting of massive sucrosic gypsum, clayey gypsiferous beds, silty shale, sandstone, limestone, and dolomite. The clayey gypsiferous beds exhibit disrupted and contorted bedding below a thin popcorn-like weathering surface and are associated with resistant and pitted, sucrosic whitish-gray gypsum. Hite (1977) interpreted these rocks to be the caprock residue of the leached diapiric salt-bearing Paradox Formation. Broken fragments and blocks of silty shale, fine-grained quartzose sandstone, micrite limestone and dolomite are generally scattered across the outcrops. Caprock exposures are predominantly light gray to yellowish gray, but may be black to greenish gray.

The diapiric nature of the Paradox Formation caprock is well displayed near the northwest nose of the Castle Valley salt-cored anticline in the NE 1/4, SW1/4, NE 1/4, section 1, T. 25 S., R. 22 E. Gypsum, carbonate, and shale, that may be fault gouge, have been cemented with calcite and silica into a coherent mass more resistant than the surrounding rock. Halite is not present at the surface; however, a small spring at this location is extremely salty. Halite crystals encrust the area around the spring.

The second exposure is located in the W 1/2, SW 1/4, SE 1/4, section 13, T. 24 S., R. 22 E., in Cache Valley. Caprock appears to be conformably overlain by the Triassic Chinle Formation on the west side of the exposure and cut off by a fault on the east side that places it against Triassic Moenkopi Formation outcrops.

## **Honaker Trail Formation**

The Honaker Trail Formation is not exposed on the Big Bend quadrangle. Nearby outcrops and drill-hole information indicate the unit is composed of fossiliferous limestone, cherty limestone, siltstone, and sandstone. The unit has interbeds of arkosic sandstone, purple siltstone, and shale that become more numerous in the northeast part of the Paradox basin near the Uncompahgre source (Doelling, 1988). Regionally, the unit ranges from 0 to 2,000 feet (0-610 m) in thickness; it is generally missing over the salt-cored anticlines, such as at Castle Valley, but is expected to be present in the areas between them. The Honaker Trail Formation is about 930 feet (283 m) thick in the No. 1 Conoco Federal 31 drill hole, in SE 1/4, NW 1/4, SE 1/4, section 31, T. 24 S., R. 23 E., along the northeast flank of the Castle Valley structure.

## **Permian Rocks**

### **Cutler Formation**

Rocks of the Permian Cutler Formation in the Paradox basin are a complex sequence of intertonguing continental red-bed, eolian, paralic (coastal), and shallow marine deposits that unconformably overlie the Hermosa Group (Campbell, 1979). The Permian rocks represent a large alluvial fan complex shed from the ancestral Uncompahgre Highland that intertongues with coastal plain deposits to the southwest, in the Canyonlands area southwest of Moab, Utah. In the Big Bend quadrangle, we recognize two units in the Cutler Formation, an

informal arkosic sandstone member (Pc), which is predominant, and a sandstone member that may be the White Rim Sandstone (Pcw?). Uplift of the salt-cored anticlines during the Permian affected deposition of the Cutler Formation. Thicker sequences of sediments were deposited in basins or synclines peripheral to the growing salt structures. The uplifted areas over the crests of the salt-cored anticlines received thinner sequences or the sediments were removed by pre-Moenkopi erosion (Doelling, 1988, p. 15).

The Cutler Formation in the Big Bend quadrangle was deposited in the medial to distal parts of a large alluvial fan emanating from the Precambrian metamorphic and granitic terrain of the ancestral Uncompahgre uplift. Campbell (1979, 1980) and Campbell and Steele-Mallory (1979) presented extensive information on the depositional environment of this formation, which is summarized here. The fluvial system consisted of braided streams on the fan surface that changed to braided, meandering streams outward from the fan. The toe of the fan was near sea level, periodically allowing marine conditions to influence sedimentation. Toward the end of Cutler deposition, a marginal marine eolian environment was present, represented by the White Rim Sandstone Member.

**Arkosic sandstone member (Pc):** The arkosic sandstone member consists primarily of subarkosic to arkosic sandstone, conglomeratic sandstone, and conglomerate interbedded with silty and sandy mudstone. Subordinate lithologies are quartzose sandstone, cherty limestone, and hard, dense mudstone. Because of lithologic heterogeneity and variable cementation, the member's outcrop appearance ranges from near-vertical cliffs to alternating ledges and slopes that form step-like escarpments. Outcrops are reddish brown, reddish purple, reddish orange,

and maroon, with subordinate amounts of brownish orange, pale red, gray, grayish red, and grayish white.

Arkosic sandstone is fine- to very coarse-grained and micaceous. Grains are generally subangular to subrounded and individual beds vary from poor to well sorted. Many beds of arkosic sandstone display small-scale trough cross-bedding and cut-and-fill structures with basal gravel lenses, suggesting deposition by fluvial processes. Gravel beds range from moderately-sorted granule and pebble conglomerate to poorly-sorted cobble conglomerate. Maximum clast size is about 10 inches (25 cm), with 0.4 to 2.4 inch (1-6 cm) clasts most common. Finer clasts are primarily quartz, feldspar, and mica, with pebbles and cobbles of granite, gneiss, schist, and quartzite. Horizontal stratification and variable bed thickness are common for the conglomeratic beds. Subarkosic to quartzose sandstone is composed mostly of fine- to medium-grained, subrounded, moderately well-sorted grains. Tabular planar cross-stratification and laminations with inverse graded bedding in some beds suggest deposition by eolian processes (Campbell, 1979). These sandstones generally display more of an orange to reddish tint, in contrast to the reddish-purple shades of the fluvial sandstones. The mudstones and siltstones are micaceous and generally structureless.

The maroon, coarser-grained, sand-rich beds are interbedded with brownish silty mudstone and siltstone beds in the upper part of the Cutler Formation at Ida Gulch and in Professor Valley along the Colorado River. The basal contacts of the coarser-grained deposits are scoured into the mudstones and contain mudstone rip-up clasts and basal gravel lenses. The coarser-grained deposits are interpreted to be fluvial braided channel deposits incised into overbank mudstones.

On the north side of Castle Creek, at the northwest nose of the Castle Valley salt-cored anticline, is an area of complexly deformed Cutler Formation that contains some interesting petrologic features and sedimentary structures. Pebbles and cobbles of angular to subrounded, pale-gray mudstone and sandstone clasts lie in disturbed beds in the fluvial cross-beds. The clasts may be detritus from the Hermosa Group or from the lower part of the Cutler Formation shed off the crest of the growing salt structure. Two small syndepositional faults were observed in the Cutler red beds at this location. The first is an apparent normal fault displacing two sets of crossbeds; slightly higher in the section, a gravel-filled channel exhibits no displacement. Nearby, the second low-angle fault cuts off a portion of a gravel-filled channel. Also, several locations in this area exhibit possible growth faults. These structural and sedimentological features, combined with the variable thickness of the formation, support the episodic growth of the Castle Valley salt diapir during deposition of the Cutler Formation. Additional observations presented in later sections will further document the growth of the salt structures.

The thickness of the arkosic sandstone member varies radically in the Big Bend quadrangle; the member is thin or missing over the salt-cored anticlines and is very thick in adjacent peripheral basins and synclines (see cross sections, plate 2). A maximum of about 1,000 feet (305 m) is present in surface exposures. Harper (1960) measured an incomplete 931-foot (284-m) section of the Cutler in section 9, T. 25 S., R. 23 E. The No. 1 Conoco Federal 31 drill hole, in SE 1/4, NW 1/4, SE 1/4, section 31, T. 24 S., R. 23 E., passed through approximately 6,235 feet (1,900 m) of the arkosic sandstone member.

**White Rim Sandstone Member? (Pcw?)**: A conspicuous grayish-white, massive sandstone as much as 250 feet (76 m) thick caps the Cutler Formation at the northwest corner of Castle Valley. It gradually thins to the southeast due to erosional truncation below the Triassic Moenkopi Formation along the flank of the anticline. At section 18, T. 25 S., R. 23 E., the lower part of an incomplete section of Cutler is "typical" reddish-purple and maroon sandstone and conglomerate. The interval contains trough cross-stratified arkosic sandstone and gravel lenses (lags?) in scour surfaces. This interval grades upward into the conspicuous grayish-white quartzose sandstone that is interbedded with minor siltstone and arkose. Primary sedimentary structures of this uppermost unit include large scale, relatively high-angle (20-30°) cross-bed sets. Quartz grains in this unit are frosted. This sequence suggests a gradual change from an alluvial-fan environment to predominantly eolian conditions. Crude dune forms mark its exhumed upper surface.

Just to the north of these outcrops, the Grand River Oil and Gas Pace State No. 1 well, drilled in SW 1/4, NW 1/4, NE 1/4, section 36, T. 24 S., R. 22 E., contained approximately 250 feet (76 m) of quartzose sandstone with frosted grains.

The massive eolian sandstone at Castle Valley resembles the White Rim Sandstone Member, which is the uppermost member of the Cutler Formation west and southwest of Moab. However, the eolian sandstone at Castle Valley cannot be physically connected with White Rim exposures in the Canyonlands area. The Cutler Formation is well exposed in Moab Canyon and no White Rim Sandstone member is present (Doelling and others, 1992). Baars (1987) presented an isopach map of the White Rim Sandstone showing a thin finger, approximately 200 feet (61 m) thick, extending from the main area of deposition along the

southwest flank of the Salt Valley salt-cored anticline and just reaching the Big Bend area of the Colorado River from the northwest.

### **Permian-Triassic Unconformity**

The Permian-Triassic unconformity in the Big Bend quadrangle is angular and is well exposed in Ida Gulch and below Porcupine Rim. At Ida Gulch, the Cutler Formation beds below the unconformity trend N. 85° W. and dip 9° NE, and are medium- to coarse-grained arkose with numerous conglomerate lenses and scattered granitic and metamorphic clasts. The unconformity is a subtle, low-relief surface with little channelization. The basal Moenkopi Formation bed above the contact is a coarse-grained arkosic sandstone with abundant quartz, chert, feldspar, and iron oxide clasts in a clay-rich matrix. It is overlain by fine-grained sandstone and silty mudstone. The Moenkopi Formation in this area strikes N. 80° W. and dips 5° NE. The angular discordance between the Cutler and Moenkopi Formations appears to increase toward the axis of the Castle Valley salt-cored anticline, since dips of the Cutler increase from 9 to 20°, while the attitude of the Moenkopi remains constant.

Over the ridge, on the northeast flank of the Castle Valley salt-cored anticline (section 9, T. 25 S., R. 23 E.), dark reddish-purple, ledgy outcrops of "typical" Cutler arkosic sandstone and conglomerate dip 20-22° toward the northeast. The ledgy beds abruptly grade into less-resistant, slope-forming, pale reddish-purple beds. The unconformity is poorly exposed in the slope, but is approximately 20 feet (6 m) below a prominent gypsum bed in

the Moenkopi. The Moenkopi Formation locally overlies rocks of the Pennsylvanian Hermosa Group on the flanks and crests of some of the salt-cored anticlines (Molenaar, 1987).

## **Triassic Rocks**

### **Moenkopi Formation**

The Moenkopi Formation of Early and Middle(?) Triassic age is missing over the Uncompahgre Plateau to the east-northeast, and regionally thickens westward toward the Cordilleran miogeocline (Baars, 1988; Doelling, 1988). The Moenkopi Formation is primarily a sequence of intertonguing deltaic and paralic (coastal) deposits that represent the initial Mesozoic marine transgression in the Colorado Plateau region (Stewart, Poole, and Wilson, 1972a). The Moenkopi Formation consists of interbedded, orangish-brown to reddish-brown, thinly laminated to thin-bedded, micaceous mudstone, siltstone, and fine-grained sandstone. Subordinate lithologies include shale, gypsum, sandstone, and conglomerate. The formation is characterized by ubiquitous oscillation ripples and mudcracks (Stewart, Poole, and Wilson, 1972a; Molenaar, 1987; Doelling, 1988).

Shoemaker and Newman (1959) investigated the Moenkopi Formation in the salt-anticline region and subdivided the formation into four members, in ascending order, the Tenderfoot, Ali Baba, Sewemup, and Parriott Members. The lower three members are widely distributed throughout the salt-anticline region, with the lower two members commonly exhibiting lateral variations in lithology and thickness. The Parriott Member occurs near

Castle Valley and at Sinbad Valley (Stewart, Poole, and Wilson, 1972a). The complex history of the Permian-Triassic sedimentation and salt tectonics in the salt-anticline region produced the lateral variations in units, differences in unit thicknesses, and the presence or absence of a given unit (Stewart, Poole, and Wilson, 1972a). This makes placing the exact location of contacts between given members difficult and arbitrary.

Thicker sequences of Moenkopi sediments were deposited in localized basins (rim synclines) peripheral to the growing salt structures. The uplifted areas, over the crests of the salt-cored anticlines, received thin sequences of sediment or the sediments were removed by pre-Chinle erosion (Stewart, Poole, and Wilson, 1972a; Doelling, 1988). The changes in the total thickness of the Moenkopi is usually the result of changes in thickness of the Sewemup and Parriott Members. At Hill 5163 near the northwest nose of the Castle Valley salt-cored anticline, the entire Moenkopi is only 550 feet (168 m) thick. The thickness of the Moenkopi increases dramatically eastward across the north-trending monocline toward Porcupine Canyon and Parriott Mesa, where the measured section is 958 feet (292 m) thick (Shoemaker and Newman, 1959). Most of this change in thickness occurs in the Sewemup and Parriott Members. Under Porcupine Rim, at the south edge of the quadrangle, the Moenkopi is approximately 600 feet (183 m) thick. However, the Burkholder No. 1 well, between the Castle Valley and Moab Valley salt-cored anticlines, penetrated approximately 1,500 feet (457 m) of Moenkopi.

**Lower member of the Moenkopi Formation (Tm1):** In the quadrangle, the Moenkopi Formation is divided into a ledge-forming lower member (composed of the Tenderfoot and

Ali Baba Members of Shoemaker and Newman (1959)), the slope-forming Sewemup Member and the ledge-forming Pariott Member. The contact between the lower member and the Sewemup Member is located at a color change from darker-brown beds below to lighter-brown beds above. It generally occurs slightly above the highest prominent ledge-forming sandstone in the lower part of the Moenkopi. This contact is at the same stratigraphic position as the contact between the Ali Baba and Sewemup Members of Shoemaker and Newman (1959). The color change has been equated to an increase in the amount of gypsum present in the Sewemup Member siltstones and mudstones (Stewart, Poole, and Wilson, 1972a).

The lower member consists mainly of lavender, silty sandstone and conglomeratic sandstone interbedded with reddish-brown to reddish-orange sandstone, siltstone, and silty mudstone. Sandstone beds form rough cliffs and ledges and the finer-grained units form rubble-covered steep slopes or recesses between ledges.

In the field, the sandstone appears arkosic and micaceous, with a distinct speckled appearance. Clasts are poorly to well sorted, fine- to coarse-grained, subangular to subrounded quartz, feldspar, mica, and opaque minerals. The sandstone is calcareous and moderately to well indurated. Sandstone beds range from thin to massive (to as much as 30 feet [9 m] in thickness). The lower contacts of many sand bodies exhibit scoured surfaces. Many sandstone beds commonly exhibit low- and/or high-angle small scale cross-stratification. Sandstone beds with conglomerate lenses are lavender to pale reddish brown, exhibit scour basal contacts, and contains granules, pebbles, and occasional cobbles of Precambrian granite and gneiss. However, some conglomerate lenses on the immediate limbs of the salt-cored

anticlines are rich in gypsum, mudstone, sandstone, limestone, and chert clasts. These particular conglomerates are matrix supported, and clasts are randomly-oriented.

Intervening siltstone is moderate reddish-orange to reddish-brown slope or bench formers. Siltstones are thinly laminated to thin bedded and are commonly marked by parallel oscillation and interference ripple marks. The ripple-marked strata are generally closely interbedded with siltstone and mudstone exhibiting cusate(?) ripple marks and mudcracks (Stewart, Poole, and Wilson, 1972a). Ripple-laminated beds typically occur in sets that range in thickness from a few inches to several feet. Mudstone and shale range from fissile to homogeneous structureless beds of variable thickness.

The thickness of the lower member of the Moenkopi Formation probably ranges from 0 to 450 feet (0-137 m) in the Big Bend quadrangle. Shoemaker and Newman (1959) measured a complete 444-foot (135-m) section of the lower member on the south side of Parriott Mesa in section 5, T. 25 N., R. 23 E. They differentiated the unit into a 220-foot (67 m) Tenderfoot Member and a 224-foot (68 m) Ali Baba Member. The thickness of the lower member ranges from 280 to 290 feet (85-88 m) below the Dome Plateau on the northwest side of the Colorado River and is 270 feet (82 m) thick at Hill 5163, in section 36 T. 24 S., R. 22 E. It is approximately 360 feet (110 m) thick below Porcupine Rim.

**Sewemup Member (Trms):** The predominant lithology of the Sewemup Member is pale reddish-orange to grayish-red, slope-forming, micaceous siltstone. The siltstone is thinly laminated to thin bedded and exhibits distinct symmetrical oscillation ripples. The sandstone is generally reddish brown to light brown, fine grained, and micaceous. Thin to thick beds of

pale lavender, coarse-grained sandstone to conglomeratic sandstone are present. As noted by Shoemaker and Newman (1959), northward of the Castle Valley salt-cored anticline, the beds of sandstone in the Sewemup Member become conglomeratic and increase in thickness and in abundance, so that the lithologic character of the Sewemup Member becomes nearly identical to the lower member of the Moenkopi Formation. However, the color change and predominance of slope-forming beds still allow placement of the intervening contact.

Mudstone is dark reddish brown, slope forming, thinly laminated to structureless, and may be indistinctly bedded. Gypsum is common as irregular veinlets and thin discontinuous(?) beds as much as 0.4 inches (1 cm) thick.

The Sewemup Member is nearly 380 feet (116 m) thick on the south side of Parriott Mesa (Shoemaker and Newman, 1959), 440 feet (134 m) thick near Rocky Rapids on the north side of the Colorado River, section 19, T. 24 S., R. 23 E., and about 200 feet (61 m) thick below the Dome Plateau in the northeast corner of the quadrangle. At hill 5163, at the north end of Castle Valley, the combined Sewemup-Parriott Member thickness is only 280 feet (85 m) thick.

**Parriott Member (Trump):** The ledge-forming Parriott Member caps the Sewemup Member and consists mainly of reddish-brown to lavender sandstone interbedded with chocolate-brown, orange-brown, and red siltstone, mudstone, and shale. Both the Parriott Member and lower member contain abundant sand-rich ledge-forming beds. Orange and red mudstone units in the Parriott Member are distinctive and resemble the overlying Chinle Formation (Shoemaker and Newman, 1959). Sandstone is fine- to medium-grained, micaceous, poorly to

well sorted, and exhibits small-scale trough cross-stratification. Many sandstone bodies are lenticular and exhibit a fining-upward sequence. A basal coarse-grained sandstone fills scours and small channels in an irregular erosional surface in the underlying ripple-laminated, fine-grained sandstone and silty mudstone of the Sewemup Member. The coarse-grained sandstone grades into a medium- to fine-grained sandstone bed approximately 2 to 3 feet (0.6-0.9 m) thick, exhibiting low-angle, small-scale trough cross-bedding or horizontal bedding. This bed grades into a massive fine-grained sandstone as much as 6 feet (1.8 m) thick that is overlain by silty mudstone and siltstone. At some locations this sequence appears to be cyclic.

The Pariott Member appears to be present only in the vicinity of the Big Bend quadrangle and adjacent to the Sinbad Valley salt-cored anticline in Colorado (Shoemaker and Newman, 1959). The unit may have been more extensive before erosion, prior to the deposition of the overlying Chinle Formation. The unit is 0 to 450 feet (0-137m) thick in the Big Bend quadrangle. Shoemaker and Newman (1959, p. 1842) measured 135 feet (41 m) on the south side of Pariott Mesa in the type section. The thickest measurement made at a surface exposure is 386 feet (118 m) above Rocky Rapids in section 19, T. 24 S., R. 23 E. From that point the unit appears to thicken westward under Dry Mesa. The Pariott Member thins northeastward under the Dome Plateau and becomes unrecognizable in the northeast corner of the quadrangle. A nearly complete section of 222 feet (68 m) of Pariott Member was measured near the roadside park at the Big Bend. The Pariott Member is present under Porcupine Rim, but is too poorly exposed to obtain an accurate measurement or to map separately from the Sewemup Member.

## **Chinle Formation**

Throughout the salt anticline region the Chinle Formation generally forms reddish, ledgy slopes covered with rubble below the massive cliffs of the Wingate Sandstone (Doelling, 1988). In the region northeast of Moab, previous investigators have subdivided the Chinle into formal and informal units, in ascending order, mottled strata, basal sandstone unit, and Church Rock Member, including the "Black Ledge" (Stewart, Poole, and Wilson, 1972b). However, they recognized the questionable use of formal members in this area because of salt movement during deposition of the formation. O'Sullivan (1970) and O'Sullivan and MacLachlan (1975) suggested that rocks assigned to the Church Rock Member in the salt anticline region are stratigraphically lower and older than the type Church Rock Member at Kayenta, Arizona, based on stratigraphic relations with the Hite Bed of the Chinle Formation, present in the Monument upwarp region southwest of Moab, Utah. Furthermore, they suggest differences in grain-size distribution, fossil content, clay mineralogy and paleogeography, and indicate that the "Church Rock" member in the northern Paradox basin is unlike the Church Rock Member at the type locality (O'Sullivan and MacLachlan, 1975). Based on stratigraphic relations in the Big Bend quadrangle we divide the Chinle Formation into informal lower and upper members. The lower member includes the rocks of the mottled strata and basal sandstone unit of the Church Rock Member. The upper member includes the remainder of the Church Rock Member.

Throughout most of the quadrangle, the contact between the Moenkopi Formation and Chinle Formation is an erosional surface with minor relief and varies from a disconformity to

a slight angular unconformity near the salt structures. The contact is at the base of a distinct light-greenish-gray to orange-pink to pale-reddish-brown quartzose sandstone and conglomeratic sandstone at the base of the lower member of the Chinle Formation. The sandstone characteristically forms a prominent white band on the steep slopes of the Triassic strata. The underlying Moenkopi Formation is generally more brownish in color, bedding is regular and distinct, and the rocks are finer grained. The Chinle is more reddish in color, bedding is irregular and less distinct, and the sandstones are coarser grained.

**Lower member (Trcl):** From the Dry Wash area (section 19, T. 24 S., R. 23 E.) westward along the Colorado River canyon below Mat Martin Point to the Big Bend, a thick package of light-greenish-gray, orange-pink to pale-reddish-brown, interbedded, quartzose sandstone and conglomerate, and minor siltstone and mudstone makes up the lower member of the Chinle Formation. The upper part of this package of strata is mottled white, light gray, red, purple, yellow, orange, and reddish brown. Sandy units form thin to massive ledges and cliffs separated by narrow steep slopes of muddy and silty units. The irregular topography and mottled coloration give the rocks a distinct rough appearance. The lower member was assigned to the Chinle Formation by Dane (1935) and called the "basal grit." Baker (1933) assigned these rocks to the Shinarump Conglomerate Member of the Chinle Formation and Stewart, Poole, and Wilson (1972b) called them "mottled strata." They used the term for mottled rocks that occur predominantly in the basal part of the Chinle Formation at locations throughout the Colorado Plateau.

The lower member consists primarily of fine- to coarse-grained quartzose sandstone and conglomeratic sandstone. The sandstone contains poorly to moderately sorted, subangular to rounded, fine- to coarse-grained quartz. Locally, it contains quartz pebbles as much as 2.5 inches (6 cm) in diameter. Some conglomeratic sandstones contain both quartz and chert pebbles. Sandstone is calcareous and cementation ranges from friable to well-indurated. Sandstone exhibits small- to medium-scale cross-stratification and both fining- and coarsening-upward sequences. Siltstone and mudstone contain scattered grains of fine- to very coarse-grained quartz sand.

Distinct horizons containing sedimentary features indicative of paleosols are present throughout the sequence. These altered rocks contain networks of vertical tubular features suggestive of fossilized root systems. The root traces range from pencil-width to 20 inches (51 cm) in diameter. The root casts are generally filled with mudstone and siltstone and a color alteration halo is present around the root trace. The root structures are in silty mudstones or coarser grained sandstone. The root structures in the medium- to coarse-grained sandstone are filled with silty mudstone creating a unique textural relationship. The two textures are generally colored differently. Calcareous and cherty nodules are commonly present. In the area of Salt Wash Rapids a 12- to 18-inch (30-46-cm) cherty horizon is present that may be a pedogenic silcrete or silicified pedogenic carbonate horizon. Interbedded silty mudstone commonly exhibits an angular blocky to granular appearance. Mineralogical differences between the mottled strata and unaltered rocks are indicative of pedogenic alteration. The mottled strata contain more mixed illite-montmorillonite clay and less illite clay and unaltered rocks (Stewart, Poole, and Wilson, 1972b).

Strata of the lower member vary widely in thickness. They also exhibit unconformable relations both internally and with the overlying and underlying stratigraphic units, indicating that the lower member was deposited during a period of active salt tectonics. The thickness of the lower member of the Chinle Formation varies in the quadrangle from 0 to more than 380 feet (0-116+ m). Figure 2 shows schematic sections (1 through 5) of the Chinle Formation at locations along the Colorado River. The member is about 140 feet (43 m) thick in the Colorado River canyon in the southwest corner of the quadrangle (location 1) and thins to about 50 feet (15 m) at the Big Bend Campground (location 2). An incomplete section (location 3) of 379 feet (116 m) was measured near Salt Wash Rapids (NW 1/4, section 4, T. 25 S., R. 22 E.) that terminated at river level. At the northeast end of Mat Martin Point, opposite Whites Rapids (location 4) the lower member is 161 feet (49 m) thick, and gradually thins to 63 feet (19 m) (location 5) at Dry Wash in the SE 1/4, NE 1/4, section 24, T. 24 S., R. 22 E. Mottled beds are present on the north side of the Cache Valley structure, but thin northeastward below the cliffs of the Dome Plateau. The lower member appears to disappear southeastward along Porcupine Rim. In places where the lower member is present, but too thin to map, it is included with the upper member on plate 1.

The variation in thickness of the lower member is mostly the result of erosion at the angular unconformity that separates the lower and upper members of the Chinle. At location 3, figure 2, below the west end of Mat Martin Point, the lower member strikes from N. 23 E. to N. 75° E. and dips from 15 to 20° NW., and is abruptly truncated by gently dipping (<5°) beds of the upper member (figure xx). This angular unconformity removes most of the mottled strata of the lower member before location 2 at the Big Bend campground. The

Thickness increases again between locations 2 and 1 (figure xx). At location 1 the dip on the lower member is 10-13° SW and approximately 5-7° greater than the upper member. Shoemaker and Newman (1959) suggested the mottled strata and quartzose sandstone below the angular unconformity at Salt Wash Rapids represent a preserved remnant of Middle Triassic rocks lost by erosion in the unconformity between the Chinle and Moenkopi Formations elsewhere on the Colorado Plateau. O'Sullivan and MacLachlan (1975) suggested that the mottled strata in the Big Bend quadrangle may be correlative with the Temple Mountain Member of the Chinle Formation in the San Rafael Swell. We suggest that our lower member is correlative with the informally named "basal white gritstone" of the Chinle Formation in the salt anticline region. Our upper and lower Chinle Formation members are separated by an unconformity that varies from a disconformity to an angular unconformity because of salt diapirs movement.

**Upper Member (Treu):** The upper member of the Chinle Formation is composed predominantly of moderate reddish-brown and pale- or grayish-red, fine-grained sandstone and siltstone. Sandstone generally exhibits indistinct bedding and occurs as lenses or layers that interfinger with siltstone beds. The fine-grained, calcareous sandstone consists of well-sorted, subangular to subrounded quartz grains and minor mica. Primary sedimentary features include horizontal stratification and medium- to small-scale, low-angle trough cross-stratification and asymmetrical ripple laminations. Siltstone is generally structureless and indistinctly bedded.

Throughout the lower two-thirds of the upper member thin beds to thick lenses of lithic pebble conglomerate are common. Lithic pebbles are reddish siltstone and mudstone, and grayish carbonate and chert. Pebbles are subangular to rounded and are intraclastic, resembling other lithologies of the upper member of the Chinle Formation. Lithic pebble conglomerate varies from clast-supported to matrix-supported with a moderately sorted sandy matrix. A distinction between the upper and lower members is that lithic pebble conglomerates have not been recognized in the lower member. The lithic pebble conglomerates are interpreted to represent the cannibalization of flood-plain deposits in the upper Chinle Formation (Blakey and Gubitosa, 1983).

The "Black Ledge" of the upper Chinle Formation is present along the Colorado River canyon from the southwest corner of the quadrangle to the Big Bend (not mapped), but not farther to the east-northeast. The "Black Ledge" forms a prominent rough cliff, covered with desert varnish, that thins to the northeast and that appears to bifurcate into thin-bedded sandstone layers interbedded with siltstones. It consists of pale-red, reddish-brown, and reddish-gray, fine-grained sandstone interbedded with lenticular conglomeratic sandstone and thin siltstone and shale beds. The interval 10 to 30 feet (3-9 m) below the Black Ledge may locally exhibit soft sediment deformation structures consisting of tight to open disharmonic folds with local slip surfaces.

At most locations near the top of the upper member of the Chinle Formation are 3 to 35 feet (1-12 m) thick lenses of light-brown to reddish-orange, very fine- to fine-grained sandstone. The sandstones are horizontally laminated to thick bedded. Faint cross bedding is sometimes present. These sandstone lenses are interbedded with pale red to reddish-brown

siltstone and mudstone. The sandstones are interpreted to be eolian sand sheets deposited prior to the advancement of the overlying Wingate Sandstone erg deposits (Blakey and Gubitosa, 1983; Dubiel and others, 1989).

The thickness of the upper member of the Chinle Formation varies from 200 to 460 feet (61-240 m) in the Big Bend quadrangle. The thinnest complete sections were measured on the south flank of Cache Valley where the lower part of the mottled beds of the lower member are cut off against a fault. There the upper member varies from 200 to 250 feet (61-76m) thick and reflect deposition of a thinner section over the Cache Valley salt-cored anticline. At most other exposures the upper member ranges from 330 to 460 feet (101-240 m) in thickness (figure 2). The thickest section was measured on the south side of Dry Wash, below Dry Mesa, in the SE 1/4, NE 1/4, section 24, T. 24 S., R. 22 E. (location 5), figure 2). The upper Chinle thins to 300 feet in exposures below the Dome Plateau in the northeast corner of the quadrangle.

## **Jurassic Rocks**

### **Wingate Sandstone (Jw)**

The Wingate Sandstone is the most prominent formation in the Big Bend quadrangle. It is the lower formation of the Glen Canyon Group which, in ascending order, consists of the Wingate Sandstone, Kayenta Formation, and Navajo Sandstone. These formations are here considered to be Lower Jurassic in age (Pipiringos and O'Sullivan, 1978), but no fossils or

evidence pertinent to constraining their age were found. Mostly composed of sandstone, the Glen Canyon Group is generally cliff forming throughout the Big Bend quadrangle.

The Wingate Sandstone forms the prominent cliff along most of the major canyons and valleys in the quadrangle. It is a reddish-brown, nearly vertical cliff, and is commonly streaked and stained to a darker brown or black by desert varnish. Erosion of the Wingate is characterized by thick slabs that separate from the cliff along vertical joints as the formation is undercut by mass wasting of the much weaker underlying Chinle Formation. Wingate Sandstone rubble is ubiquitous on the slopes below the cliffs. In several places, notably on the north rim of the eastern part of Cache Valley, the Wingate is shattered because of salt dissolution induced collapse. Here, a very ledgy and steep blocky outcrop replaces the usual cliff.

The Wingate Sandstone is mostly light-orange-brown, moderate-orange-pink, moderate reddish-orange, pinkish-gray, or pale-reddish-brown, fine-grained, well-sorted, cross-bedded sandstone. High-angle cross-beds indicate the Wingate is dominantly an eolian-deposited unit. Generally it appears massive and uniform from top to bottom; partings and other dividing features are present, but difficult to see at most locations. They are most evident near the base of the unit.

The lower contact with Chinle Formation is generally sharp and may be a disconformity. Locally, angular discordance is present, but this may be due to the presence of soft-sediment deformation in the uppermost Chinle Formation beds. Generally, sandstone on both sides of the contact are similar, but the sandstone in the uppermost Chinle is thick bedded rather than massive.

Although the Wingate Sandstone is prominently exposed in the quadrangle, the vertical outcrop habit restricts suitable locations for measurement. No drill-hole data is available in the quadrangle and the thickness range is estimated. Regionally the Wingate is 250 to 400 feet (76-122 m) thick (Doelling, 1981). In the Big Bend quadrangle area the average thickness of the Wingate Sandstone is about 300 feet (91 m).

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

The Kayenta Formation overlies the Wingate as the middle unit of the Glen Canyon Group. The Kayenta commonly caps the mesas that overlook the deep canyons and valleys and forms thick ledges above the Wingate Sandstone cliff. In some places, such as on the Dry Mesa side of the Colorado River canyon, the Kayenta merges with the Wingate Sandstone in forming a vertical cliff. Although the individual beds and lenses of the formation can be found in various hues, the overall color of the Kayenta is reddish brown and lavender. Prominent benches generally form on top of the thicker sandstone lenses. Bare rock surfaces are normal, but where unconsolidated deposits are present, they are typically thin.

The Kayenta is dominated by fluvial sandstone, but eolian and lacustrine interbeds or lenses are present, especially in the upper third of the formation. Most of the fluvial sandstone tends to be moderate orange pink with dark-reddish-brown to grayish-red, silty mudstone. The lenses normally exhibit low-angle cross-bedding, and display channeling, current ripple marks, and slump features. The grain size is variable, ranging from very fine grained to medium grained. Very fine flakes of mica are common in some of the sandstone

beds and cementation is principally calcareous. Other lithologic types in the Kayenta include: intraformational pebble conglomerate, cliff-forming, light-colored eolian sandstone; slope-forming, reddish-brown to dark reddish-brown, sandy siltstone; very fine-grained, silty sandstone; and rare, very thin beds of gray limestone. These other lithologic types are more commonly found in the upper third of the formation.

The lower fourth of the formation is dominated by very thick to massive fluvial sandstone lenses. Rare very thin partings of dark reddish-brown siltstone locally separate the sandstone lenses, which collectively form a vertical cliff above the Wingate cliff. The middle half of the Kayenta contains medium to thick sandstone beds, sporadic intraformational conglomerate lenses, and abundant siltstone partings that form benches between the lenses, giving the outcrop a more step-like configuration. The upper fourth is generally slope forming with scattered thick lenses of fluvial or eolian sandstone. Much of this upper part is reddish-brown, silty, fine-grained sandstone and sandy siltstone. A few two-inch (five-cm) beds of gray limestone, representing local lacustrine deposition, are found locally in the sequence. Contacts between fluvial and eolian lenses are generally sharp. In the Big Bend quadrangle the Kayenta ranges from 240 to 300 feet (73-91 m) thick.

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

The Navajo Sandstone is the youngest consolidated unit present in the quadrangle, except for outcrops preserved in collapsed areas on Dry Mesa and along the Cache Valley salt-cored anticline. The Navajo Sandstone is the uppermost formation of the Glen Canyon

Group and is the classic example of an eolian-deposited formation. The massive cross-bedded sandstone unit is commonly described as fossilized or petrified sand dunes. The outcrops form cliffs and large rounded cupola- or dome-like features. Large areas of unconsolidated sand commonly cover or fill hollows over cliffy exposures. The contact between the Navajo and underlying Kayenta is difficult to place. Thick eolian beds near the top of the Kayenta are similar to those in the Navajo and are thought to intertongue laterally into the Navajo Sandstone.

The Navajo Sandstone is mostly orange to light-gray, fine-grained sandstone cemented with silica or calcite. Medium to coarse grains of quartz sand are common along cross-bed laminae. Even though the Navajo is a well-cemented cliff former, the sandstone is somewhat friable in hand specimen. The sandstone is generally massive and divided into 15- to 25-foot (4.6- to 7.6-m) thick cross-bed sets. Cross-bedding angles locally exceed 30 degrees.

Locally, thin, gray, commonly cherty limestone beds are found in the Navajo Sandstone. In the Big Bend quadrangle they are present on Dry Mesa, Mat Martin Point, and the Dome Plateau. Thin reddish silty sand partings separate the 1- to 4-inch (2.5- to 10-cm) limestone beds that aggregate from 1 to 4 feet (0.3-1.2 m) in thickness. Areally these lacustrine or playa limestones extend to as much as several hundred acres (80+ hectares). At the margins of the deposits, the beds become silty and sandy and eventually thin out into the massive sandstones as partings. In the Big Bend quadrangle, these limestone beds are most common in the upper third of the Navajo Sandstone, but are locally present elsewhere. The limestone outcrops commonly form a resistant bench covered with a dark sandy or rubbly soil.

Regionally, the Navajo Sandstone thins from west to east due to erosional truncation (Doelling, 1981, Hintze, 1988). but this thinning cannot be demonstrated on the Big Bend quadrangle, because most exposures are incomplete. Scattered erosional remnants of the Navajo Sandstone are found on most of the larger mesas in the quadrangle and a complete section is only found on the north flank of the Cache Valley graben. At this location the formation is nearly 400 feet (122 m) thick. Before Pliocene to Pleistocene erosion, the thickness probably ranged from 250 to 400 feet (122 m) in the quadrangle area. The Navajo is generally very cliffy immediately above the Kayenta contact. The upper part generally forms bare-rock dome-like outcrops. The upper contact is an unconformity with little relief, which is overlain by the Dewey Bridge Member of the Entrada Sandstone.

### **Entrada Sandstone**

The Entrada Sandstone is preserved in the Cache Valley graben, along its flanks, and as remnants on Dry Mesa. The Entrada Sandstone is divided into three units, in ascending order, the Dewey Bridge, Slick Rock, and Moab members (Wright and others, 1962). The formation is Middle Jurassic in age (Hintze, 1988) and averages about 400 feet (122 m) thick in the quadrangle.

**Dewey Bridge Member (Jed):** The contact between the Navajo Sandstone and the Dewey Bridge Member of the Entrada Sandstone is easily recognizable where light-colored sandstone is overlain by dark-red or medium red, muddy, less resistant sandstone. Locally, this change

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is not pronounced, and the lower sandstones of the Dewey Bridge, although slightly darker, are also resistant. The contact is a major regional unconformity that separates Lower Jurassic strata from Middle Jurassic strata (Pipiringos and O'Sullivan, 1975).

The surface expression of this member is generally a poorly exposed earthy slope or a prominently-exposed reddish-brown recess between the overlying Slickrock Member and the underlying Navajo Sandstone. The Dewey Bridge Member is best exposed in the southeastern part and northwestern part of the Cache Valley graben. present in a few small areas in the northwestern flank of the Cache Valley graben. Additional, but poor exposures are found on Dry Mesa.

The Dewey Bridge Member is interpreted to have been deposited on broad tidal flats marginal to a shallow sea (Carmel sea) located to the west (Wright and others, 1962). It is a soft, red, muddy sandstone with irregular contorted bedding. The sandstone is generally fine-grained and silty, poorly cemented with iron oxides or calcite, and divided into indistinct "lumpy" medium to thick beds. Locally, the lower beds may be as well-cemented as the Navajo. The well-cemented beds are generally lighter in color than the remainder of the member because of the greater calcite content and the abundance of lighter reworked Navajo sand grains. The Dewey Bridge is 40 to 60 feet (12-18 m) thick in the vicinity of Cache Valley.

**Slick Rock Member (Jes):** The Slick Rock Member of the Entrada Sandstone generally forms vertical, lightly banded cliffs. In the Cache Valley area, exposures are shattered or broken into blocks by salt-dissolution faulting. The rock along the fractures is commonly

bleached. The lower contact in the Big Bend quadrangle is generally gradational over a few feet and is picked at the top of the last "lumpy" bed of the Dewey Bridge Member. The Slick Rock Member is generally massive and reddish orange rather than reddish or reddish brown. Exposures of the Slick Rock Member are limited to the west end of the north flank and the east end of the south flank of Cache Valley.

The Slick Rock Member is a massive, well-indurated, reddish-orange or brown, very fine- to fine-grained sandstone with sparse medium to coarse sand grains. It weathers to form smooth cliffs and bare-rock slopes. The Slick Rock was deposited by the wind and the rock exhibits high-angle cross-bedding like the Wingate and Navajo. However, unlike the Navajo, the sandstone is better sorted and cross-bed laminae do not etch out as well upon weathering, hence the smoother-appearing outcrops. The cementation is generally calcareous or by iron oxides.

The member is about 250 feet (76 m) thick in the Big Bend quadrangle. Accurate measurements are difficult to obtain because the unit is a massive cliff and generally not scalable. In other localities it is so fractured and broken that complete sections are difficult to find.

**Moab Member (Jem):** The uppermost member of the Entrada Sandstone in the Cache Valley area is a resistant light-gray sandstone that is strongly jointed and has thick to massive cross-bed sets. The lower contact is a prominent parting filled with a few inches (5+ cm) of reddish sandy siltstone. The Moab Member sandstone is generally lighter in color than that in the Slick Rock Member and weathers to a granular surface rather than a smooth one. The

**Moab Member** resembles the Navajo Sandstone, but is not as thick and does not exhibit high-angle cross-bedding. The unit weathers to form rounded bare-rock surfaces, and because of the prominent jointing, develops huge "pillows" or "biscuits" on the upper surface. Delicate **Arch**, the most famous in Arches National Park, has been cut in the lower part of the Moab Member and the upper part of the Slick Rock Member.

The Moab Member is a very pale-orange, grayish-orange, pale yellowish-brown, or light-gray, fine- to medium-grained, calcareous, massive, cliff-forming sandstone. It is generally well-indurated and exhibits low-angle cross-bedding. The member ranges from 90 to 120 feet (27-37 m) thick in Cache Valley.

## **Cretaceous-Jurassic Rocks**

### **Morrison Formation**

The Morrison Formation consists of three members in the Big Bend quadrangle, in ascending order, Tidwell, Salt Wash, and Brushy Basin Members. The exposures are confined to the Cache Valley graben. In addition, rubble, breccia, of landslide deposits containing unmistakable Morrison rocks have been identified on the south flank of the graben. The Morrison Formation has been considered to be Late Jurassic in age (Dane, 1935; Williams, 1964; Doelling, 1985), but recent work by Kowallis and Heaton (1987) indicates that the upper part of the Brushy Basin Member may be Early Cretaceous in age. The complete Morrison Formation is 590 to 650 feet (180-198 m) thick in Cache Valley.

**Tidwell Member (Jmt):** The lower member of the Morrison Formation in the Cache Valley graben is a very easily recognized marker unit that contrasts sharply with both the Moab Member of the Entrada Sandstone below and the Salt Wash Member above. Its dark red or lavender color and large white siliceous concretions are a trade-mark. Tidwell Member outcrops are prevalent along the trail to Delicate Arch and near the Delicate Arch Viewpoint parking lot. Fault-repeated outcrops of Tidwell are also found in the eastern part of the graben.

The Tidwell Member in the Moab area was previously assigned to the Summerville Formation (Dane, 1935; Williams, 1964). More recent work by O'Sullivan (1980, 1981) indicates that much of this interval should be assigned to the Morrison Formation. Additional work is necessary to indicate whether any strata in the Cache Valley exposures correlate with the Summerville Formation of western Grand County. We have elected to assign the entire marker unit to the Tidwell Member of the Morrison Formation.

The lower contact with the Entrada Sandstone is interpreted to be an unconformity (Peterson, 1988). The light-hued cliff-forming Moab Member stands out in contrast to the slope-forming, deep-red sandstone and siltstone of the Tidwell Member. Locally, at the base of the Tidwell, is a 1- to 2-foot (0.3- to 0.6-m) thick resistant, platy weathering, well-bedded, reworked, fine-grained, brown sandstone.

No fresh exposures of the unit are present, but in nearby areas the bedding is generally thin to shaly. Sporadic interbeds of fine-grained sandstone weather into ledges that interrupt the even slope. Near the middle of the formation is a zone of sandy nodular gray limestone and huge concretions of white to light-pink chalcedony. Concretions approach 20 feet (6 m)

in diameter, while most are 5 to 10 feet (1.5-3.0 m) in diameter. The sandy limestone beds locally are as much as 3 feet (0.9 m) thick. Thin beds of nodular limestone occur between the concretionary zone and the top of the unit.

The thickness of the Tidwell Member in Cache Valley is 40 to 60 feet (12-18 m). Dane (1935, p. 106) indicated that the Tidwell Member was deposited in rather quiet shallow waters on a gently sloping flood plain. The origin of the large siliceous concretions is still in a quandary, but may be diagenetic.

**Salt Wash Member (Jms):** The Salt Wash Member of the Morrison Formation consists of anastomosing, resistant sandstone channels, separated by thin bedded, slope-forming, red or reddish-brown, silty, fine-grained sandstone, sandy siltstone, mudstone, or claystone. Rocks of this member are the predominant exposures in the central part of the Cache Valley graben, where they are shattered and faulted by dissolution collapse.

The lower contact with the Tidwell Member is probably conformable. In outcrop it appears to be gradational and interfingering. In Cache Valley the contact is placed where the red slope-former abuts against cliff-forming, light-colored channel sandstone lenses.

The Salt Wash Member consists of sandstone, conglomeratic sandstone, mudstone, siltstone, shale, claystone, and conglomerate. Sandstone, conglomeratic sandstone, and conglomerate lenses are resistant and form ledges and low cliffs. Outcrops are generally light gray to light brown on fresh surfaces and weather to nearly white hues. The lenses represent ancient river channels (Trimble and Doelling, 1978), and individual channels can be locally traced for a few hundreds of feet. Sedimentary features, such as meanders, bars, trough cross-

stratification, cut-and-fill, are readily identifiable. The cementation is generally calcareous and the sediment grain size varies within individual lenses as well as from lens to lens. The less-resistant mudstone, siltstone, shale, and claystone generally are sandy and weather into recesses or earthy slopes. They are interpreted to represent the flood-plain deposits of the meandering flood-plain environment. The Salt Wash Member is about 250 feet (76 m) thick in the Cache Valley area.

**Brushy Basin Member (KJmb):** Whereas the Salt Wash Member is dominated by cliff-forming channel sandstones, the Brushy Basin Member is dominated by slope-forming flood-plain and lacustrine deposits. The member is exposed in the more deeply collapsed parts of the Cache Valley graben. The member is easily recognized by its bright green or blue-green color.

The contact between the Salt Wash and Brushy Basin Members is placed where the ledge-forming sandstones of the Salt Wash give way to the slope-forming mudstones of the Brushy Basin Member. Locally, however, resistant sandstone and conglomerate lenses are also found in the Brushy Basin. These are more common in the lower part of the member, and where present, are generally more conglomeratic and weather darker in color.

The Brushy Basin generally consists of variegated muddy siltstone and claystone, with lesser amounts of sandstone, conglomeratic sandstone, and limestone. In Cache Valley, the slope-formers are dominated by bright green or maroon hues. Clay present in the mudstone swells when wetted and shrinks when dried and provides typical "popcorn-" textured outcrops. The bentonitic clay is derived from the hydrolysis and devitrification of volcanic ashes

(Stokes (1952). Some of the volcanic ash is altered to zeolite minerals, which produce the bright green or blue-green color.

Sandstone, conglomeratic sandstone, conglomerate and limestone can be found throughout the member, but are generally more prevalent in the lower half. Grain size varies considerably within individual lenses and from lens to lens, ranging from very fine to very coarse sand and granules to small cobbles. Most of these ledge-forming lenses are a shade of white, gray, or brown. The coarser grained and better indurated units are generally cross-bedded.

In Cache Valley, the lower 55 feet (17 m) of the Brushy Basin consists of 60 percent slope-forming rocks interbedded with 40 percent of the ledge-forming units. Above this is a 40-foot (12-m) thick lenticular conglomeratic sandstone that grades laterally into light-colored fine-grained sandstone interbedded with variegated shale or mudstone. This is overlain by 30 feet (9 m) of mostly maroon mudstone capped by a ledge of brown- or nodular-weathering gray limestone. Next are 100 feet (34 m) of bright green earthy mudstone or shale with thin fingers of white fine-grained sandstone that is entirely slope-forming in its outcrop habit. It is capped by a gray-green, brown-weathering ridge or ledge-forming sandstone about 10 feet (3 m) thick. The uppermost unit is a greenish and tan shale or mudstone with a few ledges of "lumpy," fine-grained, cream-colored sandstone and brown-weathering, nodular gray limestone about 80 feet (24 m) thick. The Brushy Basin Member is 300 to 340 feet (91-104 m) thick in Cache Valley.

## **Cretaceous Rocks**

Cretaceous rocks are represented by three formations in the Big Bend quadrangle. These are, in ascending order, the Cedar Mountain Formation, Dakota Sandstone, and Mancos Shale. The exposures are limited to the Cache Valley graben in areas where the deepest collapse has occurred, mostly in the western part. No more than 1,300 feet (396 m) of Cretaceous strata remain preserved in Cache Valley.

### **Cedar Mountain Formation (Kcm)**

The Cedar Mountain Formation has an outcrop appearance similar to the Brushy Basin Member of the Morrison Formation. This similarity in character makes recognizing a contact between the two formations difficult. The contact is mapped at the base of a thick 10- to 20-foot (3- to 6-m) thick ledge- or cliff-forming lenticular conglomerate and quartzose sandstone. This conglomerate and sandstone are interpreted to be equivalent to the Buckhorn Conglomerate present to the west in Emery County. The contact is a questionable unconformity because of the assignment of the Brushy Basin Member of the Morrison Formation to the Lower Cretaceous.

The Cedar Mountain Formation consists of one or two cliff-forming units of sandstone, quartzitic sandstone, conglomeratic sandstone, gritstone, and conglomerate, separated by thick slope-forming mudstone and muddy sandstone. The resistant units are very similar in texture and coloration to Brushy Basin counterparts. The mudstone is also similar to that in the

Brushy Basin, but the coloration is generally not as bright. Gray and lavender mudstone is also present in the Cedar Mountain Formation and maroon mudstone is rare. Nodular, brown-weathering, gray, sandy limestone horizons are also commonly encountered in the slopes of the Cedar Mountain Formation.

In sections 9 and 10, T. 24 S., R. 22 E., south of Delicate Arch, the lowermost unit of the Cedar Mountain Formation (Buckhorn equivalent) consists of 15 feet (4.6 m) of lenticular, fine- to coarse-grained and pebbly conglomerate and quartzitic sandstone that form a very prominent ridge or cliff. This is overlain by 90 feet (27 m) of slope-forming, pastel-green shale interbedded with sporadic thin to medium lenses of tan, green, or gray medium-grained well-indurated sandstone or pebbly sandstone. The next 40 feet (12 m) is similar, but the overall color is light gray. For another 85 feet (26 m) the color alternates between lavender and gray and thin zones of nodular sandy limestone become more numerous.

The Cedar Mountain Formation is 200 to 240 feet (61-73 m) thick in Cache Valley. Like the Brushy Basin Member of the Morrison Formation, it is regarded to be a swampy flood plain deposit (Stokes, 1952). The Cedar Mountain is considered Early Cretaceous (Albian) in age (Hintze, 1988, p. 54-55).

### **Dakota Sandstone (Kd)**

The Dakota Sandstone is mostly a prominent yellow-brown-weathering resistant sandstone and conglomeratic sandstone that outcrops as hogbacks in Cache Valley. However, a lower slope-forming unit of soft yellow-gray mudstone is commonly present that rests on

light-gray and lavender mudstone of the Cedar Mountain Formation. The contact with the Cedar Mountain Formation is an unconformity (Hintze, 1988). The exact position of the contact is difficult to find in the slope, however, the color difference between mudstones is helpful.

The resistant part of the Dakota is dominated by yellow-gray, grayish-orange to brown sandstone, conglomeratic sandstone, and conglomerate. The conglomeratic beds contain mostly cobble- and pebble-sized clasts interbedded with medium- to coarse-grained sandstone. Cementation is generally calcareous and the lenses are cross-stratified. Rare fossil wood and leaf impressions are present in these more resistant units. Close examination of the mudstone slopes indicates the presence of siltstone and claystone, fine- to medium-grained, poorly-cemented sandstone, carbonaceous shale, and white limy marl.

The Dakota ranges from 40 to 50 feet (12-15 m) in thickness. Variations in thickness are commonly at the expense of the slope-forming lower unit. The hard ridge-forming part ranges from 15 to 25 feet (4.5-7.6 m) in thickness. The Dakota was deposited on a broad coastal plain in front of an advancing Mancos sea. The Dakota is Late Cretaceous (Cenomanian) in age (Hintze, 1988, p. 54-55).

### **Mancos Shale**

The Mancos Shale is the youngest formation exposed in the Big Bend quadrangle. Regionally, it is about 3,600 feet (1,096 m) thick (Willis, 1991), but only the lower 1,000 feet (305 m) are preserved in Cache Valley in the Big Bend quadrangle. Included are the Tununk

Shale Member, the Ferron Sandstone Member and the lower part of the Blue Gate Shale Member (Niobrara) of the formation.

**Tununk Shale Member (Kmf):** The Tununk Shale Member is found only in the western part of the Cache Valley graben in sections 8, 9, and 10, T. 24 S., R. 22 E. It is generally poorly exposed, but easily recognizable as part of the Mancos Shale. The contact with the Dakota Sandstone is easily recognized, but gradational over a narrow interval. The Tununk Shale is a medium-gray, bluish-gray, steel-gray, or lead-gray fissile shale that forms a soft slope. Some of the shaly horizons are silty or sandy and are slightly more resistant, but these rarely show in the Cache Valley outcrops. Most of the shale is slightly calcareous.

The Tununk is estimated to be 400 feet (122 m) thick, but may locally be attenuated because of salt-dissolution-related deformation. Near the top the member becomes sandy and grades into the Ferron Sandstone Member. The Tununk is considered to be late Cenomanian to mid-Turonian in age (Molenaar and Cobban, 1991). It was deposited in an epicontinental sea that covered the central part of the North American continent in Late Cretaceous time.

**Ferron Sandstone Member (Kmf):** The Ferron Sandstone Member is the most resistant part of the otherwise soft Mancos Shale in Cache Valley. The Tununk Shale becomes increasingly sandy toward its top, but the contact with the Ferron Member is an erosional sequence boundary (Molenaar and Cobban, 1991). The sandy character of the Ferron makes it more resistant and gives it a brownish-gray color. In Cache Valley the Ferron forms low ridges and rounded hills. Regionally the Ferron forms a low double cuesta of sandy shale separated by a

soft swale of very carbonaceous, dark fissile shale (Doelling, 1988). In Cache Valley, probably because of steep dips and attenuation, the outcrops have weathered unevenly and the double cuesta is not always recognizable.

Most of the Ferron Member is platy or thin-bedded, brown-gray, very fine-grained sandstone. The middle part of the member (about 20 to 30 feet [6-9 m] thick) consists of dark gray and black carbonaceous shale. The lower cuesta of the Ferron Sandstone is 35 to 40 feet (11-12 m) thick, the upper is about 35 to 50 feet (11-15 m) thick.

The thickness of the Ferron Sandstone ranges from 90 to 120 feet (27-37 m) in the Big Bend quadrangle. It grades upward into the Blue Gate Shale Member. Broken megafossils (mostly shellfish) commonly litter the surface near the top. The Ferron is Turonian in age (Molenaar and Cobban, 1991) and is interpreted to have been deposited in a shallow, shoaling sea.

**Blue Gate Shale Member (Kmb):** This unit is similar to the Tununk Shale Member, but generally is a lighter gray in outcrops. The contact between the Ferron and Blue Gate Members is gradational. Like in the Tununk, there are scattered sandy layers that are more tan and slightly more resistant than the encasing gray marine shale. The outcrop area in Cache Valley is one of low rolling hills.

It is estimated that the thickness of the Blue Gate Shale Member that remains uneroded in Cache Valley is no more than 500 feet (152 m). No younger consolidated units are found in the quadrangle nor in the adjacent Salt Valley anticline (Doelling, 1985).

## Quaternary Deposits

Quaternary surficial deposits in the Big Bend quadrangle represent a variety of alluvial, eolian, and mass-wasting depositional environments. Richmond (1962) studied Quaternary deposits in an approximately 520-square-mile (1,347-sq-km) area around the La Sal Mountains. Using criteria such as relative topographic position, surface expression, texture of deposits, and degree of soil development, Richmond (1962) grouped the deposits into the Gold Basin, Beaver Basin, Placer Creek, and Harpole Mesa Formations, each of which was subdivided into members. Shroder and Sewell (1985) pointed out problems with Richmond's (1962) designations, and recommended only informal use of this terminology. New detailed mapping in the region (Ross, in preparation) supports the reconnaissance investigations of Shroder and Sewell (1985). Therefore, Richmond's (1962) formational names are not used in the discussion of Quaternary deposits. Figure 3 provides an approximate correlation between Richmond's units and the informal designations of this report.

### Landslide Deposits (Qms)

The remnants of an "old" rotational slump is present at the northwest end of Castle Valley on the north side of the easternmost butte. The slump developed in the upper part of the Moenkopi Formation. The basal slip surface is well preserved. The direction of slide movement is northeast, approximately parallel to the local dip direction. The slide is highly

eroded and dissected by headward-eroding washes. Dips steepen toward the headscarp. The basal slip surface exhibits significant disruption of the slide material. Beds of both the Moenkopi and Chinle Formations are present in the slide. The extremely eroded condition of the slide and its 700-foot (213-m) height above the river suggest an early Pleistocene or older age.

Jumbled and slumped masses of the Moab Member of the Entrada Sandstone, and Tidwell and Salt Wash Members of the Morrison Formation are found in a salt-collapse basin in the northeast part of Dry Mesa, S 1/2, sections 13 and 14, T. 24 S., R. 22 E. Morrison Formation debris in this deposit was derived from outcrops present on Dry Mesa during active salt-dissolution collapse, now removed by subsequent erosion. The nearest mapped outcrops of the Morrison Formation are found in the Caehé Valley structure at altitudes lower than those of the landslide deposit. At one location a thick deposit of mixed eolian and alluvial sand, capped by a stage V petrocalcic soil, partially covers the landslide deposit. Oviatt (1988) estimates the soil to be early Pleistocene in age, making the slide material even older. Similar thick, deformed mixed eolian and alluvial sand deposits contain the Bishop (740 Ka) and Lava Creek B (620 Ka) ashes in Salt Valley and Fisher Valley (Colman and Hawkins, 1985; Oviatt, 1988). Colman and Hawkins (1985) indicate their lower basin-fill deposits (deposits beneath the Bishop ash) may be as old as Pliocene in age. We assume the landslides are early Pleistocene in age, but they may be as old as Pliocene.

Along the eastern rim of the Dome Plateau, approximately 0.5 miles (0.7 km) southeast of the mapped Qms deposit an extremely large block of Wingate and Kayenta sandstone is detached from the plateau by a large arcuate fissure, approximately 2 to 30 feet

(0.6-9.1 m) wide. The fissure appears to penetrate through the Jurassic units and root in the Chinle Formation. The fissure may have originated as a joint and is a probable headscarp. The large block of sandstone does not appear to exhibit any significant vertical displacement or rotational movement.

The more incompetent, mud-rich beds of the Chinle Formation commonly fail during erosional oversteepening and undercut the Wingate, bringing down large slide blocks. Smaller blocks separate from the cliff, fall, and break apart on the slopes below to develop talus deposits.

### **Talus Deposits and Colluvium (Qmt)**

Talus deposits and colluvium are found on steep slopes along canyon walls and below most cliffs. Talus and colluvium exhibit gradational contacts; therefore they are lumped together. Talus deposits consist of gravity-produced rock fall blocks, boulders, and smaller fragments. Colluvium consists mostly of slopewash material and is comprised of poorly sorted, angular to subangular rock fragments in a matrix of coarse to fine sand, silt, and clay. Some colluvium may display a weak discontinuous bedding parallel to slope, but most is structureless (Richmond, 1962). Colluvium generally supports vegetation, whereas talus contains little fine material between blocks and supports little vegetation.

The best preserved Qmt deposits occur as cones and sheets on the slope of the Triassic formations beneath the overlying Jurassic Glen Canyon Group sandstone cliffs. The deposits range from a thin veneer to a thick 10-foot (3-m) layer. The deposits may exhibit relatively

smooth concave surfaces locally scored by shallow gullies. The deposits are commonly gradational and interfinger with alluvial fan material (Qaf0 and Qafy) at their downslope extent. The contact between the Qmt deposits and alluvial fan deposits is arbitrarily placed at a break in slope.

### **Pediment-Mantle Deposits (Qpm2, Qpm3, Qpm4)**

Along the flanks of the Colorado are continuous and discontinuous deposits of locally-derived alluvial material that extend into the surrounding bedrock exposures. These deposits are relatively thin gravel veneers on pediment surfaces, and are mixed alluvial fan and ephemeral stream deposits (Colman and Hawkins, 1985). Locally, they contain eolian and sheetwash sand deposits.

The deposits are subdivided into three units (Qpm2, Qpm3, Qpm4) based on relative height above the present drainage channel and alluvial terrace deposits along the river. The relative elevations are similar to those of the alluvial terrace gravels.

The oldest deposits (Qpm3, Qpm4) consist predominantly of poorly sorted, sandy, matrix-supported gravel. Locally, lenses of sand-rich and clast-supported gravel are present. Clast size in the gravel deposits ranges from pebbles to boulders. Matrix material consists of reddish-brown, calcareous sand and silt. Clasts are comprised of lithologies common to the Permian and Mesozoic formations in the immediate source areas. Well-rounded Precambrian igneous and metamorphic clasts derived from the Permian Cutler Formation or from alluvial terrace gravels are locally present. The pediment deposits are locally interbedded with

alluvial terrace river gravels. Along the west side of the Colorado River at New Rapids debris of Qpm4 overlies a 10-foot (3-m) bed of Qat4 river gravel. The basal portion of the Qpm4 deposit is a discontinuous 20-foot (6-m) layer of bouldery gravel comprised mainly of Jurassic Glen Canyon Group sandstone. This is overlain by a sand-rich unit that weathers to earthy, rounded hills and slopes. The sand-rich unit is composed of subangular, fine-grained sand and silt and weathers to a reddish tint above a buff-colored slope.

### **Terrace Gravel Deposits (Qat2, Qat3, Qat4)**

Alluvial terrace gravel deposits are common at numerous locations along the Colorado river. The highest terrace (Qat4) is represented by rounded knobs of gravel capping small hills approximately 130 feet (40 m) above the present river level. Qat3 deposits exhibit a similar morphology at approximately 100 feet (30 m) above the river.

The deposits consist of subrounded to rounded, poorly stratified, clast-supported gravel in gray, calcareous, sandy matrix (Colman and Hawkins, 1985). Clasts are mostly 2 to 6 inches (5-15 cm) in diameter with the largest about 12 inches (30 cm). Some clasts are disintegrated. The gravels contain a wide variety of lithologies including Precambrian granitic and high-grade metamorphic rocks, Tertiary (?) basaltic and intermediate composition igneous rocks, and late Paleozoic to Mesozoic sedimentary rocks. Associated with the gravels are beds of moderately sorted cross-bedded sand.

## **Alluvial Deposits (Qa1, Qa2, Qag3, Qag4).**

Alluvial deposits ranging from middle Pleistocene to Holocene are present in the Big Bend quadrangle. Harden and others (1985) showed that Holocene alluvium in the Spanish-Moab Valley area (equivalent to our Qa1 and Qa2) are easily distinguishable from Pleistocene alluvium (equivalent to our Qag3 and Qag4) because of overall finer grain size. Holocene alluvium mapped as Qa1 is confined to active stream channels. The generally finer grained sediment is mostly poorly-sorted sand and pebbly gravel. Alluvium along the present Colorado River channel is included with Qa1 deposits, although it has clast types similar to the terrace gravel deposits (Qat). Bars and levees along the river bank are comprised mostly of sand and pebbly sand with sporadic large subangular to well-rounded cobbles and boulders.

Castle Creek and Placer Creek are the main drainages for Castle Valley. The creeks converge in the lower part of Castle Valley in the southeast corner of the Big Bend quadrangle. Alluvium (Qa1) is mapped in the larger active channels. Slightly older alluvium (Qa2) forms the valley-fill material present at the surface in lower Castle Valley. Castle Creek has incised about 30 feet (9.1 m) into Qa2 alluvium below the creek confluence. Qa2 deposits consist mainly of sand, silt, and clay, with occasional gravel lenses. However, the amount of gravel in these deposits increases up the drainage system. As observed by Richmond (1962) and Harden and others (1985), the Qa2 alluvium characteristically exhibits weak soil development. Exposures of Qa2 along lower Castle Creek exhibit several weak buried A horizons. Minor disseminated pedogenic carbonate (weak Stage I) may be present at some locations (Harden and others, 1985).

Older alluvial deposits of Qag3 and Qag4 typically consist of poorly sorted, unstratified to poorly defined subhorizontal-bedded, sandy, cobble gravel. The gravels are generally clast supported, with some layers exhibiting imbricated clasts. Local, small, and irregular accumulations of boulders on the Qag3 and Qag4 surfaces are suggestive of sieve deposits. In general, the Qag3 deposits form a dissected, stony surface that slopes inconspicuously into the Qa2 surface. Soils associated with Qag3 deposits exhibit weak argillic horizons in fine-grained alluvium and calcic horizons in gravelly alluvium. The calcic horizons range from continuous coatings on clast bottoms (Stage I) to continuous carbonate coatings on clasts and disseminated carbonate in the matrix with occasional nodules.

Qag4 deposits are preserved as low relief, subtle ridge surfaces in the southeast corner of the quadrangle. The Qag4 deposits are capped by the eroded remains of a pedogenic carbonate soil horizon. The calcic horizon varies from coalesced carbonate nodules to pebble coatings cemented in a plugged horizon (Stage IV). The variability in pedogenic carbonate development appears to be a function of surface stripping by erosion. This calcic horizon can be traced up valley into the Warner Lake quadrangle where it caps a broad whaleback feature (Ross, in preparation).

Another well-indurated calcic horizon, exhibiting Stage IV morphology, is poorly exposed along the dry wash that separates the two Qag4 deposits. This calcic horizon cannot be traced up valley to older terrace surfaces. Calcic soil development is slightly better developed, but resembles that of the Qag4 deposits that overly it at this location. Harden and others (1985) suggested, on the basis of calcic soil development, that alluvial deposits equivalent to unit Qag3 are correlative with Pinedale-age deposits of the Rocky Mountain

region. Furthermore, they conclude that alluvial deposits equivalent to unit Qag4 are correlative to Bull Lake-age deposits.

Information from water-well logs (Utah Division of Water Rights, unpublished data) and cuttings from two petroleum wells (Utah Geological Survey Core Library, unpublished data) suggest that as much as 350 feet (107 m) of gravelly alluvium is present beneath the surface of lower Castle Valley.

### **Alluvial Fan Deposits (Qafy, Qafo)**

Along the margins of Castle Valley, especially below Porcupine Rim, alluvial fans have coalesced to form apron-like gentle slopes inclined toward the valley. The alluvial fan surfaces are extensively dissected by numerous gullies. The fans grade upslope into talus and colluvium and downslope into alluvium. Younger alluvial fans (Qafy) head in gullies of older fan deposits (Qafo) and overlap older fan surfaces downslope. Remnants of successively older beheaded fan surfaces stand above the younger surfaces.

The deposits consist of poorly-sorted, angular to subangular boulders, cobbles, and gravels in a crudely-bedded, fine-grained matrix. Cut-and-fill channel features are sometimes present. Deposit thickness ranges from 6 feet (1.8 m) to 40 feet (12 m) in water-well holes. Sedimentary features, such as cut-and-fill structures and structureless matrix-supported gravel layers suggest unchanneled slopewash and channelized debris flows and ephemeral stream action.

### **Mixed Alluvial and Colluvial Deposits (Qac)**

Areas of mixed alluvial and colluvial deposits parallel the ephemeral washes of Cache Valley. The active channels contain sand and cobble alluvium choked with angular cobbles and boulders that slide in from adjacent bedrock outcrops. Wider area deposits consists of sand or mud derived from local bedrock sources mixed with clayey, silty, and sandy sheetwash. The deposits are probably Holocene and late Pleistocene in age and are as much as 15 feet (5 m) thick.

### **Mixed Eolian and Alluvial Sand Deposits (Qea, Qeao)**

Many deposits of unconsolidated sand have a mixed eolian and alluvial origin (Qea). The majority of the sand was probably deposited by the wind, but alluvial processes, such as sheetwash and ephemeral streams, have deposited new sand and reworked the eolian material. Generally, these deposits are restricted to areas where occasional sheetwash runoff reworks the predominantly eolian-derived material. Most of these deposits are probably Holocene in age.

However, on the southwest side of Cache Valley, calcic soil development on mixed eolian and alluvial sand deposits (Qeao) suggests an early Pleistocene age. The Cache Valley petrocalcic soil reaches carbonate morphologic stage V and is found on an eolian-mantled geomorphic surface that truncates gently-dipping strata of Jurassic age (Oviatt, 1988). The older mixed eolian and alluvial deposits are approximately 160 feet (49 m) thick, consisting of horizontally bedded sand and silt with minor clay and gravel lenses. This section fills an

approximately 500-foot (152-m) wide paleocanyon. No buried soils or unconformities have been observed in the finer-grained fill material, suggesting the sediments accumulated rapidly and nearly continuously (Oviatt, 1988).

### **Eolian Sand Deposits (Qes)**

Areas of small-scale dunes and thin sheet accumulation of eolian sand (Qes) are present on the massive sandstone plateaus in the quadrangle. The relatively thin, discontinuous deposits are commonly found in narrow canyons, erosional surface depressions, and on the lee side of irregular bedrock outcrops. Most eolian deposits support sparse vegetation and are partially stabilized. The deposits are probably Holocene in age.

## **STRUCTURAL GEOLOGY**

The Big Bend quadrangle is located in an interesting place in the Paradox fold and fault belt. It lies at the junction of three major salt-tectonic structures: the collapsed Castle Valley salt-cored anticline, Cache Valley graben, and Professor Valley graben. Regionally, Mesozoic and Tertiary strata dip gently northward from the La Sal Mountains-Moab region toward the Book Cliffs into the Uinta Basin (Williams, 1964). The salt tectonic structures, and related structures on their flanks disrupt the otherwise simple homocline. The homocline represents regional subsidence of the Uinta Basin during the Laramide orogeny (Late Cretaceous through Eocene). Superimposed on the regional homocline are northwest-trending

broad folds that are interpreted to have formed during the Laramide orogeny (Williams, 1964). Post-Laramide(?) extensional faults may have formed along some of the salt-cored anticlines (McKnight, 1940). However, the origin of these normal faults is conjectural (Hite and Lohman, 1973, Woodward-Clyde Consultants, 1983).

### Cache Valley Graben

The Cache Valley graben extends west-northwest from the Colorado River and connects with the Salt Valley salt-cored anticline, which trends northwesterly (figure 1). The graben formed by dissolution of salt at depth and by collapse of overlying strata into the void (Doelling, 1983). Pre-Paradox Formation fault systems and the presence of a linear belt of thick diapiric salt controlled the trend of the structure. The major displacing fault in the fault zone on the south margin of the graben is termed the South Flank fault and the major displacing fault on the north margin is termed the North Flank fault.

The strata found in the Cache Valley graben are the youngest consolidated rocks to be found in the quadrangle (figure 4, cross section C-C'). The attitude of strata found in the graben vary from horizontal to vertical, generally striking in linear belts that subparallel graben escarpments and faults. The more competent units are represented geomorphically by hogbacks. They are shattered by many fractures. The less competent units have been locally folded, but most units are broken and tilted.

The Mancos Shale covered the quadrangle prior to salt dissolution collapse sometime in Late Tertiary time. The presence of Mancos Shale in the graben indicates at least 4,400

feet (1,341 m) of collapse into a void created by the removal of salt from the Paradox Formation by ground water. To illustrate the magnitude of lost salt and the affect the collapse has had in preserving younger strata, the Mancos would be exposed at an altitude of nearly 9,000 feet (2,743 m) above sea level had it remained uneroded on the surrounding mesas. Therefore, 3,700 feet (1,128 m) of strata have been removed by erosion since salt dissolution began. The collapse of the Mancos Shale and other units was not all at once, but occurred intermittently along the flanking faults over an extended period of time.

Deep V-synclines have developed at the north and south margins of the Cache Valley graben leaving a broad anticline in the middle. A V-syncline is a salt-dissolution induced structure with a V-shaped cross section (Doelling, 1985, 1988). Strata reverse dips sharply across the hinge of such a syncline. Dips on the north side of the north V-syncline range to 20 degrees and dips on the south side range to 40 degrees. Dips along the south V-syncline are steep, commonly approaching 80 degrees. Both synclines are well developed in section 10, T. 24 S., R. 22 E. (see figure 4, cross-section D-D').

The central area of the Cache Valley graben is a shattered anticline. The depth of dissolution collapse decreases eastward to the drainage divide above the Colorado River in section 18, T. 24 S., R. 23 E. (figure 4, cross section H-H') East of the drainage divide the depth of dissolution collapse increases until it reaches the river. On the northwest bank of the Colorado River, the upper part of the Triassic Chinle Formation is juxtaposed against the Permian Cutler Formation. A meaningful calculation of displacement at this location is not possible because of the unpredictable thickness variations of Triassic units in the vicinity of the salt-cored anticlines. The Wingate and Chinle Formations between the two flanking

faulted zones collapse sharply into a V-syncline between the drainage divide and the Colorado River (figure 4, cross section I-I').

### **South Flank Fault**

Strata forming the south escarpment of the Cache Valley graben are structurally higher than those forming the north escarpment at the west margin of the quadrangle (see figure 4, cross section C-C'). This apparent displacement decreases eastward (figure 3, cross section D-D'). The displacement that occurs across the South Flank fault continues westward to the center of Salt Valley where Pennsylvanian rocks are found adjacent to Cretaceous rocks (Doelling, 1985). At the west margin of the quadrangle Triassic rocks are juxtaposed against Cretaceous rocks, indicating an estimated displacement of nearly 2,800 feet (853 m), but most of this is the result of salt-dissolution collapse. Comparing units across the graben indicates a displacement of approximately 500 feet (152 m) (cross section C-C'). The displacement may be due to a transfer of stresses created by postulated tectonic fault movement in Pre-Paradox rocks or by asymmetry across the Cache Valley salt-cored anticline. The amount of topographic relief of the south escarpment at the west end of the quadrangle is almost 700 feet (213 m).

Eastwardly, (cross section E-E' to cross section G-G'), figure 4, the stratigraphic displacement along the South Flank fault diminishes and is distributed along many branching faults. Formations exposed at the top of the escarpment drape into the graben, dropping gradually deeper across each successive fault. Each block of strata between the faults dips a

bit more steeply to the north into the graben. All of the observable fault planes are high angled. The stratigraphic displacement along the South Flank fault increases from about 500 to 900 feet (152-274 m) from cross section G-G' to cross section I-I'.

### **North Flank Fault**

The north escarpment is formed by a fault zone that parallels the South Flank fault zone. The fault zone is as much as a half mile (0.8 km) wide and contains numerous subparallel and branching faults. The greatest displacement occurs across the North Flank fault that forms the north boundary of the Cache Valley graben (figure 4). The apparent displacement across the North Flank fault is 500 to 600 feet (152-183 m) at cross section A-A' (plate 1) where the Navajo Sandstone is juxtaposed against the Salt Wash Member of the Morrison Formation. Eastward, in sections 11 and 13, T. 24 S., R. 22 E., the Chinle is placed against the Salt Wash Member indicating that the apparent displacement increases to 1,400 feet (427 m) (figure 4, cross section F-F'). The displacement decreases from cross section F-F' to H-H' to less than 100 feet (30 m) and then increases to about 1,000 feet (305 m) near the Colorado River (cross section I-I')

The dip of strata increase southward as each fault in the North Flank zone is crossed (North drape). The dips on the fault blocks steepen to as much as 45 degrees. The North drape rocks also plunge gently westward into the Salt Wash syncline, the axial trace of which is located 1 mile (1.6 km) west of the quadrangle.

## Elephant Butte Folds

The Elephant Butte folds, which extend into the quadrangle from the west, south of Cache Valley graben, warp strata on Dry Mesa. The Elephant Butte folds trend generally east-west and plunge gently westward toward the north-south axis of the Salt Wash syncline (Doelling, 1983, 1985). The trace of the Salt Wash synclinal axis is aligned along Salt Wash, a drainage that flows southward across the Cache Valley graben and Elephant Butte folds a mile (1.6 km) west of the quadrangle's west margin.

The principal Elephant Butte fold on Dry Mesa is a syncline (Dry Mesa syncline) that approximately divides Dry Mesa in half. The Dry Mesa syncline is a broad gentle feature; dips on the south limb range to 5 degrees and dips on the north limb range to 7 degrees. The Navajo Sandstone and Dewey Bridge Member of the Entrada Sandstone core the shallow Dry Mesa syncline.

Another syncline (North Dry Mesa syncline) with an arcuate axial trace is found 1/2 mile (0.8 km) south of the Cache Valley graben in the eastern part of the mesa. At its west end the axial trace of the syncline plunges southwesterly toward the axis of the Dry Mesa syncline. The North Dry Mesa syncline is doubly-plunging along its east part and forms a small structural basin (plate 1). The basin center is located in the SW 1/4, section 14, T. 24 S., R. 22 E., and is about a mile (1.6 km) long and 1/2 mile (0.8 km) wide. Dips on the flanks of the basin range to 40 degrees. The Navajo Sandstone and Entrada Sandstone are preserved in the small basin.

Between the Dry mesa syncline and the North Dry Mesa syncline is a high-angle normal fault that dies out into a fault-propagated anticline. Dip in the strata changes sharply across the fault, as if someone had broken a board in two. On the south side of the fault dips range from 5 to 10 degrees to the southwest and dips range from 12 to 20 degrees to the north on the north side of the fault.

### **Castle Valley Structural Features**

Castle Valley is one of several northwest-trending, steep-walled valleys at the crest of salt-cored anticlines characteristic of the Paradox fold and fault belt. The elongate oval-shaped valley is approximately 10 miles (16 km) long and 3 miles (4.8 km) wide and results from two phases and styles of deformation. The first was the diapiric growth of the Pennsylvanian Paradox Formation during the Late Pennsylvanian to Late Triassic, and the second was the salt dissolution collapse of the anticlinal crest of the diapir during the late Cenozoic.

#### **Castle Valley Salt-Cored Anticline**

The Castle Valley structural feature is a salt-cored anticline that plunges to the northwest. The southeastern extension of the structure is complicated by the late Oligocene intrusions of the northern La Sal Mountains. Mapping in the La Sal Mountains (Hunt, 1958; Shoemaker and others, 1958; Ross, in preparation), supports the hypothesis that the Castle

Valley salt-cored anticline is a northwestward continuation of the very large Paradox Valley salt-cored anticline in western Colorado.

In general, Jurassic rocks form a massive cliff that rims the valley and dips away from the structure at angles as much as 10 degrees. Rocks in the slopes below the rim commonly dip more steeply with progressively older strata. At the northwest end of the valley, the anticline is slightly asymmetrical with the southwest limb exhibiting an overall steeper dip (plate 2, cross-section B-B').

Regional gravity studies (Case and Joesting, 1972; Case and others, 1963) indicate closely-spaced gravity contours along the margins of the salt-cored anticline suggesting the diapir is steep-walled with approximately 7,000+ feet (2,134+ m) of structural relief.

The Mississippian Leadville Limestone and a thin overlying section of pre-Paradox Formation Pennsylvanian rocks (Molas and Pinkerton Trail Formations) formed the basin floor on which the Paradox Formation sediments were deposited. The Leadville Limestone makes a good marker horizon to determine the amplitude of Paradox basin salt anticline diapirs. The Union of California Burkholder No. 1 well, drilled in section 1, T. 26 S., R. 22 E., southwest of Castle Valley, encountered Leadville at an altitude of 5,285 feet (1,611 m) below sea level. No. 1 Conoco Federal 31 drill hole, located in the SE 1/4, NW 1/4, SE 1/4, section 31, T. 24 S., R. 23 E. (plate 1), on the north flank of Castle Valley, encountered Leadville Limestone at an altitude of 6,081 feet (1,853 m) below sea level. A line formed by connecting the subsea elevations of the top of the Leadville Formation in these drill holes can be used to define the roughly planar surface marking the floor of the Paradox basin. Therefore the approximate structural relief of the Castle Valley salt diapir is a minimum of

9,000 feet (2,743 m). The Conoco well, adjacent to Castle Valley, encountered the Paradox Formation at an altitude of 2,982 feet (909 m) below sea level, indicating a steep intrusive margin for the Castle Valley salt diapir.

The progressive growth of the salt diapirs through time produced variations in stratigraphic thickness and numerous angular unconformities, wedgeouts, and steeper dips on successively older strata along their margins. At Castle Valley, the period of active diapir growth occurred during Pennsylvanian to Triassic time, affecting the Honaker Trail, Cutler, Moenkopi, and Chinle Formations. These formations form the synkinematic layer (strata deposited during salt flowage). From surface exposures, significant angular unconformities (5 degrees or greater) occur within the Cutler Formation, between the Cutler and Moenkopi Formations, within the upper part of the lower Moenkopi, and between the lower and upper beds of the Chinle Formation. At several locations along the southwest flank of Castle Valley, southeast of the quadrangle, the Cutler Formation-Paradox Formation caprock contact is vertical to slightly overturned ( $85^{\circ}$  NE), suggesting the diapir penetrated the Honaker Trail and Cutler Formations and possibly the Moenkopi Formation (plate 2, cross section B-B'). Younger formations are folded over the salt core and probably thin over the crest.

At the northwest nose of the Castle Valley structure is a small, northwest-plunging anticline in the Cutler Formation. Within a cliff face, the indistinct stratification of the conglomeratic sandstone define the gentle fold. The axial trace of the anticline is subparallel with the axial trace of the Castle Valley salt-cored anticline.

## **Hill 5163 Monocline**

A north-striking, north-plunging, east-dipping monocline extends off the northwest nose of the Castle Valley salt-cored anticline in section 36, T. 24 S., R. 23 E. The stratigraphic thickness of the Moenkopi Formation, especially the upper two members, changes dramatically across the monocline. The formation nearly doubles in thickness from 550 feet (168 m) at hill 5163 to approximately 958 feet (292 m) at the south end of Parriott Mesa (Shoemaker and Newman, 1959). In addition, the strata of the Cutler Formation also change across the monocline. The White Rim Sandstone Member is about 240 feet (73 m) thick on the west side of the monocline (and in cuttings from Grand River Oil and Gas, Castle Creek State No. 1 well, NW 1/4, NE 1/4, section 36, T. 24 S., R. 22 E.) and no White Rim Member exposures are present on the east side. The variations in stratigraphic thickness across the monocline and the presence of other syndepositional fault structures in the Cutler Formation indicate the monocline was developed during movement of the salt.

## **Faults**

High-angle, normal fault systems are present on both sides of Castle Valley. The fault zone along the southwest side of the valley is covered by surficial debris of the coalesced alluvial fans below Porcupine Rim. Shallow water well data and unpublished mapping in the Rill Creek (Ross and Doelling, in preparation) and Warner Lake quadrangles (Ross, in preparation) tentatively indicate the position of the fault zone. It is located where less than 50 feet (15 m) of surficial deposits that covers shallow bedrock abruptly thickens into deposits of valley-fill alluvium (plate 2, cross-section B-B').

The fault system along the northeast flank of Castle Valley is well exposed in the Moenkopi Formation below Parriott Mesa. The faults cut the rocks into long, narrow fault blocks in a zone paralleling the valley axis. The outermost fault trends N. 65° W. and dips valleyward 70° SW. The strike of this fault rotates counter-clockwise to nearly east-west at its northwest end. The fault displaces strata 60 to 70 feet (18-21 m). Inboard of this fault are numerous closely-spaced fractures (faults and joints) with a similar trend. The high-angle faults strike N 40° W. and dip 8° SW (only traceable ones are shown on plate 1), and rotate blocks valleyward displacing strata progressively downward toward the valley axis. Block rotation appears to increase valleyward. Individual faults exhibit small displacement, but the overall offset for the fault zone appears to be significant. The Moenkopi Formation in the fault zone is extensively fractured and highly weathered to reddish-brown mounds and ridges. The discontinuous fractures have a complicated anastomosing pattern in the zone. The bounding fault can be traced southeastward to fractured and valleyward rotated exposures of Cutler Formation.

The faults are similar to fault zones along the margins of most salt-cored anticlines in the region. These faults formed as a result of the collapse of the salt diapir due to dissolution and flowage of the underlying salt (Dane, 1935; Cater, 1970; Doelling, 1983, 1988).

At the northwest end of the valley is a somewhat fan-shaped pattern of high-angle normal faults. Most of the faults trend west-northwest. Only significant faults are shown on the map; some splay into additional faults with small displacement (about 1 to 2 feet [0.3-0.6 m]). Smaller fractures are marked by linear zones of brecciation and siliceous/calcareous veins. Numerous microcrystalline quartz-barite-calcite veins are present in the Cutler

Formation White Rim Sandstone Member? section in the area. South of Castle Creek, the larger west-northwest-trending faults form a sequence of downthrown-to-the-north blocks. North of Castle Creek the faults form narrow step-down grabens that are sporadically cross-cut by irregularly trending faults. In this area, the complex structure (numerous fractures and steeply dipping beds) and poorly bedded, massive conglomeratic sandstone of the Cutler Formation makes the positioning of some faults rather tenuous.

Several faults in this area can be constrained with respect to time of movement. Several small syndepositional(?) faults occur within the arkosic facies of the Cutler Formation. The normal faults offset strata for a short distance and then are terminated by gravel-filled channel deposits exhibiting no apparent displacement. Another normal fault cuts off a part of the gravel-filled channel with no offset of overlying beds. Two larger northwest-trending and steeply southwest dipping ( $70-75^{\circ}$  SW) normal faults (plate 1) in the Cutler Formation do not offset the overlying Moenkopi Formation.

A vertical fault trends directly into the axis of the Hill 5163 monocline. On the upthrown side near the fault, competent thicker sandstone beds in the Moenkopi Formation are slightly faulted and the interbedded, incompetent fissile sandstones are folded, suggesting bending or squeezing. This fault appears to have formed during folding of the monocline.

All of these faults formed during diapiric growth of the salt anticline in the Permian and Lower Triassic. Several of the large faults at the northwest end of Castle Valley extend as much as 0.5 mile (0.8 km) from the Castle Valley salt-cored anticline into the Porcupine Rim cliff and cut the Glen Canyon Group sandstone formations. Displacements on the mesa

amount to as much as 40 feet (12 m). Bleaching, caused by ground-water flow, is evident along some of the faults.

### **Richardson Amphitheater Faults**

The Richardson Amphitheater faults at Stearns Creek generally trend west-northwest across the northern half of the quadrangle and join the Cache Valley graben and Professor Valley graben. The Richardson Amphitheater faults are high angle normal faults. The complex criss-cross fault pattern masks a narrow step-down graben with an overall east-west trend. The graben is cut and segmented by numerous faults that form small elongate blocks that have rotated independently. The faults are steeply dipping to vertical, closely spaced, have small displacement, and sometimes exhibit opposite sense of movement on either side of a crossing fault (figure 5). The cross-sectional appearance looks something like a scissor movement.

Numerous other fractures, too small to map at this scale are present in the faulted area. The northwest-trending fractures are consistent and regularly spaced. Slickensides displaying a variety of vertical, dip-slip, and horizontal orientations are common in this area. Coarse crystalline(?) barite-calcite veins are commonly associated with the faults. The veins range from small to large and generally run parallel to subparallel to the faults.

## **Big Bend Fault Zone**

A northwest-trending system of high-angle normal faults cut the Colorado River canyon at the Big Bend. The faults trend between N. 35° W. and N. 70° W. and are vertical to steeply dipping (mostly greater than 80°). The fault swarm's overall structure is a step-down graben with overall displacement greatest toward the center. Offset ranges to as much as a few tens of feet, with the narrow graben-bounding faults having about 40 feet (12 m) of offset. The faults continue northwestward into Arches National Park (The Windows Section quadrangle) along the southwest flank of the Windows anticline (Doelling, 1985, 1988).

## **Big Bend Salt Pillow**

Several geologic features suggest that a semicircular, thickened mass of Paradox Formation salt may be present in the subsurface beneath the Big Bend in the Colorado River. Stratigraphic analysis indicates that the lower member of the Chinle Formation thins across the Big Bend area due to erosional truncation (figure 2, locations 1, 2, and 3) and that angular unconformities dip away from the apparent core of this high. Similar relationships may exist in the Sewemup Member of the Triassic Moenkopi Formation, but are not exposed. Regional gravity survey data (Case and Joesting, 1972) indicate a semicircular gravity low about 1 mile (1.6 km) in diameter, with a possible 2 to 4 milligal anomaly, at the Big Bend. This information suggests that a small salt pillow is present at the Big Bend and that it may be a secondary salt structure of the Castle Valley salt diapir.

Another hypothesis may account for the observations at the Big Bend. Locations 1, 2, and 3 of figure 2 may mark the edge of a Triassic basin or synclinal depocenter that formed as deeper salt was withdrawn to form the Castle Valley diapir. The Big Bend area (location 2, figure 2) did not subside as much and remained relatively higher after salt movement giving the appearance of a structural high.

## ECONOMIC GEOLOGY

Geologic resources to be considered in the Big Bend quadrangle include sand and gravel, copper, uranium, gold, petroleum, gypsum, barite, and calcite.

### Sand and Gravel

Colorado River alluvium (Qal) and terrace alluvium (Qat) contain materials used in the construction of highways. Cutbank tests were conducted on the deposits by the Utah Department of Transportation (UDOT, about 1967) at three localities and found material suitable as base and surfacing gravel and for use in concrete and asphalt mixtures (table 1). The quality of the sand and gravel that could be extracted from terraces and alluvium along the river is not expected to vary. The tested river terraces contained 80,000, 460,000, and 290,000 cubic yards of gravel. Many other deposits were not evaluated, but the total amount of sand and gravel resources are large. The gravel pit in the NE 1/4, section 30, T. 24 S., R. 23 E., is intermittently active and used for road repair.

## Copper and Uranium

Small copper workings are present along the north flank faults of Cache Valley. One occurrence, located in the E 1/2, NE 1/4, section 9, T. 24 S., R. 22 E., is found along a fault just outside Arches National Park. The copper shows are found south of the down-thrown side of the fault, which trends nearly east-west and dips 75° south, placing the Salt Wash Member of the Morrison Formation (south side) against the Navajo Sandstone. Observable at the prospect are copper carbonates (malachite, azurite), copper pitch, and limonite. No mineralization is evident in the Navajo Sandstone. The mineralization is partly controlled by fractures and partly by a favorable sandstone horizon in the Salt Wash Member adjacent to the fault. Minerals generally coat fractures, but some are disseminated in the sandstone. The mineralization gradually dies out south of the fault where adjacently present greenish siltstone and shale (mudstone) beds become reddish.

The small prospect or mine at this locality consists of a shaft 10 x 5 x 15 feet (3 x 1.5 x 4.6 m) deep, that is cut into a thick lens of sandstone in the Salt Wash Member of the Morrison Formation. A 30-foot (9.1 m) adit intersects the shaft from the east. At a lower elevation and 270 yards (82 m) to the west, another adit has been driven southward in the Navajo Sandstone, crossing the fault about 50 feet (15 m) from the portal. An incline connects with this adit south of the fault and extends upward and eastward 30 degrees. The incline crosses the adit and continues westward about 10 feet (3 m). The length of the incline between the surface and the adit is about 35 feet (10.7 m). The incline follows the dip of the Salt Wash Member bedding. A 1/2 ton (0.4 tonne) stockpile, containing about 0.5 percent

copper, is found next to the surface opening of the incline. A sandstone lens above a green siltstone parting is irregularly mineralized and is 1 to 3 feet (0.3-0.9 m) thick.

Copper mineralization is also present in slickensided, brecciated conglomeratic sandstone in the Cedar Mountain-Dakota formation undifferentiated unit in the fault zone along the south side of Cache Valley. The rock is highly fractured, dipping as much as 80° northward. The mineralization consists of copper oxides, mostly malachite, with a little copper pitch and cuprite. The mineralization coats fracture surfaces, pebbles, and grit in the conglomerate. The mineralization appears to die away 75 feet (23 m) north of the fault. No mineralization is evident in the Chinle Formation on the south side of the fault. Workings consists of some shallow pits and dog holes.

Local shows of copper occur in other places in the thicker lenses of Salt Wash sandstone in Cache Valley. Malachite coats bedding planes and is found in thin stringers. The control appears to be strictly stratigraphic. Volumetrically there is little copper in comparison to sandstone.

The Salt Wash Member of the Morrison Formation is an important host of uranium mineralization in the region (Doelling, 1969). Most of the Salt Wash Member in Cache Valley shows background radiation with a counter, but radiation is higher where limonite stains are yellow and brown, and where dark streaks are found. The sandstone lenses in Cache Valley are relatively thin, and the intervening siltstone or very fine-grained silty sandstone is red and not gray. Ore bodies, when found, generally occupy the lowest parts of thick Salt Wash Member sandstone lenses where intervening siltstones are gray or green.

Locally, in Cache Valley, a thicker sandstone channel can be recognized. Radiation and shows of copper generally increase at the base of these.

### **Gold**

The gravels of the Colorado River (Qal) and the terrace alluvium (Qat) contain small amounts of flour and rare flakes of gold. A small, but, unknown quantity of gold may have been recovered in the quadrangle from past operations carried out near Salt Wash Rapids, New Rapids, and other locations along the Colorado River. The gold occurs in black, magnetite-bearing, coarse, sandy streaks in the river alluvium. The gold content is usually uniformly distributed vertically through the river bed alluvium (Qal) and terrace alluvium (Qat2, Qat3). However, the upstream ends of the gravel bars and higher terraces may be slightly richer in gold content (Butler, 1920).

### **Petroleum**

Two wells, the Grand River Oil and Gas, Castle Creek State No. 1 well, NW 1/4, NE 1/4, section 36, T. 24 S., R. 22 E., and the No. 1 Conoco Federal 31 drill hole, located in the SE 1/4, NW 1/4, SE 1/4, section 31, T. 24 S., R. 23 E. are known to have been drilled in the Big Bend quadrangle for petroleum. Although hydrocarbon shows were encountered in the Conoco well, both were abandoned as dry holes. Hydrocarbon shows were encountered in the clastic units interbedded with the salts of the Paradox Formation, and in the Mississippian

Leadville Formation. Carbon dioxide shows were present in the Leadville Formation in the Conoco well.

Areas to the west of Moab have been the site of recent horizontal drilling, with local production of oil and gas from the Long Canyon, Cane Creek, Big Flat, and Bartlett Flat fields (figure 1). Current horizontal drilling activity is focusing on the Cane Creek black shale and clastic interval in the lower part of the Paradox Formation. The Devonian formations are also sometimes listed as potential petroleum reservoirs.

### Evaporites

Gypsum beds are present in the Moenkopi Formation and in the caprock of the Paradox Formation. The beds in the Moenkopi are believed to be too thin to mine. Gypsum beds in the Paradox Formation caprock are impure.

Potash (sylvite) and carnallite, and halite are known to occur in the Paradox Formation. Potash is solution-mined from the Cane Creek anticline 16 miles (26 km) west of Moab (Doelling and others, 1992). These salts are present in the Castle Valley and Cache Valley salt-cored anticlines. A shallow petroleum drill hole in the Castle Valley salt-cored anticline southeast of the quadrangle confirmed the presence of potash deposits (Hite and Lohman, 1972). The internal structure of the salt diapirs is normally very complex, and much exploratory drilling will be necessary to define the resource. The Paradox Formation is presumed too deep and thin for economical extraction under other areas in the quadrangle.

## **Barite**

A few prospect pits have been dug into barite veins associated with the Richardson Amphitheater faults in the vicinity of Stearns Creek. The Moenkopi Formation is bleached to light gray or yellowish gray and shows of calcite, barite, quartz, malachite, and hematite are present. Breit and others (1990) showed that barite fracture-fillings are associated with faulting and the barite solutions originated in the Paradox Formation of the Hermosa Group. The occurrences are small. No analyses testing the purity of the barite are available.

## **Calcite**

Acicular calcite occurs along several faults associated with the dissolution of salt in salt-cored anticlines. The shattered Moab Tongue of the Entrada Sandstone commonly contains thin calcite veins along fractures which locally thicken to as much as 5 feet (1.5 m). A small mine was opened to exploit the calcite in the NE 1/4, NE 1/4, NW 1/4, section 14, T. 24 S., R. 22 E., in Cache Valley. A 15-foot (4.6 m) adit was driven into a cliff at a bearing of N. 35° E., and intersected a fault trending N. 63° W., that separates the Navajo Sandstone from the Moab Tongue of the Entrada Sandstone. The calcite vein is 1 to 5 feet (0.3-1.5 m) thick along the fault. The acicular calcite in the vein is partly brecciated. Shattered blocks of sandstone are also found as vein-filling material. The vein extends 120 feet (36.6 m) along the fault at this locality.

## GROUND WATER

The bedrock aquifers in the Big Bend quadrangle are largely untested. The sandstone formations of the Glen Canyon Group are considered the most important bedrock aquifer of the region (Feltis, 1966; Blanchard, 1990). However, only remnants of these units are present in the quadrangle. Most exposures are severed from recharge areas by deeply eroded canyons. Nevertheless, small springs issue intermittently from these formations at many localities. The potential for small amounts of water is good. The quality of water obtained from these aquifers is generally good, with concentrations of dissolved solids 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). Recharge to the mesas southwest of Castle Valley may be much better because of their connection with recharge areas around the La Sal Mountains.

The Triassic formations are generally regarded as aquicludes and rarely yield water. The Cutler Formation yields water to wells on the southwestern side of Castle Valley. According to Blanchard (1990), thirty wells had been drilled that produced from 20 to 40 gal/min (1.3-2.5 l/sec) without measurable drawdown, with dissolved solids concentrations ranging from 1,420 to 3,450 mg/l. These wells had concentrations of selenium that exceeded State of Utah drinking-water standards. Water from the Cutler Formation is expected to be slightly saline to saline in quality in the area of the Big Bend quadrangle.

Deeper groundwater aquifers have been subdivided into three hydrostratigraphic units, each possessing similar hydrogeologic characteristics (U.S. Department of Energy, 1984).

The upper hydrostratigraphic unit consists of the Permian rocks and the upper two-thirds of the Honaker Trail Formation. The middle unit includes the remainder of the Honaker Trail Formation and the Paradox Formation. The lower unit includes all the carbonate rock units below the Paradox Formation. The recharge for the upper unit includes the La Sal Mountains. The water yields from the upper unit are expected to be small and of variable quality, tending to be saline. The middle unit consists of horizons acting as aquicludes alternating with others of variable water-bearing capacity. When water is found it is generally very saline. The lower hydrostratigraphic unit consists of carbonates with good porosity and permeability. Oil-well data generally indicate large quantities of salty water.

Ground water is also present in the surficial deposits of the quadrangle. More than 100 wells have been drilled in the unconsolidated deposits in Castle Valley. Sampled wells indicated dissolved solid concentrations ranging from 169 to 1,020 mg/l (Sunsion, 1971). Recharge to the Castle Valley wells is assumed to be in upvalley locations along Placer and Castle Creeks, which originate in the La Sal Mountains. Mixing with subsurface spring sources in the Cutler Formation, and possibly the salt diapir, probably accounts for the more saline water. Similarly, water from the Colorado River recharges gravelly aquifers under adjacent bottom land. Unconsolidated sand on the benches collects rainwater and snowmelt that may provide small amounts of water for stock.

## **GEOLOGIC HAZARDS**

Geologic hazards in the Big Bend quadrangle are typical of those expected in the canyon country of southeast Utah. These include debris and mud flows, stream flooding, rock falls, problem soils, indoor radon gas, and culinary water contamination. For a more detailed discussion of the geologic hazards in Castle Valley see Mulvey (1992).

### **Debris Flows/Alluvial Fan Flooding and Stream Flooding**

Erosion by running water is the most active and potentially damaging hazard in the quadrangle (Mulvey, 1992). The sparsely vegetated steep slopes and deep, narrow ephemeral stream channels are subject to rapid erosion from waters generated by cloudburst storms and spring snowmelt runoff.

Debris flow, debris flood (hyperconcentrated stream flow), and normal stream flow form a continuum of sediment/water mixtures. Debris flows and floods generally remain confined to stream channels in high relief areas, but may exit the channels and deposit debris where slope gradients decrease (that is, alluvial fans) along their travel paths. The heterogeneous lithologies, weathering characteristics, and geomorphic character of the Moenkopi, Chinle, Wingate, and Kayenta Formations in the Canyonlands area are conducive to the accumulation of talus and colluvium on slopes, providing ample material for debris flows.

The alluvial fans on the southwest side of Castle Valley are particularly susceptible to debris flow and flooding hazards. The Colorado River canyon corridor has numerous steep gulleys that drain to the river, and is also susceptible, especially on the side in which State Highway 128 is located. The ephemeral stream channels that drain Castle Valley are also potential debris flow carriers. Overland sheetflow and/or floodwaters may scour material from the ground surface and stream channels, thereby increasing the proportion of bed/suspended load until the mixture becomes a debris flow (Mulvey, 1992).

Stream flooding may originate by direct precipitation, melting snow, or a combination of both. Primary drainage channels, such as Castle Creek, Placer Creek, and Professor Creek are generally deeply incised (10-30 feet [3-9 m]), and seasonal snowmelt or cloudburst runoff are contained. Flooding of the adjoining areas is possible, but unlikely due to the depth of incision. Flood damage along primary drainage channels is generally confined to stream bank undercutting (Mulvey, 1992).

Flooding of the Colorado River occurs during unusually high spring runoff years because the river is unregulated by engineered structures upstream of the Big Bend quadrangle. The river undercut its banks in June of 1983, when a section of U-128 was washed out at the bend below Whites Rapids. The west-bound pavement, embankments, and culverts were washed out along the highway for a distance of about 100 yards (Davis, 1989). Large amounts of fill and riprap material had to be hauled to repair the roadway. The damage cost was more than \$200,000.

## Rock Fall

Rock falls occur sporadically throughout the rugged topography of southern Grand County. In the quadrangle, rock fragments from Kayenta, Wingate, Chinle, and Moenkopi Formations cliffs commonly produce rock fall debris. The most susceptible cliffs or slopes are those broken by fractures that subparallel cliff-faces.

Porcupine Rim, along the southwestern margin of Castle Valley is an area of chronic rock fall activity. Since 1959 five major rock falls have occurred along this escarpment. The locations of four of these rock falls are marked on the geologic map (plate 1). Northwest-trending joints and fractures are common in the massive cliffs of the Kayenta and Wingate Formations, which are slowly being undercut by erosion of the less resistant Chinle Formation. Homes built at the foot of the Porcupine Rim slopes are especially prone to this hazard.

Rock fall debris may travel great distances down slope by rolling, bouncing, and sliding. The potential large size of some debris and relatively high velocity of travel present a hazard to engineered structures and personal safety for the southwest side of Castle Valley. Rock fall debris is found below all of the massive cliffs throughout the quadrangle and is a constantly threatening geologic hazard along Utah Highway 128 in the narrow canyon of the Colorado River. Each spring rock debris must be cleared away by the Utah Department of Transportation to keep the highway safe for travelers.

## Problem Soils

The bentonitic clay minerals of the Moenkopi, Chinle, Morrison, and Cedar Mountain Formations, and the soils derived from them, are capable of absorbing large quantities of water (Schulz, 1963; Stewart, Poole, and Wilson, 1972a, 1972b). As the moisture content of these units changes, the clay minerals expand and contract producing as much as a 10 percent volume change (Shelton and Prouty, 1979). The "popcorn" surface of weathered Moenkopi and Chinle outcrops is indicative of the shrinking and swelling nature of the formations. These formations commonly exhibit this surface texture in the Porcupine Canyon, Castle Valley, and Ida Gulch areas.

Alluvial fan sediments derived from the Moenkopi and Chinle Formations are areas favorable for the development of collapsible soils (Mulvey, 1992). These soils are subject to volumetric changes that could damage structures built upon them. The existence of collapsible soils in Castle Valley and surrounding areas is undocumented, but geologic conditions are favorable for their development.

Fine-grained soils and surficial deposits (Qa2) prone to piping and rapid erosion cover much of the lower part of Castle Valley. Cloudburst storm floods can quickly remove large volumes of material. Piping is subsurface erosion by ground water that flows into permeable noncohesive layers in unconsolidated sediments, removes fine sediments, and exits at a spot where the layer intersects the surface. The removal of fine particles increases void space thereby producing a "pipe" and promoting enhanced erosion. Piping is common in arid/semi-arid climates where fine-grained, non-cemented, Holocene-age alluvium is incised by

ephemeral stream channels. Several large pipe-related erosional gulleys are present in Qa2 sediments along Castle Creek below its confluence with Placer Creek.

### **Indoor Radon Gas**

Radon is a naturally occurring radioactive gas derived from geologic materials. When inhaled, radon decay particles may cause lung cancer. Radon gas is very mobile and may migrate through void space in rock and soil and be captured in poorly ventilated buildings thereby causing a health hazard.

A potential radon health hazard is dependent on three factors: 1) a source of radon, 2) depth to ground water, and 3) permeability of the substrata (B.J. Solomon, 1992, personal communication). Many of the sedimentary rocks in the Big Bend quadrangle are potential sources of radon. The igneous rocks of the La Sal Mountains contain small amounts of uranium (Ross, in preparation) to warrant them as a potential radon source. The Morrison Formation contains small uranium deposits in the Warner Lake quadrangle to the southeast. The Chinle Formation, which crops out in the canyon walls is locally radioactive, even though no uranium deposits have been located on the quadrangle. The surficial deposits in Castle Valley, and other places in the Big Bend quadrangle, are derived from these sources and have the potential to produce concentrations of radon gas.

Areas with ground water levels deeper than 30 feet (10 m) have a higher potential for radon gas movement to the surface or into basements of homes. The gravelly to sandy alluvium of Castle Valley is poorly lithified and is highly permeable, allowing easy migration

for the gas. The permeability of the local bedrock units is highly variable and is controlled by the lithology and degree of cementation.

### **Culinary Water Contamination**

The community of Castle Valley has no municipal wastewater disposal system, each individual home has its own septic system (1992). Currently, much of the culinary water in the valley is obtained from shallow (less than 100 feet [ $<30$  m]) unconfined aquifers in the alluvial valley fill (Utah Division of Water Rights, 1991, unpublished data; Mulvey, 1992). The deposits are relatively permeable and are laterally and vertically discontinuous, which can cause insufficient filtering, thereby contaminating the local ground-water system.

### **Earthquake Hazard**

The northern Paradox Basin, in which the Big Bend quadrangle is located, appears to lack prominent natural earthquake activity (Smith and Sbar, 1974). Two events, measured on the Modified Mercalli Scale, were felt at Green River. The first occurred on July 30, 1953 (Intensity V), the second on March 31, 1954 (Intensity IV). These events may be attributed to induced seismicity related to coal mining in the Book Cliffs. Induced seismicity is defined as man-related earthquakes triggered by mine excavation, reservoir impoundment, fluid injection, and underground failure.

## SCENIC RESOURCES

The Big Bend quadrangle displays typical red-rock canyonland vistas. The Colorado River has incised a large meander loop in the southwest corner of the quadrangle and the high canyon walls are lined with the scenic vertical cliffs of the Glen Canyon Group. Utah Highway 128 is a beautiful 35-mile (56 km) river drive that extends eastward from Moab to Dewey. The buttes and mesas between Castle Valley and the Richardson Amphitheater are picturesque and are often photographed to appear on postcards. Excellent views of the Priest and Nuns and Castle Rock, both of which are located in the adjacent Fisher Towers quadrangle and the northern La Sal Mountains, are visible from Castle Valley. Several classic Hollywood western movies were filmed in the Big Bend and adjacent quadrangles.

River running in rafts is a recreational activity conducted along the Colorado River in the Big Bend quadrangle. Part of the enjoyment of participation is a chance to view the geologic scenery. Faulting and collapse features associated with salt dissolution are well displayed in the vicinity of New Rapids.

Many undeveloped vistas of the canyons, Professor Valley, Richardson Amphitheater, and Castle Valley, are available from the mesas, but these are difficult to access. Access is possible by hiking, or with four-wheel drive vehicles or mountain bicycles. The cliff tops are generally 1,000 to 2,000 feet (305-610 m) above the valley and canyon bottoms and many interesting and spectacular views can be obtained by those who make the effort to reach them.

### **Delicate Arch and Arches National Park**

## **Delicate Arch and Arches National Park**

Delicate Arch is a common symbol for Utah and appears on Utah's centennial license plates. The arch is located in the Big Bend quadrangle, SW 1/4, NW 1/4, SW 1/4, section 4, T. 24 S., R. 22 E., in Arches National Park. According to Stevens and McCarrick (1988) it is the best known arch in the world. It is considered the most beautiful and interesting arch in Arches National Park. The light opening is 46 feet (14 m) high and 32 feet (10 m) wide. The pedestals of the arch are carved from the Slickrock Member and the span from the Moab Member of the Entrada Sandstone.

Several additional smaller arches are present on the quadrangle in the Delicate Arch area. These include the free-standing Frame and Echo Arches; the cliff-wall Diving Board and Goosehead Arches; and the pothole Tapered Arch, all cut in the Entrada Sandstone. Still other small arches are found to the east in Winter Camp Wash canyon. These include Cliff Top, Winter Camp, Donut, Mirror, and Solo Arches, cut in the Kayenta and Navajo Formations.

## **Cache Valley**

The salt dissolution features exposed in Cache Valley are among the best in the Paradox basin, making this a world-class geologic site. Collapsed formations, tilted strata, V-synclines, and faults are well exposed to view and study. The nearly 2,000-foot (610 m) displacement of the Wingate Sandstone and older formations into the collapse structure west

of New Rapids is plainly visible from the Colorado River and represents a geologic event of immense proportions.

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## Captions for figures and tables

Figure 1. Map showing area of Big Bend and adjacent quadrangles in east-central Utah.

Principal structural and geomorphic features, highways, and settlements are also shown. Circled numbers west of Moab represent the approximate locus of small oil fields tapping Pennsylvanian and Mississippian reservoirs: Bartlett Flat (1), Big Flat (2), Long Canyon (3), Shafer Canyon (4), and Cane Creek (5).

Figure 2. Schematic stratigraphic sections of the Chinle Formation

Figure 3. Diagram correlating Richmond's (1962) units with those appearing in this report.

Figure 4. Supplemental cross sections and index map to Cache Valley.

Figure 5. Simplified fault pattern of New Rapids area from the geologic map, illustrating the hinge point and opposite offset along the same fault.

Table 1. Sand and gravel tests run by the Utah Department of Transportation on Colorado River alluvium in 1962 (UDOT, approximately 1967). Thicknesses and depths shown are in feet, most other analyses are in percent. Sample 1 is located in the W 1/2, SW

1/4, section 33, T. 24 S , R. 22 E.; sample 2 is located in the W 1/2, NE 1/4, section 35, T. 24 S., R. 22 E.; and sample 3 is located in the NE 1/4, section 30, T. 24 S., R. 23 E. The latter sample location has been an active UDOT pit for several years (1992).

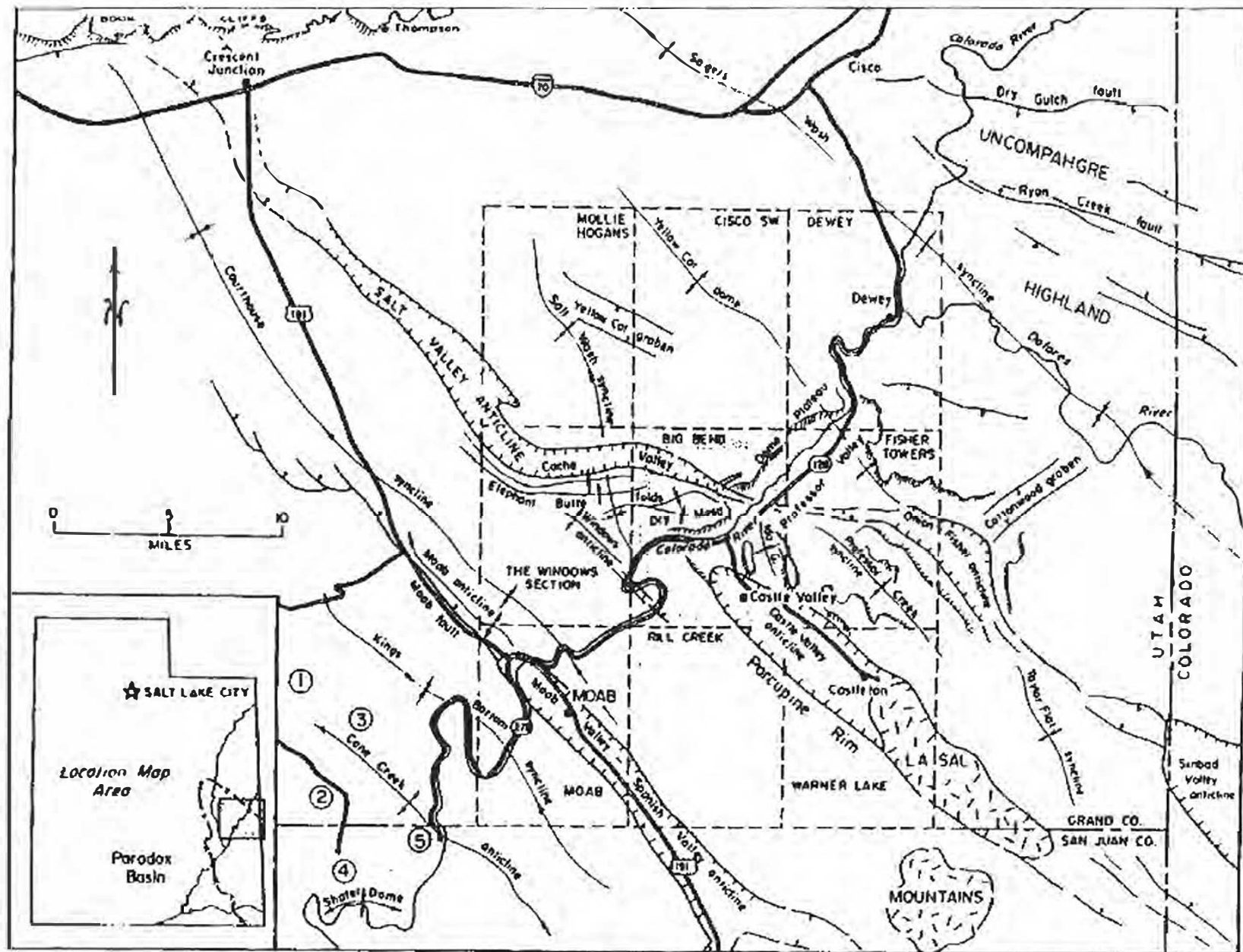


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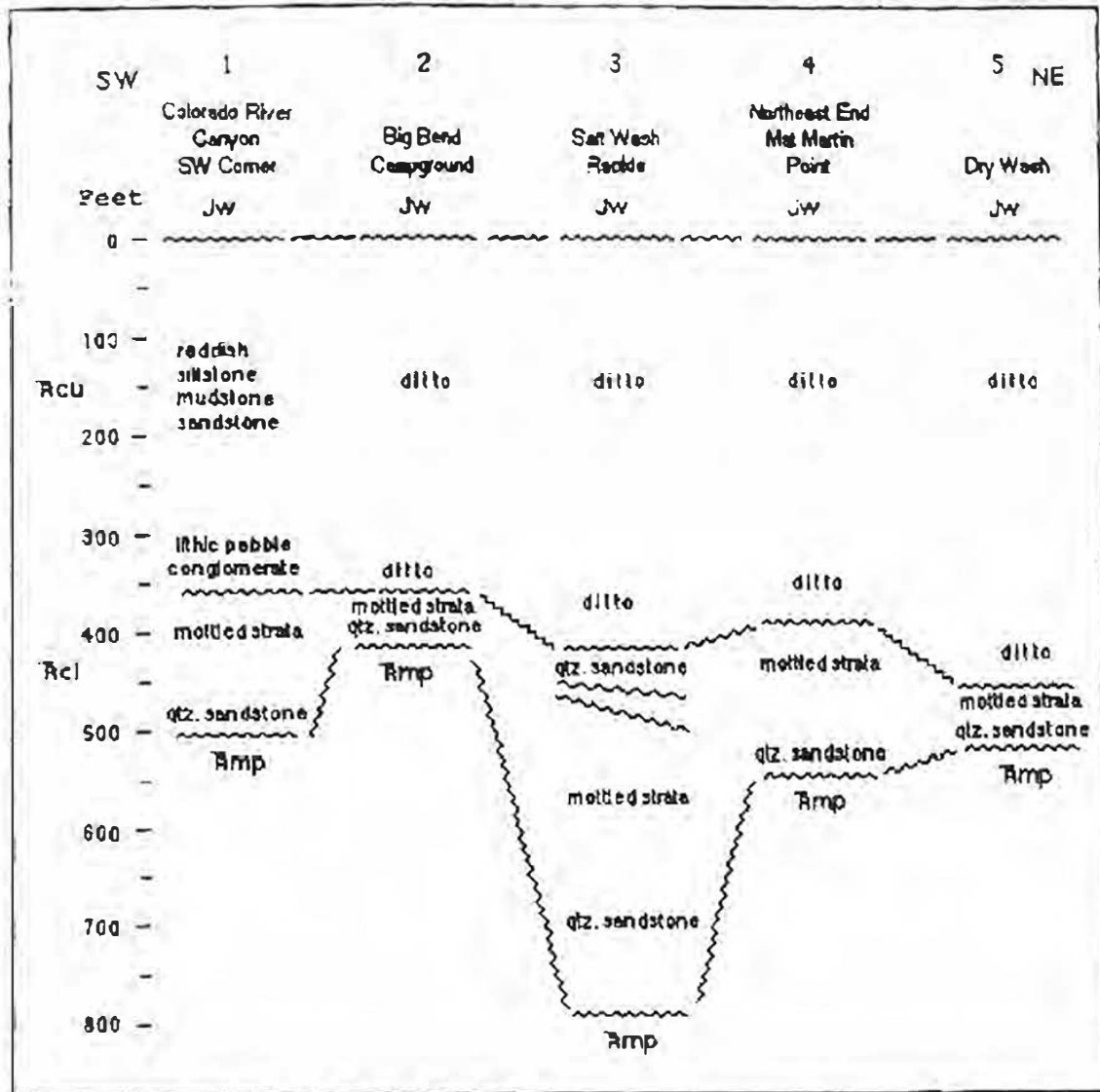
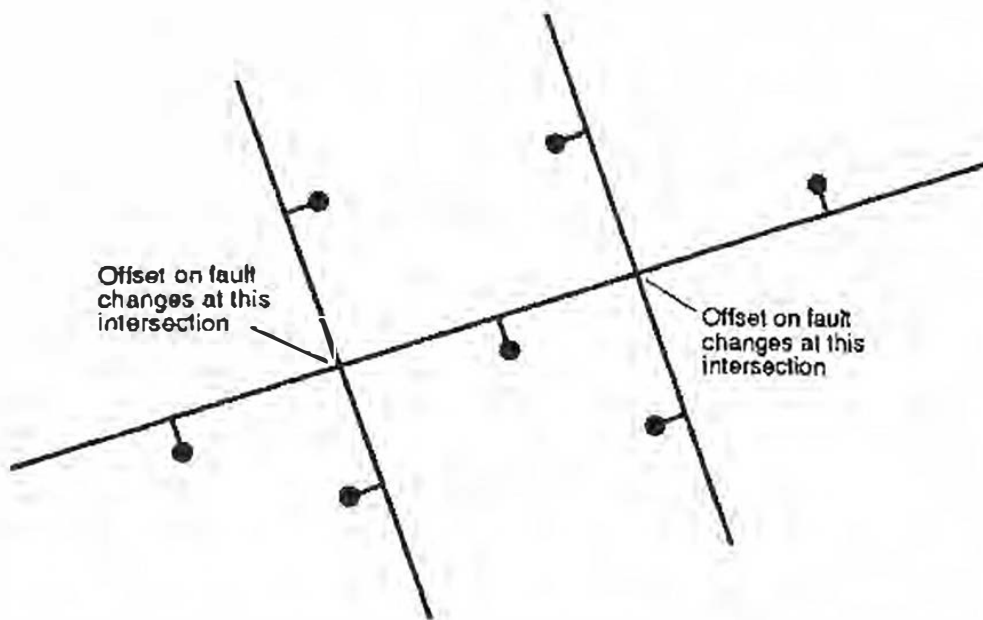
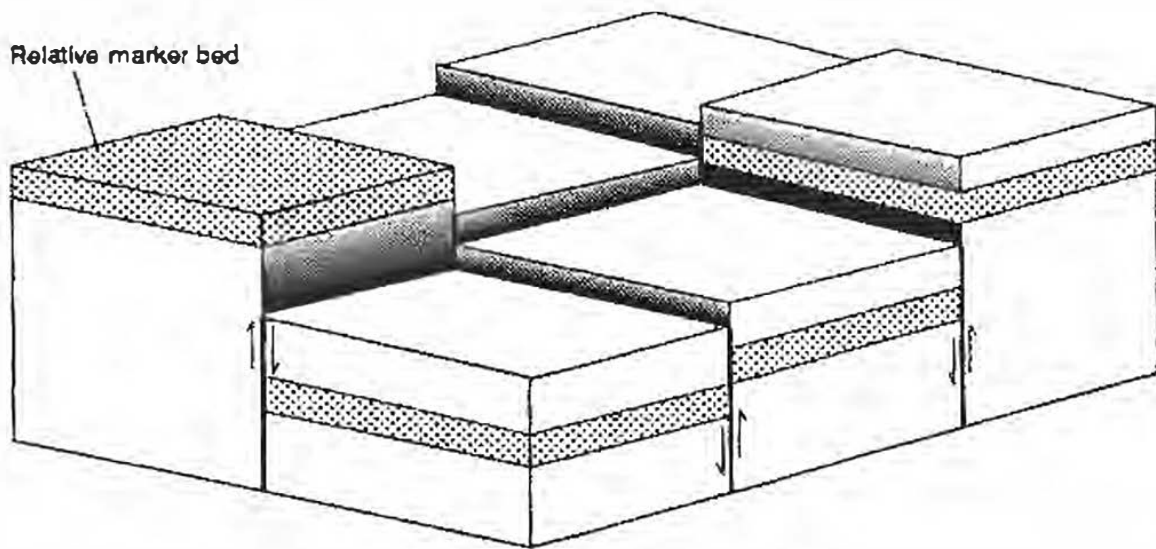


Figure 2. Schematic stratigraphic sections of the Chinle Formation.





Simplified Map of Pattern of Faults



Simplified Block Diagram of Faults

Figure 5. Simplified fault pattern of New Rapids area from the geologic map, illustrating the hinge point and opposite offset along the same fault.

Table 1. Sand and gravel tests run by the Utah Department of Transportation on Colorado River alluvium in 1962. (UDOT, approximately 1967). Thicknesses and depths shown in feet, most other analyses are in percent. Sample 1 is located in the W 1/2, SW 1/4, section 33, T. 24 S., R. 22 E.; sample 2 is located in the W 1/2, NE 1/4, section 35, T. 24 S., R. 22 E.; and sample 3 is located in the NE 1/4, section 30, T. 24 S., R. 23 E. The latter sample location has been an active UDOT pit for several years (1992).

MATERIAL					TEST DATA - REPRESENTATIVE SAMPLE															
USE OF MATERIAL	TYPE OF DEPOSIT	PRESENT ESTIMATED QUANTITY (CU. YDS.)	THICKNESS OF MATERIAL	DEPTH OF OVERBURDEN	DATE SAMPLED *	TYPE OF SAMPLE	DEPTH OF SAMPLE	SIEVE ANALYSIS								LIQUID LIMIT	PLASTICITY INDEX	SWELL	A. A. S. H. O. CLASSIFICATION	ABRASION 500 REV.
								BEFORE CRUSHING		PERCENT PASSING AFTER CRUSHING TO 1" MAX. SIZE										
								> 3"	> 1"	1"	1/2"	NO. 4	NO. 10	NO. 40	NO. 200					
1	B.G., S.G. River Terrace	80,000	8	0	1958	Cut Bank	0-10	2.5	21.5	100		51.3	41.8	29.5	8.6	16.4	NP	.012	A-1-a	20.9
2	B.G., S.G. River Terrace	460,000	12	0-1	1958	Cut Bank	0-12	23.4	46.7	100		42.2	34.3	21.6	5.4	17.5	NP	.010	A-1-a	29.3
3	B.G., S.G. River Terrace	290,000	20	0-1	1958	Cut Bank	0-10	11.9	34.3	100		39.8	35.7	21.2	1.1	22.2	NP	.015	A-1-a	24.4

## DESCRIPTION OF MAP UNITS

**Eolian sand deposits** - Generally fine- to medium-grained quartzose sand forming thin, discontinuous accumulations of sand sheets and small dunes.

**Mixed eolian and alluvial sand deposits** - Thin accumulations of mainly sand deposited and reworked by eolian and alluvial processes; moderate to well sorted; generally restricted to ephemeral washes and hollows. Qeao deposit is mainly sand but contains minor clay and gravel lenses; forms a thick deposit capped by a Stage V petrocalcic soil suggesting an early Pleistocene age. Qeao thickness locally exceeds 160 feet (49 m).

**Mixed alluvial and colluvial deposits** - Poorly sorted mixture of clay through cobble size detritus with occasional boulders; clasts vary from subrounded to angular; located along narrow ephemeral washes where colluvium is reworked and transported away by alluvial processes in active channels. Thickness up to 15 feet (5 m).

**Alluvial deposits** - Qa1 and Qa2 contain generally finer grained detritus; consist mainly of poorly to moderately sorted silts, sand, and lenses of gravel; located along Colorado River and the larger creeks and ephemeral washes. Qag3 and Qag4 contain generally coarser grained detritus; consist of poorly-sorted, poorly stratified sandy cobble gravel; form dissected stony surfaces and subtle ridges in Castle Valley; deposits exhibit pedogenic carbonate soils ranging from stage I to stage IV.

**Terrace gravel deposits** - Moderately sorted, subrounded to rounded, poorly stratified gravel in a gray calcareous sandy matrix; forms rounded knobs on small hills along the Colorado River; variety of clast lithologies that are exotic to quadrangle; Qat2 is 6-40 feet (2-12 m) above the river; Qat3 is about 100 feet (30 m) above the river; Qat4 is about 130 feet (40 m) above the river.

**Pediment-mantle deposits** - Poorly sorted, sandy matrix-supported gravel; locally contains lenses of sand and/or clast-supported gravel; gravel ranges from pebbles to boulders; deposits are locally sourced and have an orange-red-purple shading; detritus deposited as a relatively thin veneer on uneven pediment surfaces; mixed alluvial fan, ephemeral stream, colluvial, and eolian processes. Deposits are subdivided based on height above current drainage and grading to alluvial terraces along the river.

**Talus deposits and colluvium** - Generally angular rock-fall blocks, boulders, and small fragments deposited as veneers on slopes below ledges and cliffs; colluvium contains additional slopewash debris of poorly sorted rock fragments in a sandy to muddy matrix.

**Landslide deposits** - Large coherent blocks to fragmented masses of bedrock and surficial debris transported downslope by mass movement.

## Mancos Shale

**Blue Gate Shale Member** - Mostly light-gray marine shale, slope-former, containing occasional sandy beds which are slightly more resistant. Youngest consolidated unit exposed in Cache Valley. In completely exposed in mapped area. Incomplete thickness 500+ feet (152+ m).

**Ferron Sandstone Member** - Light-brown to medium-gray sandstone, sandy shale, marine shale, and carbonaceous shale, thin bedded, more resistant than members above and below, locally fossiliferous near top. Thickness 90-120 feet (27-37 m).

**Tuwunk Shale Member** - Medium-gray marine shale, slope former containing a few sandy beds, especially near the top; sandy beds are yellow gray to brown gray. Thickness about 400 feet (122 m).

**Dakota Sandstone** - Light-gray to yellow-gray, sandstone, conglomeratic sandstone, and conglomerate, with subordinate gray sandy shale and carbonaceous shale; forms ridges in Cache Valley. Thickness 40-50 feet (12-15 m).

**Cedar Mountain Formation** - Variegated slope-forming mudstone interbedded with ledge-forming gray and brown quartzite, conglomerate and gritstone. Mudstone is mostly light green, gray, lavender, and white. Locally deformed and attenuated with Dakota

Formation (Kdcm), especially on the south wall of Cache Valley. Thickness 200-240 feet (61-73 m).

## Morrison Formation

Brushy Basin Member - Mostly variegated to bright green, slope-forming mudstone with thin ledges of conglomeratic sandstone, conglomerate, nodular weathering limestone, and gritstone. Ledgeformers are more abundant in the lower part of the member. Locally attenuated. Thickness 300-340 feet (91-104 m).

Salt Wash Member - Light yellow-gray, cross-bedded, lenticular, ledge-forming sandstone interbedded with red and gray, slope-forming mudstone and siltstone. Thickness about 250 feet (76 m).

Tidwell Member - Reddish silty shale, with interbeds of fine-grained yellow sandstone and gray limestone; lower half of unit slightly more resistant; contains large, white, siliceous concretions in upper half of unit. Thickness 40-60 feet (12-18 m).

## Entrada Sandstone

Moab Member - Pale-orange, grayish-orange, pale yellowish-brown, or light-gray, fine- to medium grained, calcareous, massive, cliff-forming sandstone; upper surfaces prominently jointed. Thickness 90-110 feet (27-34 m).

**Slick Rock Member** - Reddish-orange or brown, very fine- to fine-grained eolian sandstone; calcareous or iron oxide cemented; massive; weathers to form smooth cliffs and bare rock slopes; commonly covered with self-derived sand; not as resistant as Moab Member above, but more resistant than Dewey Bridge Member below. Thickness 250-350 feet (76-107 m).

**Dewey Bridge Member** - Dark reddish, fine-grained, silty sandstone; mostly iron oxide cemented; in irregularly contorted, indistinct "lumpy" medium to thick beds; formerly known as Carmel Formation. Thickness 40-60 feet (12-18 m).

**Navajo Sandstone** - Orange to light-gray, eolian sandstone, mostly fine grained, cemented with silica or calcite; crops out as vertical cliffs in deep canyons and as domes and rounded knolls elsewhere; contains local thin, hard, gray carbonate beds; well displayed, high-angle cross beds. Thickness 250-400 feet (76-122 m).

**Kayenta Formation** - Moderate-orange-pink, reddish-brown, and lavender sandstone interbedded with subordinate dark-reddish-brown to grayish-red silty mudstone, lavender-gray intraformational conglomerate, and limestone mostly of fluvial or lacustrine origin; light-orange to light-gray eolian sandstone beds become more prominent in upper third; commonly micaceous; mostly cemented with calcite; resistant, forms thick step-like ledges between the more massive Navajo and Wingate

Sandstones, upper part less resistant, important bench former in quadrangle. Thickness 240-300 feet (73-91 m).

Wingate Sandstone - Mostly light-orange-brown, moderate-orange-pink, or moderate reddish-orange, fine-grained, well-sorted, cross-bedded sandstone; calcareous or siliceous cement; forms nearly vertical cliffs along canyon walls or thick-terraced cliff where shattered; cliff surfaces commonly veneered with dark brown desert varnish. Thickness 240-350 feet (73-107 m).

#### Chinle Formation

Upper member - Moderate reddish-brown or grayish-red, fine- to coarse-grained sandstone and siltstone with subordinate pebble- or gritstone, and gray limestone; slope-forming with prominent ledges, slope-forming units fine-grained, and generally display indistinct bedding, ledge-formers are fine- to coarse-grained, and platy to very thick bedded. Thickness 200-460 feet (61-140 m), sections under 300 feet (91 m) over or immediately adjacent to salt-cored anticlines.

Lower member - Mottled gray, purple, and reddish-brown interbedded sandstone, conglomerate, and siltstone; forms alternating ledges and slopes; contain paleosol layers exhibiting abundant and distinct vertical tubes with fossil plant remains. Thickness 0-380+ feet (0-116+ m), locally missing over or near salt-

cored anticlines and very thick in irregular depositional basins or synclines peripherally located to salt-cored anticlines.

## Moenkopi Formation

**Pariott Member** - Reddish-brown sandstone interbedded with chocolate-brown, orange-brown, or red siltstone, mudstone, and shale; sandstone is fine- to medium-grained and commonly pebbly, micaceous, poorly to well sorted, and forms a series of ledges; siltstones and mudstones form steep slopes. Thickness 0-450 feet (0-137 m), local to the vicinity of the Big Bend quadrangle.

**Sewemup Member** - Pale reddish-orange to grayish-red, slope-forming siltstone with subordinate reddish-brown, fine-grained sandstone; thinly laminated to thin bedded; gypsum is common as irregular veinlets and thin beds; commonly cemented with gypsum; sandstone is commonly ripplemarked. Thickness 0-470 feet (0-143 m), locally missing over salt-cored anticlines, thick elsewhere.

**Lower member** - Reddish-brown and lavender, silty, ledge-forming sandstone and conglomeratic sandstone interbedded with slightly darker reddish-brown to reddish-orange, slope- and recess-forming sandstone, siltstone, and silty mudstone; micaceous and feldspar bearing; platy to medium bedded, commonly ripplemarked or mudcracked. Thickness 0-450 feet (0-137 m), may be missing over salt-cored anticlines, greater than 190 feet (58 m) elsewhere.

## Cutler Formation

White Rim Sandstone Member? - Grayishwhite, quartzose, high-angle cross-bedded sandstone interbedded with minor siltstone and arkose; massive; resistant cliff-former. Thickness 0-250 feet (0-76 m), exposures limited to southwest flank of Castle Valley.

Arkosic sandstone member - Reddish-brown and reddish-purple, subarkosic to arkosic sandstone, conglomeratic sandstone, and conglomerate interbedded with silty and sandy mudstone and shale; thin bedded to massive, form steep slopes, ledges, and cliffs. Thickness 0-6,235+ feet (0-1,900+ m), upper 1,000 feet (305 m) exposed at surface, mostly missing over salt-cored anticlines.

Honaker Trail Formation - Interbedded limestone and micaceous sandstone, not exposed at the surface. Thickness 0-930+ feet (0-283+ m), missing over salt-cored anticlines.

Paradox, Pinkerton Trail, and Molas Formations - Sucrosic gypsum, clayey gypsiferous beds, silty shale, sandstone, limestone, and dolomite, contorted bedding in two small exposures; halite and other salts present in subsurface in salt-cored anticlines; upper surface of salt-cored anticlines consists of caprock composed of insoluble rock types. Thickness 1,500-3,060+ feet (457-933+ m) except in salt-cored anticlines where the maximum thickness may approach 9,000 feet (2,700 m).

Leadville Formation - Limestone and dolomite, subsurface only. Thickness about 450 feet (137 m).

Devonian rocks undivided - Limestone, dolomite, sandstone, minor shale, subsurface only. Thickness about 340 feet (104 m).

## SUPPLEMENTAL FIGURES

Figure 6. View to southwest of Porcupine Rim from Castle Valley. White Rim? Member of Cutler Formation (Pcw?) pinches out to southeast (left). The White Rim? crops out only at the northwest end of Castle Valley in the Big Bend quadrangle.

Figure 7. South end of Parriott Mesa. Trml = lower member of Moenkopi Formation, Trms = Sewemup Member of Moenkopi Formation, Trmp = Parriott Member of Moenkopi Formation, Trc = Chinle Formation, Jw = Wingate Sandstone, and Jk = Kayenta Formation.

Figure 8. View north to eastern point of Dry Mesa. Trml = lower member of Moenkopi Formation, Trms = smooth slopes of Sewemup Member of Moenkopi Formation, Trmp = ledgy Parriott Member of Moenkopi Formation, Trcl = lower member of Chinle Formation, Trcu = upper member of Chinle Formation, Jw = Wingate Sandstone, Jk = Kayenta Formation, and Qmt = talus.

Figure 9. View west across Colorado River just south of mouth of Salt Wash. Trcl = lower member of Chinle Formation, Trcu = upper member of Chinle Formation, Jw = Wingate Sandstone, Jk = Kayenta Formation, and Qmt = talus. Note angular unconformity at Trcu-Trcl contact.

Figure 10. View west at Big Bend of Colorado River. The three formations of the Glen Canyon Group: Wingate Sandstone, Kayenta Formation, and Navajo Sandstone form an 800-foot (244-m) cliff at this location. The Big Bend is the only location on the quadrangle where the "Black Ledge" of the Chinle Formation is developed.

Figure 11. East end of the Cache Valley graben in Professor Valley. pc = Cutler Formation, Trml = lower member of Moenkopi Formation, Trm = Moenkopi Formation, Trc = Chinle Formation, Jw = Wingate Sandstone, Jk = Kayenta Formation. Note that the Wingate Sandstone forming the high cliff in the background has collapsed nearly to river level by salt dissolution in the subsurface Paradox Formation. A characteristic V-syncline is present at the deepest part of the collapsed rock sequence.

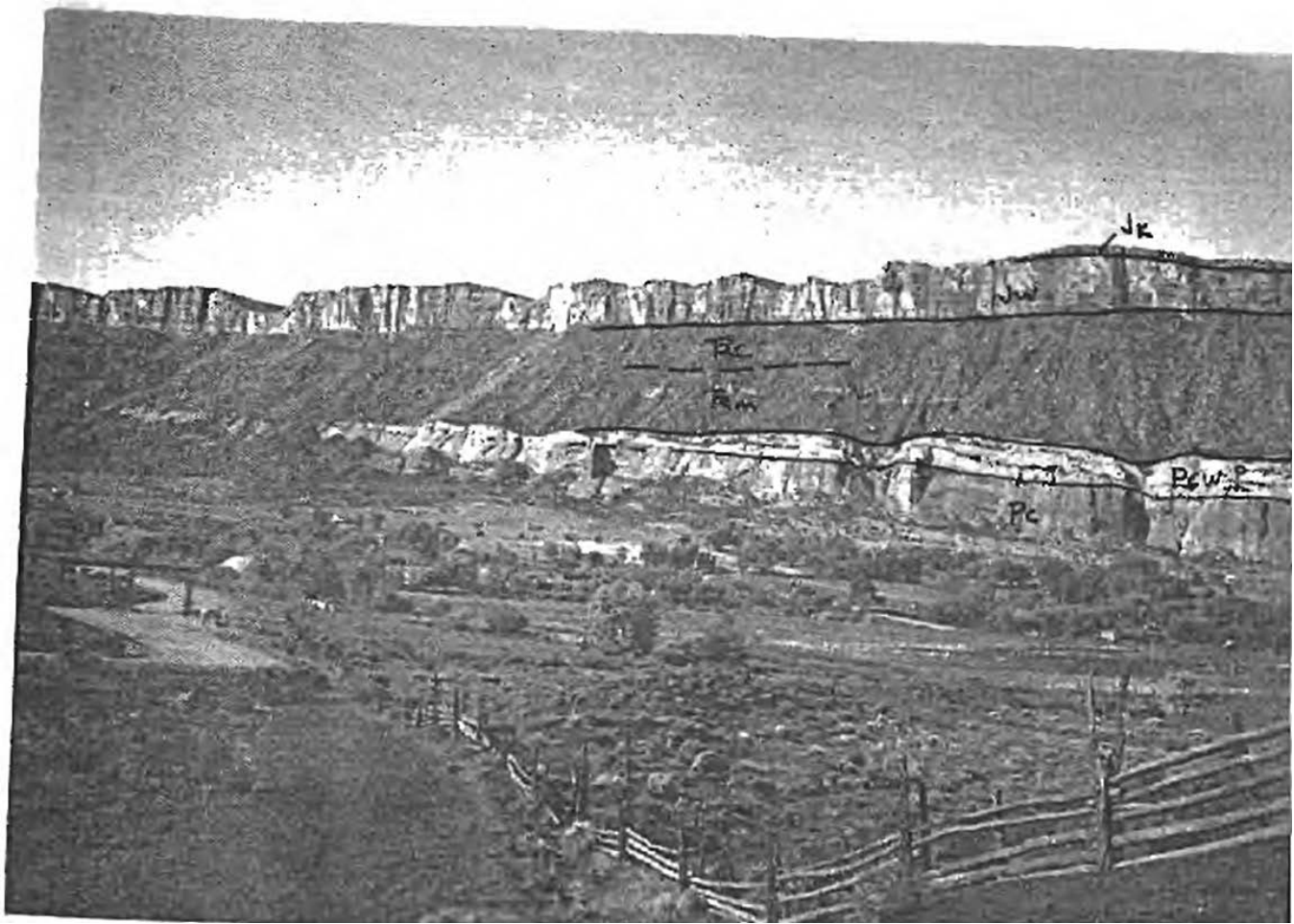


Figure 6. View to southwest of Porcupine Rim from Castle Valley. White Rim? Member of Cutler Formation (Pcw?) pinches out to southeast (left). The White Rim? Member crops out only at the northwest end of Castle Valley in the Big Bend quadrangle.

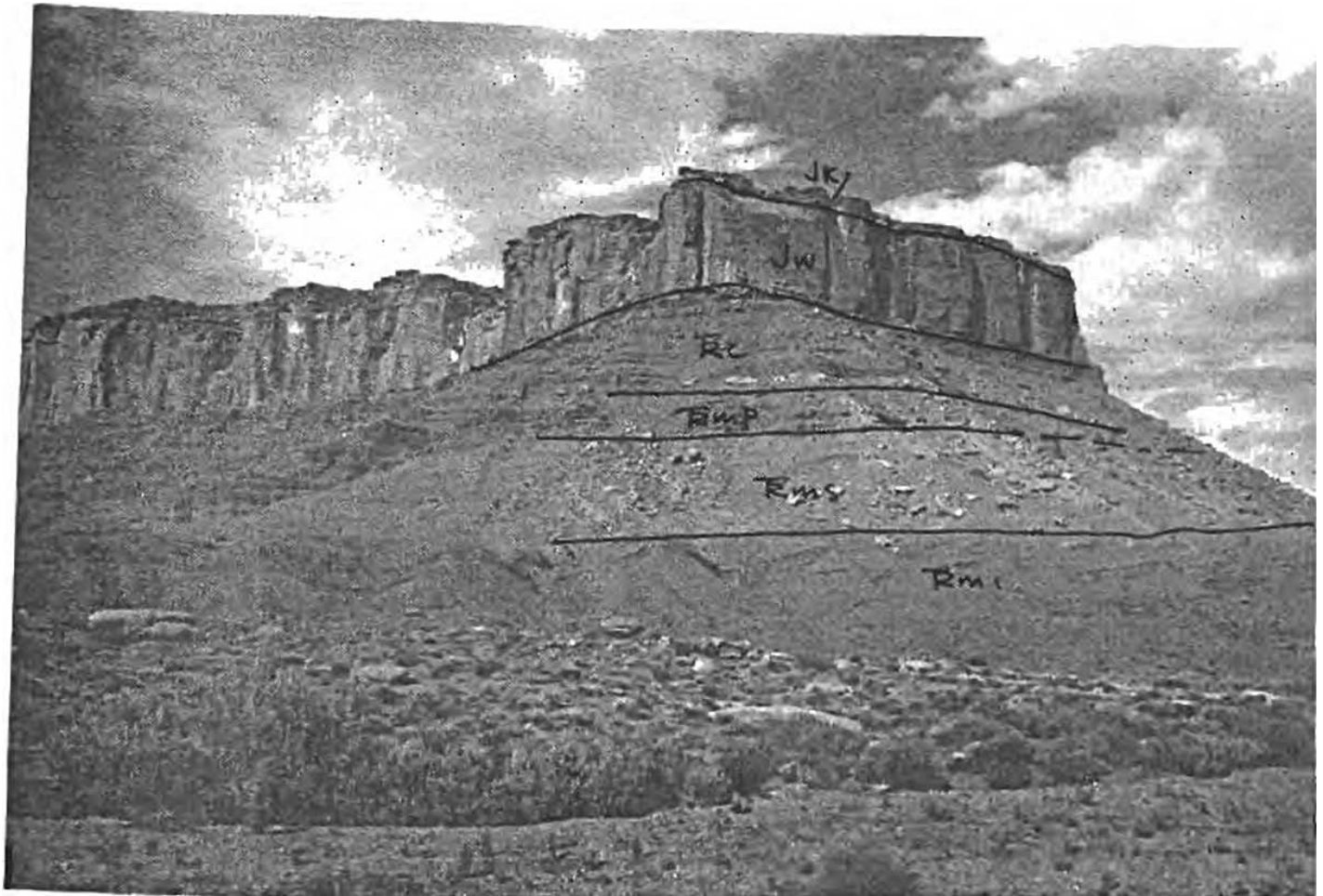


Figure 7. South end of Parriott Mesa. Trml = lower member of the Moenkopi Formation, Trms = Sewemup Member of the Moenkopi Formation, Trmp = Parriott Member of the Moenkopi Formation, Trc = Chinle Formation, JW = Wingate Sandstone, and JK = Kayenta Formation.

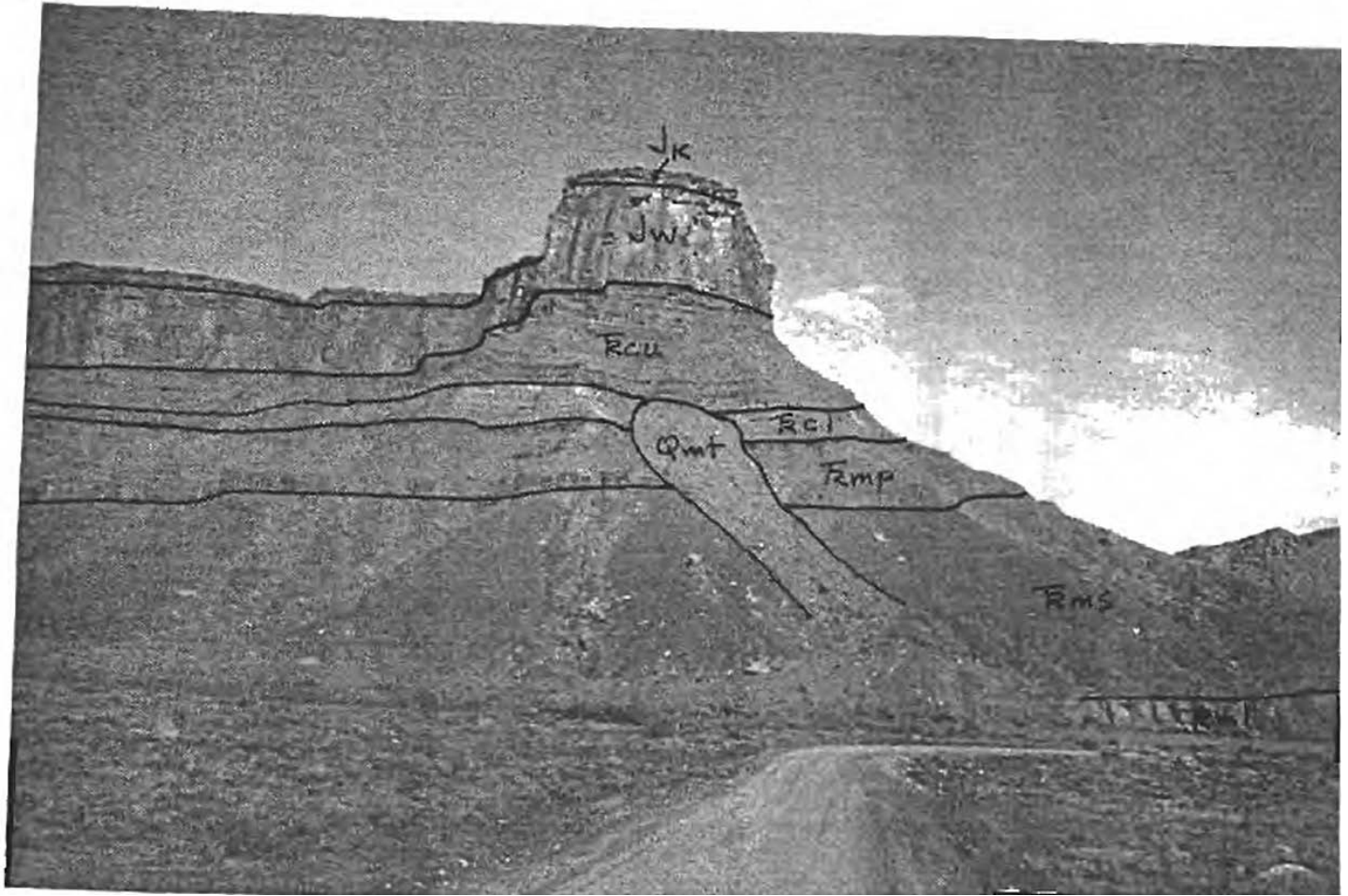


Figure 8. View north to eastern point of Dry Mesa. Trml = lower member of the Moenkopi Formation, Tims = Sewemup Member of the Moenkopi Formation, Trmp = Pariott Member of the Moenkopi Formation, Trcl = lower member of the Chinle Formation, Trcu = upper member of the Chinle Formation, JW = Wingate Sandstone, Jk = Kayenta Formation, and Qmt = talus.

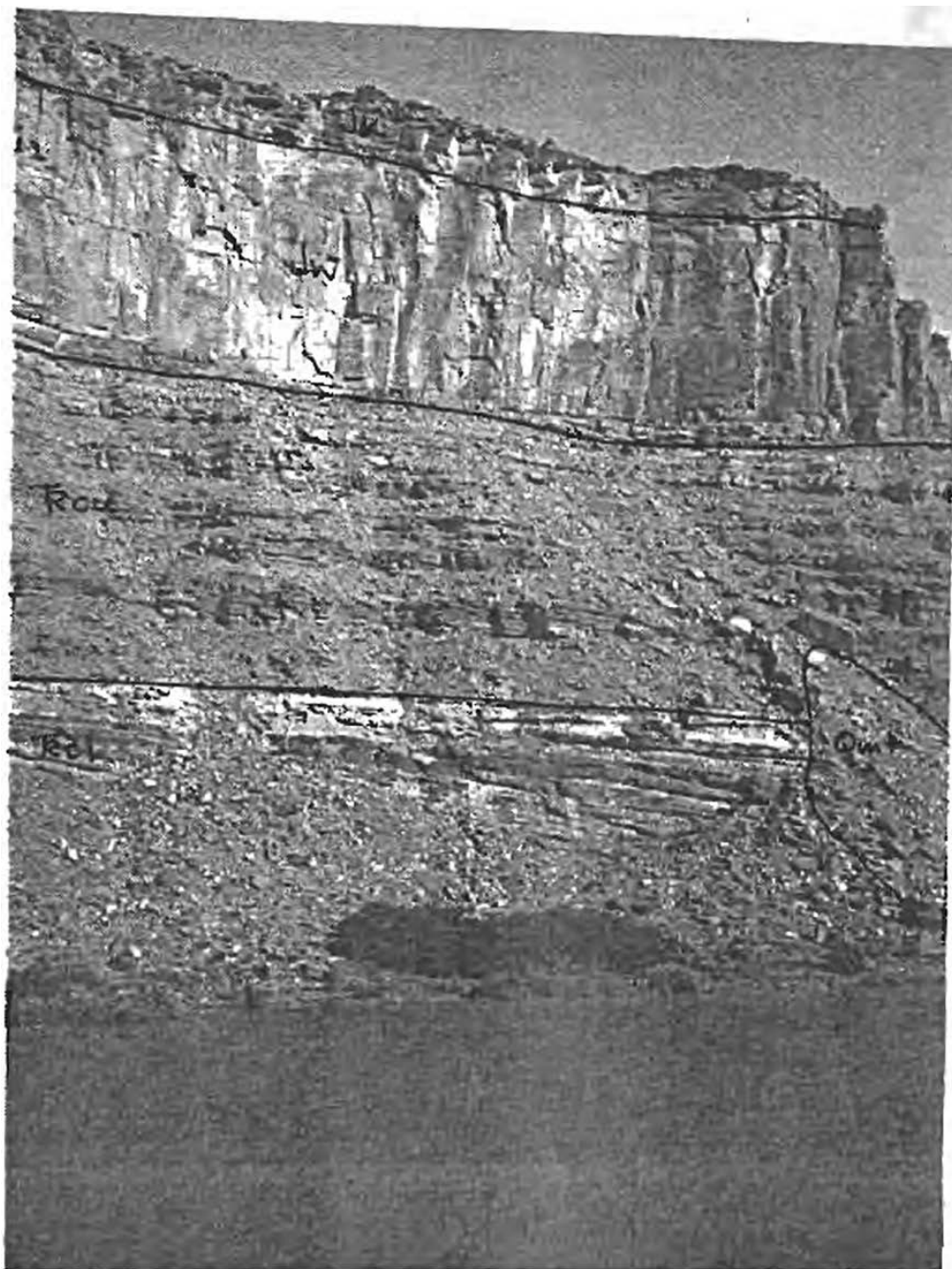


Figure 9. View west across Colorado River south of mouth of Salt Wash. Trcl = lower member of Chinle Formation, Trcu = upper member of Chinle Formation, Jw = Wingate Sandstone, JK = Kayenta Formation, and Qnt = talus. Note angular unconformity at Trcu-Trcl contact.



Figure 10. View west at Big Bend of Colorado River. The three formations of the Glen Canyon Group: Wingate Sandstone, Kayenta Formation, and Navajo Sandstone form an 800-foot (244-m) cliff at this location. The Big Bend is the only location on the quadrangle where the "Black Ledge" of the Chinle Formation is developed.

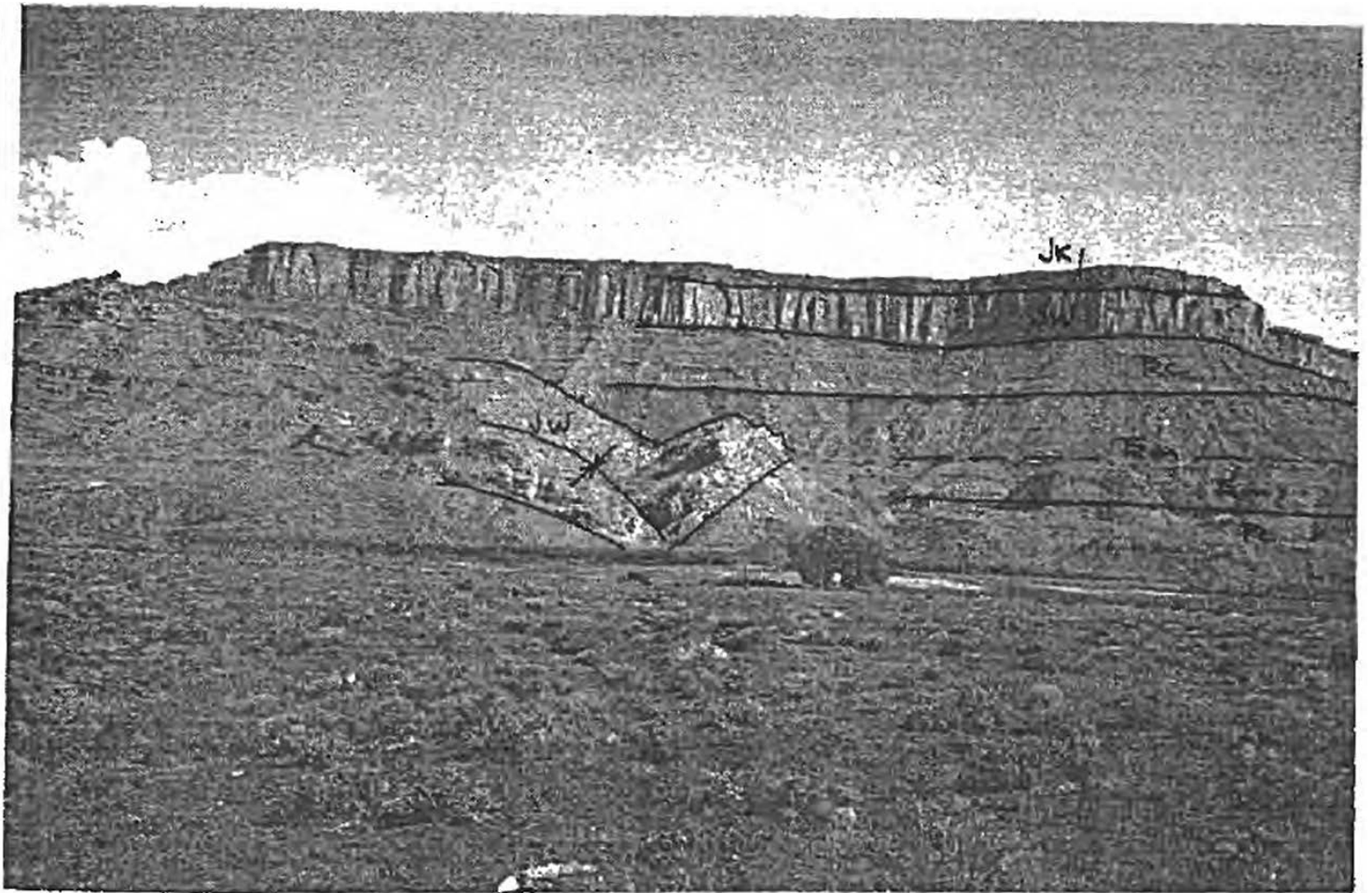
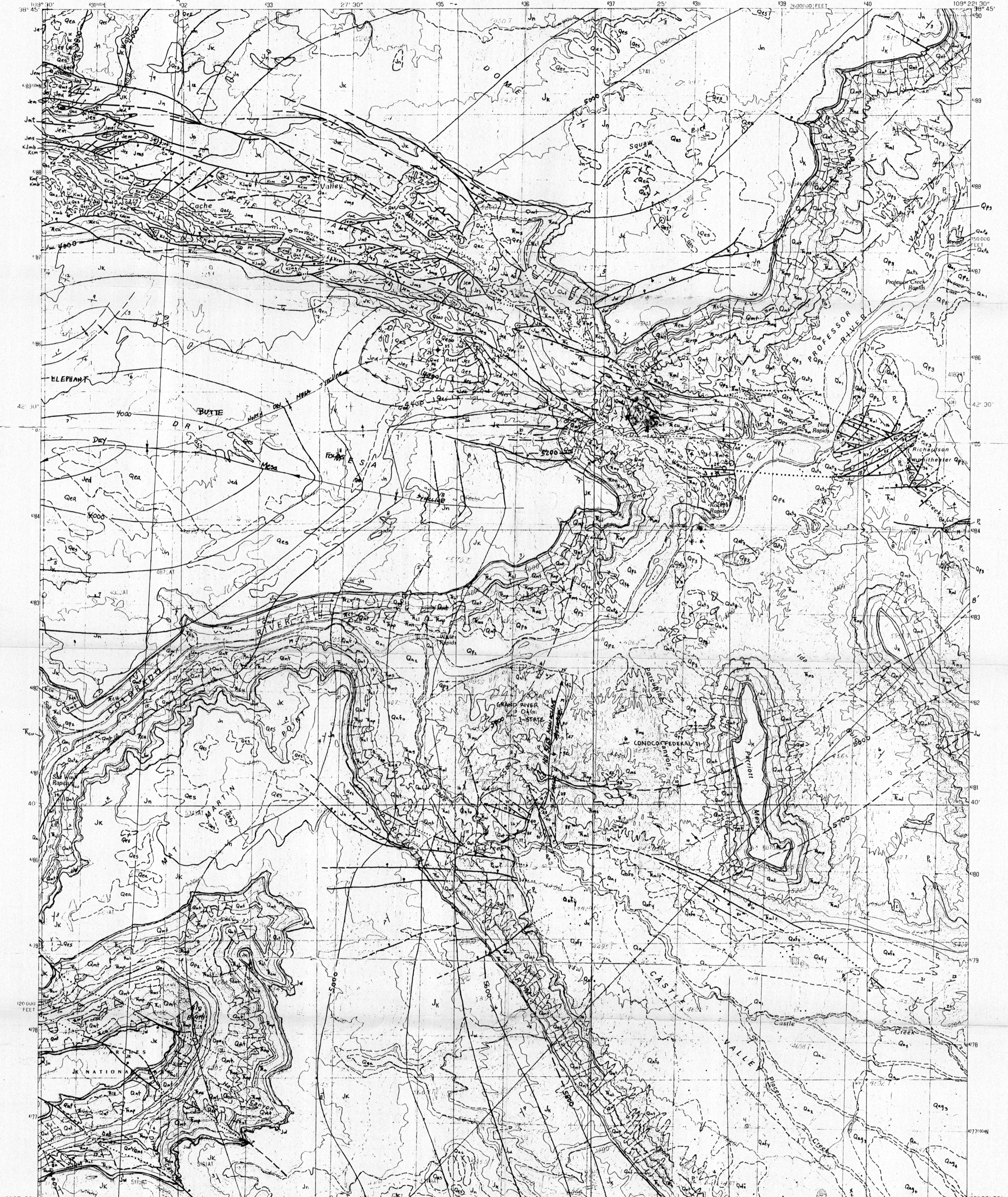
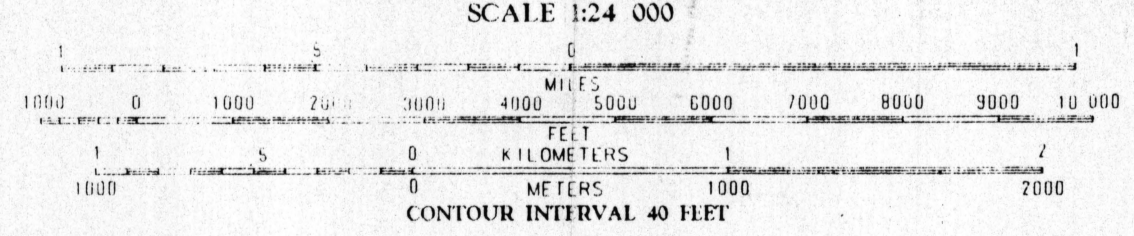


Figure 11. East end of the Cache Valley graben in Professor Valley. Pc = Cutler Formation, Trml = lower member of the Moenkopi Formation, Trm = Moenkopi Formation, Trc = Chinle Formation, Jw = Wingate Sandstone, and Jk = Kayenta Formation. Note that the Wingate Sandstone forming the high cliff in the background has collapsed nearly to river level by salt dissolution in the subsurface Paradox Formation. A characteristic V-syncline is present at the deepest part of the collapsed rock sequence.



PRODUCED BY THE UNITED STATES GEOLOGICAL SURVEY  
CONTROL BY USGS NORS/NOAA  
COMPILED FROM AERIAL PHOTOGRAPHS TAKEN 1960  
FIELD CHECKED 1981 MAP EDITED 1985  
PROJECTION LAMBERT CONFORMAL CONIC  
GRID 1800-METER UNIVERSAL TRANSVERSE MERCATOR ZONE 12  
HORIZONTAL DATUM 1983 NORTH AMERICAN DATUM  
UTM GRID DECLINATION 13° EAST  
1983 MAGNETIC NORTH DECLINATION 13° EAST  
VERTICAL DATUM NATIONAL GEODETIC VERTICAL DATUM OF 1955  
HORIZONTAL DATUM 1983 NORTH AMERICAN DATUM  
To place on the predicted North American Datum of 1983,  
move the projection lines as shown by dashed corner ticks  
(6 meters north and 59 meters east)  
There may be private inholdings within the boundaries of any  
Federal and State Reservations shown on this map  
All marginal data and lettering generated and positioned by  
automated type placement procedures

**PROVISIONAL MAP**  
Produced from original  
manuscript drawing. Infor-  
mation shown as of date of  
field check. 2



ROAD LEGEND

- Improved Road
- Unimproved Road
- Trail
- Interstate Route
- U.S. Route
- State Route

QUADRANGLE LOCATION

ADJACENT 7.5 QUADRANGLE NAMES

1	2	3	4	5	6	7	8
1 Middle Hogue	2 Clois SW	3 Derry	4 The Windows Section	5 Huber Towers	6 Mack	7 Hill Creek	8 Warner Lake

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS  
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225  
OR RESTON, VIRGINIA 22092

**BIG BEND QUADRANGLE**  
by  
**Hellmut H. Doelling and Michael L. Ross**

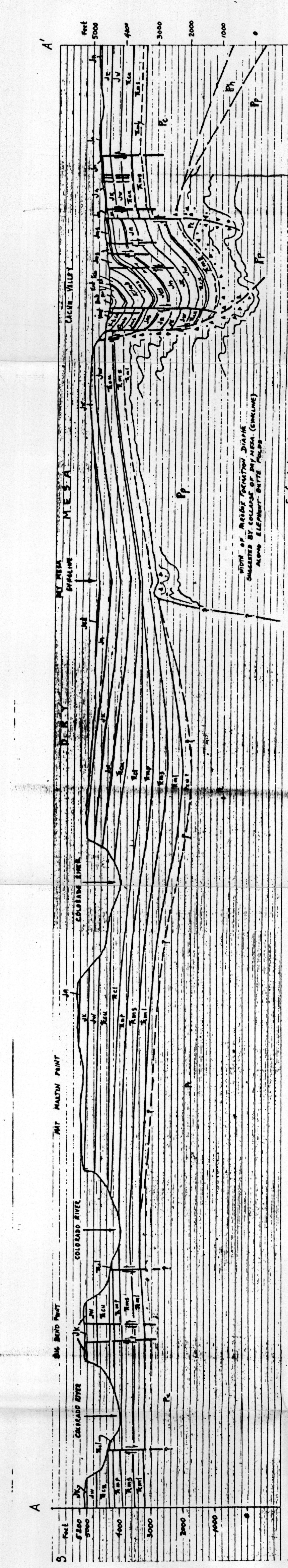
STRUCTURAL CONTOUR OVERLAY  
200-foot structure contours approximately drawn on base of Wingate Sandstone.  
Supplemental contours and projected contours dashed. Diapiric structures may not be directly  
reflected in the Jurassic rocks. Major diapiric activity subsided in the latest Triassic.  
COGEMAP PROJECT 1434-92-A-1087  
STATE CONTRACT 93-1356

782095

# GEOLOGIC MAP of the BIG BEND QUADRANGLE GRAND COUNTY, UTAH

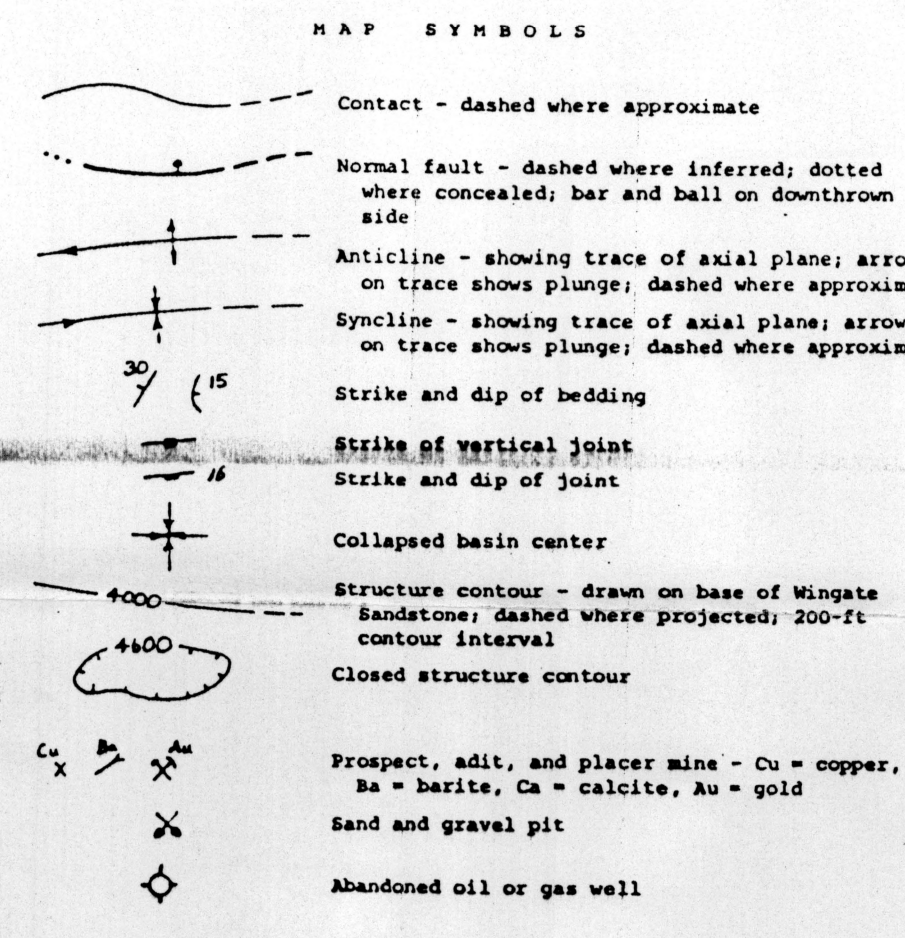
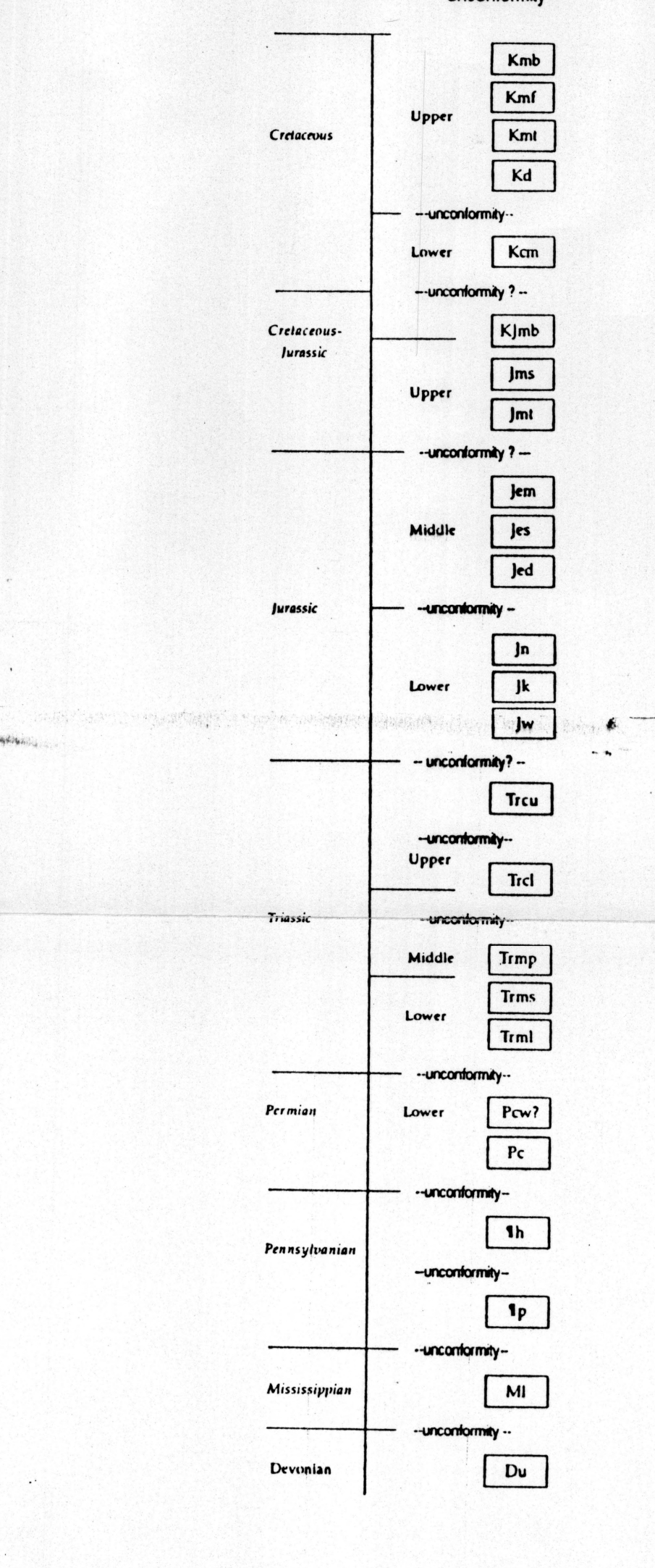
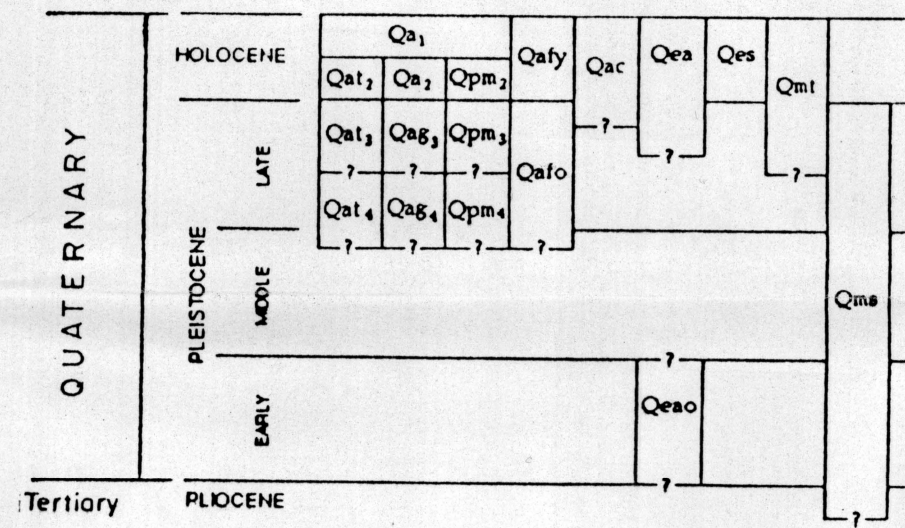
Plate 2  
OPEN-FILE REPORT 285  
UTAH GEOLOGICAL SURVEY  
a division of  
UTAH DEPARTMENT OF NATURAL RESOURCES

July 1993



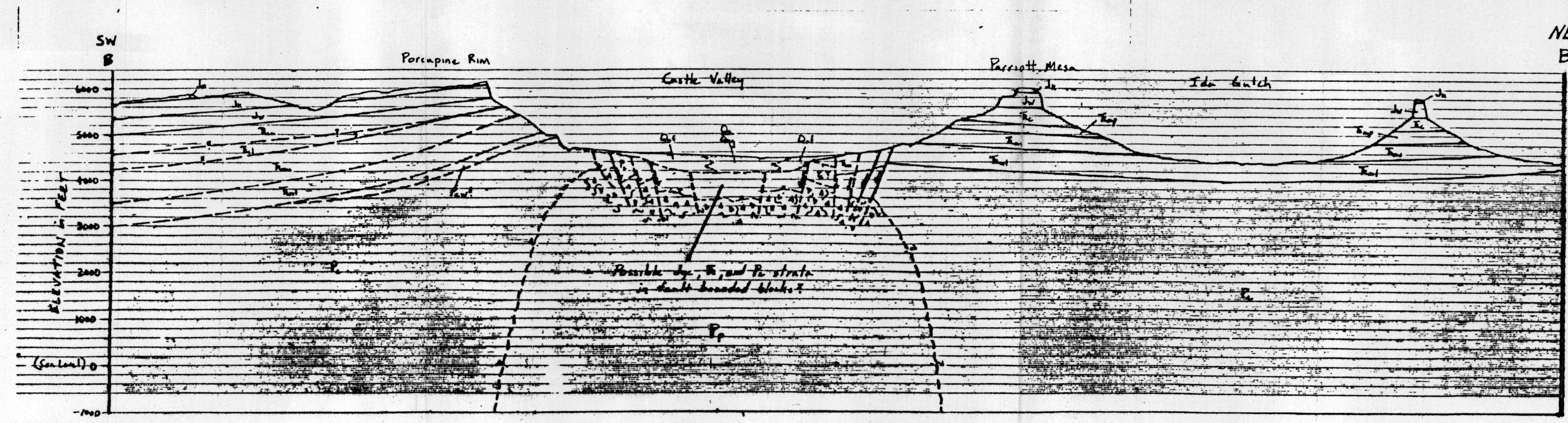
PERIOD	EPOCH	FORMATIONS AND MEMBERS	SYMBOL	THICKNESS (feet)	LITHOLOGY
Quaternary	Holocene	Surficial deposits		0-350+ 10-107+	Lower part unsorted unconformity
		Blue Gate Shale Member	Kmb	500+ (152+)	Sandy beds Light gray shale
Cretaceous	Upper	Ferron Member	Kmf	80-120 (27-37)	Sea shells near top
		Tununk Shale Member	Kml	400 (122)	Medium gray shale
		Delora Formation	Kd	40-50 (12-15)	unconformity
		Cedar Mountain Formation	Kcm	200-240 (61-73)	Ridge-forming ledges unconformity?
		Brusky Basin Member	Kjmb	300-340 (91-104)	Green, zeolitic shale
	Lower	Morrison Formation	Jms	250 (76)	Lenticular channel sandstones
		Salt Wash Member	Jms	250 (76)	Lenticular channel sandstones
		Tidwell Member	Jtm	40-60 (12-18)	Large chert concretions unconformity?
		Moab Member	Jem	90-110 (27-34)	Highly jointed Arches
		Slick Rock Member	Jes	250-350 (76-107)	Conorted bedding unconformity
Jurassic	Middle	Dewey Bridge Member	Jdb	40-60 (12-18)	Conorted bedding unconformity
		Navajo Sandstone	Jn	250-400 (76-122)	Large-scale, high-angle cross-stratification Pinnated sand dunes Thin limestone ledges
		Kayenta Formation	Jk	240-300 (73-91)	Ledge and bench former
		Wingate Sandstone	Jw	240-350 (73-107)	Prominent vertical cliff former Desert-weathered surfaces
		Utter Formation	Ju	200-460 (61-140)	"Black Ledge" locally present
	Lower	Chinle Formation	Jcl	0-380+ (0-116+)	unconformity Sikrete horizons Mottled siltstone and sandstone Paleosols
		Paria Member	Jmp	0-450 (0-137)	"Ledy" Moenap
		Sewmup Member	Jms	0-470 (0-143)	Smooth slopes Ripple marks and rain-drop imprints Thin gypsum beds Mud cracks
		Moenkopi Formation	Jmi	0-450 (0-137)	Ripple marks
		White Rim Sandstone Mbr?	Jcw?	0-250 (0-76)	Gypsum bed unconformity White eolian sandstone
Permian	Lower	Arkosis sandstone member	Pc	0-1,000 (0-305) exposed at surface	Subarkosis and arkosis lunnet and eolian sandstone
		Utter Formation	Ju	6,235+ (1,900) surface and known subsurface	Thin limestone beds
		Honeker Trail Formation	Ph	0-930+ (0-283+)	interbedded limestone and micaceous sandstone
Pennsylvanian	HERMOSA-GROUP	Paradox, Pinkerton Trail and Moles Formations	Pp	0-100+ (0-30+) exposed as caprock	unconformity Evaporite caprock (gypsum and shale)
		Leadville Formation	MI	450 (137) subsurface only	Limestone and dolomite
Devonian	Upper	Devonian rocks undivided	Du	340 (104) subsurface only	Limestone, dolomite, sandstone, minor shale

### CORRELATION OF MAP UNITS



### DESCRIPTION OF MAP UNITS

- Qes** Eolian sand deposits — Generally fine- to medium-grained quartzose sand forming thin, discontinuous accumulations of sand sheets and small dunes.
- Qea** Mixed eolian and alluvial sand deposits — Thin accumulations of mainly sand deposited and reworked by eolian and alluvial processes; moderate to well sorted; generally restricted to ephemeral washes and hollows. Qea deposits a mainly sand, but contains minor clay and gravel lenses; forms a thick deposit capped by a stage V petrocalcic soil suggesting an early Pleistocene age. Local thickness may exceed 160 feet (49 m).
- Qeo** Mixed alluvial and colluvial deposits — Poorly sorted mixture of clay through cobble size detritus with sporadic boulders; classifies vary from subrounded to angular; located along narrow ephemeral washes where colluvium is reworked and transported away by alluvial processes in active channels. Thicknesses up to 15 feet (5 m).
- Qac** Alluvial fan deposits — Deposits of poorly sorted, angular to subrounded boulders, cobbles, and gravels in a crudely-bedded finer grained matrix; form gentle to moderate apron-like slope at the base of bedrock outcrop; younger fan deposits (Qa1) head in gullies of older fan deposits (Qa2). Deposit thicknesses range from 0 to 250 feet (2-76 m).
- Qa1** Alluvial deposits — Qa1 and Qa2 contain generally finer grained detritus; consist mainly of poorly to moderately sorted sand and lenses of gravel; located along Colorado River and the larger creeks and ephemeral washes. Qa3 and Qa4 contain generally coarser grained detritus; consist of poorly sorted, poorly stratified sandy, cobble gravel; form dissected stony, and surface and subsurface in Castle Valley; deposits exhibit pedogenic carbonate soils ranging from stage I to stage IV.
- Qa2** Terrace gravel deposits — Moderately sorted, subrounded to rounded, poorly stratified gravel in a gray, calcareous sandy matrix; forms rounded knobs on small hills along the Colorado River; variety of class lithologies that are angular to subangular and 0.40 to 0.12 m above the river; Qa3 is about 100 feet (30 m) above the river; Qa4 is about 130 feet (40 m) above the river.
- Qa3** Pediment-mantle deposits — Poorly sorted, sandy matrix-supported gravel; locally contains lenses of sand and/or clay-supported gravel; gravel ranges from pebbles to boulders; deposits are locally sourced and have orange-red-purple shading; detritus deposited as a relatively thin veneer on uneven pediment surfaces; mixed alluvial fan, ephemeral stream, colluvial, and eolian deposits are subdivided based on height above current drainage and grading to alluvial terraces along the river.
- Qa4** Talus deposits and colluvium — Generally angular rock fall blocks, boulders, and small fragments deposited as veneers on slopes below ledges and cliffs; colluvium contains additional slopewash debris of poorly sorted rock fragments in a sandy to muddy matrix.
- Qms** Landslide deposits — Large coherent blocks to fragmented masses of bedrock and surficial debris transported downslope by mass movement.
- Kmb** Blue Gate Shale Member — Mostly light gray marine shale, slope-former, containing local sandy beds which are slightly more resistant; younger bedrock unit exposed in Cache Valley. Incomplete thickness 500+ feet (152+ m).
- Kmf** Ferron Sandstone Member — Light-brown to medium-gray marine sandstone, sandy shale, shale, and carbonaceous shale; thin bedded; slightly more resistant than Moab above; locally fossiliferous near top. Thickness 80-120 feet (27-37 m).
- Kml** Tununk Shale Member — Medium gray marine shale, slope former containing a few sandy beds, especially near the top; sandy beds are yellow gray to brown gray. Thickness about 400 feet (122 m).
- Kcm** Cedar Mountain Formation — Variegated slope-forming mudstone interbedded with ledge-forming gray and brown calcareous sandstone, conglomerate, and gritstone. Mudstone is mostly light green, gray, lavender, and white; locally deformed and attenuated with Dakota Formation (Kdcm), especially on south wall of Cache Valley. Thickness 200-240 feet (61-73 m).
- Kjmb** Brusky Basin Member — Mostly variegated to bright green, slope-forming mudstone with thin ledges of calcareous sandstone, conglomerate, and gritstone. Mudstone is mostly light green, gray, lavender, and white; locally deformed and attenuated with Dakota Formation (Kdcm), especially on south wall of Cache Valley. Thickness 300-340 feet (91-104 m).
- Jms** Morrison Formation — Light gray to yellow-gray sandstone, conglomeratic sandstone, and conglomerate, with subordinate gray sandy shale and carbonaceous shale; forms ridges in Cache Valley. Thickness 40-50 feet (12-15 m).
- Jtm** Tidwell Member — Reddish-silt shale, with interbeds of fine-grained yellow sandstone and gray limestone; lower half of unit slightly more resistant; contains large, white, siliceous concretions in upper half of unit; formerly mapped as Summerville Formation. Thickness 40-60 feet (12-19 m).
- Jem** Moab Member — Pale-orange, grayish-orange, pale yellowish-brown, or light gray, fine- to medium-grained, calcareous, massive, cliff-forming sandstone; upper surfaces prominently jointed. Thickness 90-110 feet (27-34 m).
- Jes** Slick Rock Member — Reddish-orange or brown, very fine- to fine-grained eolian sandstone; calcareous or iron oxide cemented; massive; weathers to form smooth cliffs and bare rock slopes; commonly covered with self-derived sand; not as resistant as Moab Member above, but more resistant than Dewey Bridge Member below. Thickness 250-350 feet (76-107 m).
- Jdb** Dewey Bridge Member — Dark reddish, fine-grained, silty sandstone; mostly iron oxide cemented; in irregularly contorted, indistinct "lumpy" medium to thick beds; formerly known as Carmel Formation. Thickness 40-60 feet (12-18 m).
- Jn** Navajo Sandstone — Orange to light-gray eolian sandstone, mostly fine grained, cemented with silica or calcite; crops out as vertical cliffs in deep canyons and as domes and rounded hills; locally thin, hard, gray carbonate beds; well displayed, high-angle cross beds. Thickness 250-400 feet (85-122 m).
- Jk** Kayenta Formation — Moderate-orange-pink, reddish-brown, and lavender sandstone interbedded with subordinate dark-reddish-brown to grayish-red silty mudstone, lavender-gray intraformational conglomerate, and limestone mostly of fluvial or lacustrine origin; light-orange to light-gray eolian sandstone beds become more prominent in upper third; commonly micaceous, mostly cemented with calcite; resistant, forms thick step-like ledges between the more massive Navajo and Wingate Sandstones, upper part less resistant, important bench former in quadrangle. Thickness 240-300 feet (73-91 m).
- Jw** Wingate Sandstone — Mostly light-orange-brown, moderate-orange-pink, or moderate reddish-orange, fine-grained, well-sorted, cross-bedded sandstone; calcareous or iron oxide cemented; forms nearly vertical cliffs along canyon walls or thick-teraced cliff where weathered; cliff surfaces commonly veneered with dark-brown desert varnish. Thickness 240-350 feet (73-107 m).
- Jcl** Chinle Formation — Moderate reddish-brown or grayish-red, fine- to coarse-grained sandstone and siltstone with subordinate pebble- or gritstone, and gray limestone; slope-forming with prominent ledges, slope-forming units fine-grained and generally display indistinct bedding, ledge-formers are fine- to coarse-grained, and platy to very thick bedded. Thickness 200-460 feet (61-140 m), sections under 300 feet (91 m) over or immediately adjacent to salt-cored anticlines.
- Jmp** Lower member — Mottled gray, purple, and reddish-brown interbedded sandstone, conglomerate, and siltstone; forms alternating ledges and slopes; contain paleosol layers exhibiting abundant and distinct vertical tubes with fossil plant remains. Thickness 0-380+ feet (0-116+ m); locally missing over or near salt-cored anticlines and very thick in irregular depositional basins or synclines peripherally located to salt-cored anticlines.
- Jms** Moenkopi Formation — Reddish-brown sandstone interbedded with chocolate-brown, orange-brown, or red siltstone, mudstone, and shale; sandstone is fine- to medium-grained and commonly pebbly; micaceous, poorly to well sorted, and forms a series of ledges; siltstones and mudstones form steep slopes. Thickness 0-450 feet (0-137 m), local to the vicinity of the Big Bend quadrangle.
- Jms** Sewmup Member — Pale reddish-orange to grayish-red, slope-forming siltstone with subordinate reddish-brown, fine-grained sandstone; thinly laminated to thin bedded; gypsum is common as irregular veinlets and thin beds; commonly cemented with gypsum; sandstone is commonly ripplemarked. Thickness 0-470 feet (0-143 m), locally missing over salt-cored anticlines, thick elsewhere.
- Jmi** Lower member — Reddish-brown and lavender, silty, ledge-forming sandstone and conglomeratic sandstone interbedded with slightly darker reddish-brown to reddish-orange, slope- and recess-forming sandstone, siltstone and silty mudstone; micaceous and ledge-bearing; platy to medium bedded, commonly ripplemarked or mudcracked. Thickness 0-450 feet (0-137 m), may be missing over salt-cored anticlines, greater than 190 feet (58 m) elsewhere.
- Jcw?** Cutler Formation — White Rim Sandstone Member? — Grayish-white, quartzose, high-angle cross-bedded sandstone interbedded with minor siltstone and arkosis; massive; resistant cliff-former. Thickness 0-250 feet (0-76 m), exposures limited to southwest flank of Castle Valley.
- Pc** Arkosis sandstone member — Reddish-brown and reddish-purple, subarkosis to arkosis sandstone, conglomeratic sandstone, and conglomerate interbedded with silty and sandy mudstone and shale; thin bedded to massive, forms steep slopes, ledges, and cliffs. Thickness 0-6,235+ feet (0-1,900+ m), upper 1,000 feet (305 m) exposed at surface, mostly missing over salt-cored anticlines.
- Ph** Honeker Trail Formation — Interbedded limestone and micaceous sandstone, not exposed at the surface. Thickness 0-930+ feet (0-283+ m), missing over salt-cored anticlines.
- Pp** Paradox, Pinkerton Trail, and Moles Formations — Succroic gypsum, clayey gypsiferous beds, silty shale, sandstone, limestone, and dolomite; contorted bedding in two small exposures; halite and other salts present in subsurface in anticlines; upper surface of salt-cored anticlines consists of caprock composed of salt-saturated rock types. Thickness 1,500-3,060+ feet (457-933+ m) except in salt-cored anticlines where the maximum thickness may approach 9,000 feet (2,700 m).
- MI** Leadville Formation — Limestone and dolomite, subsurface only. Thickness about 450 feet (137 m).
- Du** Devonian rocks undivided — Limestone, dolomite, sandstone, minor shale; subsurface only. Thickness about 340 feet (104 m).



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