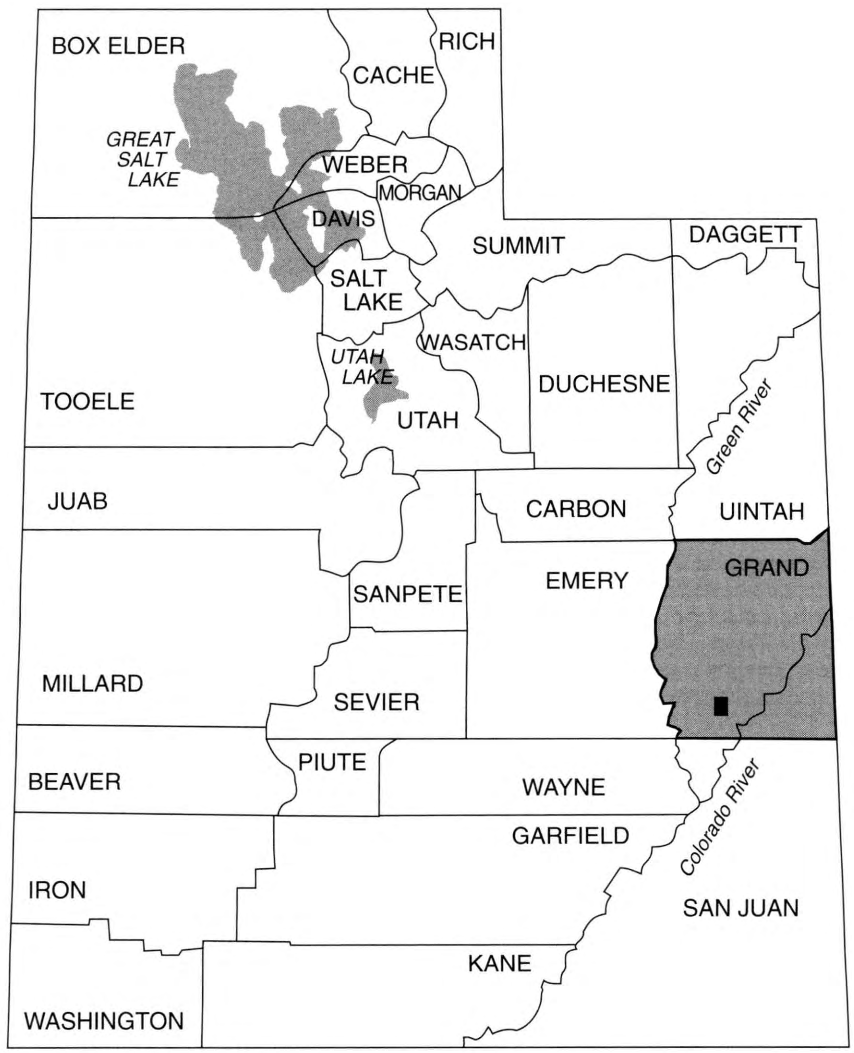
GEOLOGIC MAP OF THE MERRIMAC BUTTE QUADRANGLE, GRAND COUNTY, UTAH

by

Hellmut H. Doelling and Craig D. Morgan



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ABSTRACT

The Merrimac Butte quadrangle is located 8 to 18 miles (13-29 km) northwest of Moab, in Grand County, Utah, along U.S. Highway 191. It lies at the north end of the Canyonlands red rock country with typical high cliffs and deep canyons, especially in the south half of the quadrangle. It is an important transportation corridor and the west boundary of Arches National Park extends into the quadrangle from the east.

Exposed bedrock units range from Pennsylvanian to Cretaceous in age, with scattered Quaternary cover. Ascending, the units include the Pennsylvanian Honaker Trail Formation, the Permian Cutler Formation, the Triassic Moenkopi and Chinle Formations, the Jurassic Wingate, Kayenta, Navajo, Entrada, Summerville, and Morrison Formations, and the Cretaceous Cedar Mountain, Dakota, and Mancos Formations. Principal surficial deposits include alluvium, talus, colluvium, eolian sand, and landslides.

Some bedrock units thin out over salt-flowage structures in the underlying Middle Pennsylvanian Paradox Formation and thicken in the adjacent rim synclines. Salt in the Paradox is thickest in the south half of the quadrangle but is absent in parts of the north half of the quadrangle. Conversely, Late Pennsylvanian to Triassic units are very thick to the north but are thinner to the south. Salt tectonics primarily affected Pennsylvanian to Triassic units and there is evidence that Middle and Lower Jurassic units were similarly affected, but to a lesser extent.

The Moab fault reaches its maximum displacement of 3,500 feet (1,067 m) in the quadrangle. The northwest-trending structure dips to the northeast at 50 to 65 degrees and movement was nearly vertical. Splay faults adjoin the Moab fault in the northwest part of the quadrangle and take up about 400 feet (122 m) of the Moab fault's displacement to the north. Beds southwest of the Moab fault generally dip westward to the Kings Bottom syncline. The axial trace of the syncline crosses the southwest corner of the quadrangle. Beds northeast of the Moab fault are folded, forming the Moab anticline and the Courthouse syncline. The Salt Valley anticline is present in the northeast corner of the quadrangle.

Uranium ore was mined from the basal Chinle Formation in the quadrangle and there is good potential for the production of potash and other salts from the Paradox Formation. Other potential commodities include oil and gas, copper, gemstones, and cement rock. Bedrock aquifers are the Wingate, Navajo, and Entrada Sandstones. The principal geologic hazards in the quadrangle are flooding and debris flows, rock falls, landsliding, expansive clays, and blowing sand.

INTRODUCTION

The Merrimac Butte quadrangle, located in east-central Utah, is named after a natural feature located near the west edge of the quadrangle. A part of Arches National Park makes up the east margin of the quadrangle. A segment of U.S. Highway 191, between Crescent Junction and the town of Moab, extends from the northwest to the southeast part of the quadrangle. Utah Highway 313 extends southwest from U.S. 191 from about the middle of the quadrangle and provides access to Dead Horse Point State Park and Canyonlands National Park (figure 1).

Altitudes in the quadrangle range from about 4,150 feet (1,265 m) along Courthouse Wash along the east margin of the southeast quadrant to 5,735 feet (1,748 m) on the cliff rim above Moab Canyon in the southwest part of the southeast quadrant.

Dane (1935), McKnight (1940), Yeats (1961), Williams (1964), Parr (1965), and Doelling (1985, 1993) geologically mapped all or parts of the quadrangle, mostly at smaller scales. Bates (1955) mapped the quadrangle photogeologi-

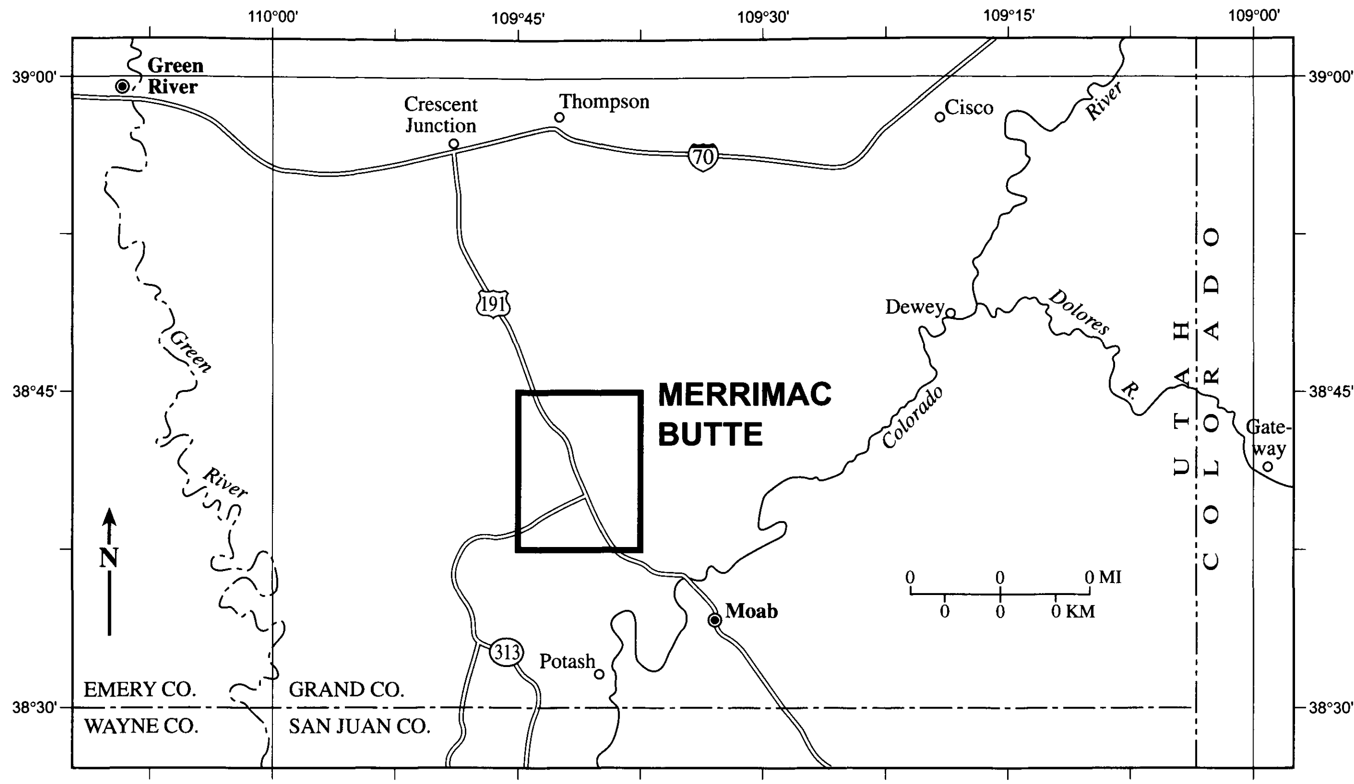

Figure 1. Index map for Merrimac Butte quadrangle, showing southern Grand County, Moab, and the Green and Colorado Rivers.

cally at 1:24,000 scale. For this investigation Doelling mapped the surface and Morgan provided subsurface data.

STRATIGRAPHY

Exposed rock formations in the Merrimac Butte quadrangle range in age from Late Pennsylvanian (Virgilian) to Late Cretaceous (Cenomanian). Drill holes have penetrated additional Pennsylvanian, Mississippian, and Devonian rocks. These drill holes indicate that salt in the Middle Pennsylvanian Paradox Formation is thick in the south part and thin or missing in the north part of the quadrangle. Salt movement greatly affected the Middle Pennsylvanian through Upper Triassic strata in the quadrangle. Lower Jurassic strata show less dramatic effects. Contemporaneous sedimentation and salt tectonics produced lateral variations in lithofacies, and differences in unit thicknesses and geometry of Middle Pennsylvanian through Lower Jurassic units (Stewart and others, 1972a).

Subsurface Units

Devonian- to Pennsylvanian-aged rocks below the upper part of the Pennsylvanian Honaker Trail Formation have been encountered in drill holes in the quadrangle, but are not exposed at the surface. Formations encountered in drill holes (ascending) are the Devonian Elbert Formation and Ouray Limestone, the Mississippian Leadville Formation, and the Pennsylvanian Molas, Pinkerton Trail, Paradox, and Honaker Trail Formations.

In the Paradox basin the Devonian is represented by the Aneth, Elbert, and Ouray Formations, but the Aneth is missing in the quadrangle area (Parker and Roberts, 1963). The Elbert is divided into a lower McCracken Sandstone Member and an upper unnamed member. The upper member of the Elbert Formation consists of sandy limestone, dolomite, and minor shale (Doelling and others, 1994). The upper member has been penetrated by two drill holes in the quadrangle (maximum of 167 feet [50.9 m]) (see cross- section A-A′). The Elbert Formation is 200 to 260 feet (62-79 m) thick in surrounding drill holes (Parker and Roberts, 1963).

The Upper Devonian Ouray Limestone consists of light- to medium-gray, finely crystalline dolomite and limestone, with very widely spaced thin stringers of green shale (Parker and Roberts, 1963). The Ouray Limestone is 80 and 140 feet (24 and 43 m) thick in the two wells (see cross-section A-A′) in the Merrimac Butte quadrangle.

The Mississippian Leadville Formation consists of limestone, dolomite, and widely spaced chert pods (Wengerd and Matheny, 1958). The limestone is finely crystalline and light gray with local green and brown tinges. Dolomite is irregularly interbedded with the limestone. The Leadville is 500 feet (152 m) thick in two drill holes (see cross-section A-A′) in the quadrangle. The contact with the overlying Pennsylvanian Molas Formation is an unconformity that represents 25 million years of subaerial erosion (Wengerd and Matheny, 1958).

Pennsylvanian rocks are divided into the (ascending) Molas, Pinkerton Trail, Paradox, and Honaker Trail Formations. The Molas Formation includes a basal paleosol and paleokarst filling consisting of limestone clasts in a red and muddy siltstone matrix (Wengerd and Matheny, 1958). The lower part of the formation fills depressions on a Leadville Formation karst topography. The upper part of the Molas is red-brown to variegated siltstone, red shale, calcareous sandstone, and lenses of gray to red-yellow limestone deposited during a marine transgression (Wengerd and Matheny, 1958). The Molas Formation ranges from 0 to 86 feet (0-26 m) thick and is overlain by the Pinkerton Trail Formation.

The Pinkerton Trail Formation consists of interbedded limestone, dolomite, silty carbonaceous shale, and calcareous siltstone (Wengerd and Matheny, 1958). Limestone and dolomite are finely crystalline and some beds are argillaceous. The formation marks a transition from open to restricted marine conditions. The thickness of the Pinkerton Trail varies from 40 to 70 feet (12-21 m) and its upper contact is gradational with the Paradox Formation.

The Paradox Formation consists of cyclically interbedded evaporite and clastic sequences deposited under restricted marine conditions within a subsiding basin. Hite (1960) identified and numbered sequentially, from youngest to oldest, 29 cycles of paired evaporite and clastic (marker bed) sequences in the Delhi Oil No. 2 Utah well, section 18, T. 25 S., R. 21 E. (Salt Lake Base Line and Meridian). Some of these cycles are not present in other drill holes in the Merrimac Butte quadrangle. Evaporite sequences consist mostly of finely crystalline, finely laminated halite, with widely spaced undulatory anhydrite beds. Colors range from gray to gray brown and red brown. Sylvite and carnallite are interbedded with some of the halite beds, and salts 5, 9, and 19 contain particularly thick or pure intervals of potash. Thicknesses of individual evaporite sequences encountered in drill holes range up to nearly 1,000 feet (305 m). Original stratigraphic thicknesses have been modified by salt deformation. The salt section in the Sevenmile Canyon area (Morgan, 1993a) and the neighboring Salt Valley anticline are greatly thickened while in the Tiger Oil No. 12-11 State well, section 11, T. 24 S., R. 20 E., on the west flank of the Salt Valley anticline, salt is absent (Morgan, 1993b). Marker beds consist of interbedded shale, siltstone, limestone, dolomite, and anhydrite. Shale and siltstone are mostly black, argillaceous, and carbonaceous. Limestone and dolomite vary from dark gray to gray and are micritic (Doelling and others, 1994).

The lower contact of the Paradox Formation is placed at the transition from interbedded limestone, dolomite, siltstone, highly carbonaceous shale (>150 API gamma-ray units), and anhydrite of the Paradox Formation to the dominantly interbedded limestone, dolomite, and siltstone of the Pinkerton Trail Formation that generally lacks the highly carbonaceous shale and anhydrite. The upper contact of the Paradox Formation is placed at a distinctive peak in gamma-ray intensity, known as the Paradox marker, observed in well logs (Hite and Cater, 1972). The marker is an anhydrite bed in the shale facies overlying salt cycle 2. Cycle 1 typically is a carbonate deposit in most of the northern Paradox basin and is generally included in the Honaker Trail Formation, but it does contain halite in some of the drill holes in the Merrimac Butte quadrangle. Total thickness of the Paradox Formation, as cut in drill holes, ranges from 504 to more than 6,900 feet (154 to >2,103 m) in the quadrangle. We estimated that it is at least 11,500 feet (3,505 m) thick in the Salt Valley salt-cored anticline (cross-section A-A´, plates 1 and 2).

The subsurface Honaker Trail Formation consists of interbedded sandstone, siltstone, limestone, and dolomite. Most sandstone beds are very light gray to yellow gray, micaceous, very fine to fine grained, and highly calcareous. A few sandstone beds are red, arkosic, and fine to medium grained. Siltstone is mostly yellow to green gray, highly micaceous, and variably calcareous. Limestone is gray to very light gray, finely crystalline, and generally argillaceous (Doelling and others, 1994). Limestone beds increase upward in abundance and thickness within the lower part of the formation. Total thickness of the formation in drill holes varies from 1,870 to 2,408 feet (570-734 m). The Honaker Trail contact with the overlying Permian Cutler Formation is difficult to define from geophysical well logs. The contact is missing over the Salt Valley anticline (cross-section A-A´).

Pennsylvanian Rocks

Honaker Trail Formation (IPh)

About 110 feet (34 m) of the upper part of the Honaker Trail Formation may be seen in the NW 1/4 section 18, T. 25 S., R. 21 E. Yeats (1961) previously mapped this exposure as the Rico Formation. These outcrops consist of gray, lavender, and brown, somewhat nodular-weathering, ledge-forming limestone (60 percent) and red-brown, brown, and yellow-gray, resistant sandstone (40 percent).

Limestone beds are variably argillaceous, contain vugs filled with quartz or calcite, weather hackly, and contain fossil debris. They are mostly thin to medium bedded and resistant. Types of limestone include biomicrite, biosparite, sandy sparite, and micrite (Melton, 1972). Fossils include horn corals, brachiopods, bryozoa, crinoid columnals, various spines and spicules, fusulinids, and rare trilobites. Identified fusulinids date the Honaker Trail Formation in the Merrimac Butte quadrangle as Virgilian (latest Pennsylvanian) in age (Fusulinid Biostratigraphy, Inc., written communication, 1991).

Sandstone beds are fine to coarse grained, micaceous, and subarkosic. A few beds are pebbly. Bedding is thick to massive. In places the beds are divided by thin siltstone or shaly partings. Cross-bedding is locally displayed along the resistant ledges.

The basal contact of the Honaker Trail is not exposed in the quadrangle. The upper contact (Pennsylvanian-Permian boundary) with the overlying Cutler Formation is placed at the top of a light-gray, sandy limestone bed overlain by either a thin, purple siltstone slope capped by a conspicuous white and red-brown, fine-grained sandstone bed, or by just the white and red-brown sandstone. The contact with the Cutler Formation may be a paraconformity.

The Honaker Trail Formation was deposited on a shallow marine shelf and in nearshore environments during latest Desmoinesian through Virgilian time (Melton, 1972; Doelling and others, 1994).

Permian Rocks

Cutler Formation (Pc)

Outcrops of the Permian Cutler Formation in the Merrimac Butte quadrangle are exposed on the southwest side of the Moab fault trace from Moab Canyon to as far north as Corral Canyon. The exposures consist of interbedded red to red-orange, mostly fine-grained subarkosic to quartzose sandstone, and red-purple arkosic, conglomeratic sandstone. The red to red-orange sandstones are generally more resistant than the red-purple sandstones and conglomeratic sandstones. Subarkosic to quartzose sandstone is fine to medium grained, moderately well sorted, generally micaceous, and displays tabular-planar cross-bedding and horizontal bedding. The arkosic sandstones are poorly sorted and are medium to coarse grained. Conglomeratic beds and lenses contain granitic or gneissic pebbles and cobbles, commonly as much as 2 inches (5 cm) in diameter. The arkosic sandstone beds contain abundant visible mica and feldspar grains. Arkosic beds are commonly trough cross-bedded and have cut-and-fill features.

A few siltstone and limestone beds are present in the Cutler, especially in the lower part of the outcrop. Siltstone is generally purple, red, or green, thin bedded, and forms slopes. Limestone is light gray, thin to medium bedded, and forms ledges. Limestone beds commonly contain fossil debris.

Doelling and others (1994) divided the Cutler into informal upper and lower members in the adjacent Gold Bar Canyon quadrangle. Their division was based on the presence of persistent limestone beds in the lower member (Loope and others, 1990). We did not divide the formation in the Merrimac Butte quadrangle, though we noted two limestone beds in Cutler outcrops southwest of the Moab fault, because the beds could not be traced far enough to divide the unit into members. One bed is about 110 feet (34 m) and the other 250 feet (76 m) above the contact with the underlying Honaker Trail Formation. The lower Triassic Moenkopi Formation overlies an angular unconformity at the top of the Cutler. The Cutler is as much as 1,100 feet (335 m) thick in outcrop. It may be as much as 4,000 feet (1,220 m) thick in the subsurface under the northern part of the quadrangle and is absent over the Salt Valley salt-cored anticline (cross-section B-B´, plate 2).

The Cutler Formation in the Moab region consists of intertonguing fluvial redbeds, eolian sandstone, and sparse, shallow marine carbonate beds. These sediments were deposited in a transition zone between alluvial-fan environments along the southwest flank of the ancestral Uncompahgre highland, eolian environments of the time-equivalent Cedar Mesa Sandstone to the southwest, and shallow marine environments to the west-northwest of Moab (Mack, 1977; Campbell, 1980; Stanesco and Campbell, 1989).

Triassic Rocks

Moenkopi Formation (Ŧm)

The Lower Triassic Moenkopi Formation crops out from the southwest wall of Moab Canyon northward nearly to Corral Canyon. It mostly consists of interbedded fine-grained sandstone, siltstone, and mudstone, in contrast to the coarser grained, sandy lithologies of the Cutler Formation. The Moenkopi has an overall red-brown to red-orange color, commonly described as "chocolate" brown (Doelling, 1988).

Moenkopi Formation outcrops in the southern part of the quadrangle, on the southwest flank of Moab Canyon, are crudely divisible into three parts: a lower steep slope, a middle ledge former, and an upper steep slope. These divisions may correspond to Shoemaker and Newman's (1959) Tenderfoot, Ali Baba, and Sewemup Members.

The lower steep slope consists of interbedded medium-"chocolate"-brown silty sandstone, sandy mudstone, fissile siltstone, and shale. Bedding is indistinct, thin, and relatively continuous. Sandstone and siltstone are micaceous and well indurated. Ripple marks are particularly common in the thin-bedded, fine-grained sandstone beds.

The mostly thin beds of the lower steep slope become progressively thicker upsection, forming a gradational boundary with the middle ledge former. The thicker beds form distinct ledges, which dominate the middle ledge former and set it apart from the steep slope former units above and below. Most of the descriptive elements of the lower steep slope are valid for the middle ledge former. The boundary between the middle ledge former and the upper steep slope is more abrupt. Bedding in the upper steep slope is thin to fissile, but generally thinner than in the lower steep slope. Also, the upper steep slope displays a light-"chocolate"-brown rather than a medium-"chocolate"-brown coloration.

The upper contact with the Chinle Formation is an angular unconformity with slight irregular relief. The "chocolate"-brown, thinly bedded Moenkopi is overlain by either a white quartzose conglomeratic sandstone or a mottled variegated mudstone, siltstone, or sandstone of the basal Chinle Formation. Locally the overlying Chinle unit consists of brown, resistant sandstone, pebbly conglomeratic sandstone, or pebble conglomerate.

In outcrop the Moenkopi Formation ranges from 0 to about 340 feet (0-104 m) in thickness. The outcrop southwest of the Moab fault gradually thins northward, and the unit is completely cut out by the unconformity at Corral Canyon where the Chinle Formation rests directly on the Cutler Formation. Finch (1954) measured a section of only 20 feet (6 m) about 1,500 feet (457 m) south of Corral Canyon in section 27, T. 24 S., R. 20 E. The Shell #1 Leggett well, NE 1/4 section 12, T. 24 S., R. 20 E., penetrated 2,500 feet (762 m) of Moenkopi Formation in the rim syncline southwest of Salt Valley.

The Moenkopi Formation is a sequence of redbeds deposited in fluvial, mudflat (tidal?), sabkha, and shallow marine environments (Stewart and others, 1972a; Dubiel, 1994).

Chinle Formation (TRc)

The Upper Triassic Chinle Formation is exposed in the cliff wall southwest of the Moab fault. The exposure is cut off by the Moab fault north of Corral Canyon. The Chinle Formation forms gray-red to red-brown, ledgy slopes covered with rubble below the massive cliff of the Wingate Sandstone. The formation consists mainly of interbedded fluvial sandstone, mudstone, siltstone, and pebble conglomerate. The mudstone and siltstone form slopes separated by continuous to discontinuous ledges and cliffs of sandstone and conglomerate.

Based on stratigraphic relations in the Big Bend quadrangle, Doelling and Ross (1998) divided the Chinle Formation into informal lower and upper members as was done in the Moab area by Baker (1933), Dane (1935), O'Sullivan (1970), Stewart and others (1972b), O'Sullivan and MacLachlan (1975), Blakey and Gubitosa (1983), and Hazel (1991). The two members are separated by an unconformity that appears to be regional in extent. Both members are present in the Merrimac Butte quadrangle, but were not differentiated on the map because the lower member outcrops are thin and discontinuous.

Basal conglomeratic sandstone of the lower member is subarkose and sublitharenite composed of quartz, chert, and feldspar grains. The sandstone is generally poorly sorted and consists of angular to subrounded, medium- to very coarse-grained sand, granules, and pebbles. Locally, the sandstone is moderately sorted and fine to medium grained. Sandstone varies from friable to well indurated. Cementation is mainly calcareous, but is locally siliceous. Coloration is generally gray orange pink to gray pink, but is locally yellow gray, very pale orange, and pale yellow brown. Small-scale trough cross-bedding and cut-and-fill features are common. Locally, lenses of conglomerate containing angular, dark-red-brown siltstone and mudstone clasts scoured from the underlying Moenkopi Formation are present at the base.

Siltstone and mudstone of the lower member are commonly mottled yellow, purple, orange, red brown, gray, and white. Interbedded siltstone and mudstone commonly have an angular blocky to granular appearance. Mineralogical differences between the mottled strata and unaltered rocks are indicative of pedogenic alteration as are local calcareous and chert nodules. Oxidation and reduction of the sediments during rise and fall of the ground-water table during or shortly after deposition of the sediments may have contributed to the mottled coloration (R.F. Dubiel, U.S. Geological Survey, verbal communication, December, 1993). In the Merrimac Butte quadrangle, outcrops of the lower member of the Chinle range from 0 to 65 feet (0-20 m) thick. The lower member is generally missing north of Sevenmile Canyon; it is exposed in a Moab fault slice just south of Utah Highway 313 east of the Union Pacific railroad tracks.

The upper member can be divided on geomorphic appearance into a lower slope-forming unit, a middle ledge-forming unit, an upper slope-forming unit, and, locally, an upper ledge-forming unit. The lower slope-forming unit consists mostly of gray-red and green-gray siltstone, mudstone, and sandstone with thin, discontinuous ledges of sandstone and brown conglomeratic sandstone. Bedding in the slope is characteristically indistinct. Siltstone and mudstone are commonly micaceous and weather fissile to blocky. Quartzose sandstone is fine to medium grained with ripple laminations and small-scale cross-beds. Conglomeratic sandstone is intraclastic, calcareous, and typically forms lenses with scoured bases.

The middle ledge-forming unit consists of brown-gray, green-gray, and red-brown conglomeratic sandstone and sandstone interbedded with red-brown siltstone and mudstone. These strata form thick to massive ledges separated by thin beds that form steep slopes. The unit is a series of fluvial channel sequences that commonly consist of a basal intraclastic conglomeratic sandstone that grades upward through cross-bedded sandstone, siltstone, and mudstone. Pebble conglomerate forms lenses above scour surfaces and contains abundant petrified wood. Fine- to medium-grained sandstone is calcareous and quartzose. Siltstone varies from horizontally laminated and ripple laminated to structureless. Mudstone is calcareous. The uppermost massive conglomeratic sandstone ledge is coated with dark-brown desert varnish and is informally referred to as the Black Ledge (Stewart and others, 1972b).

The upper slope-forming unit consists of alternating and indistinctly bedded, red-brown to gray-red siltstone, mudstone, and sandstone similar to the lower slope-forming unit. Fine- to medium-grained sandstone and conglomeratic sandstone form thin- to medium-bedded ledges that disrupt the slope. Calcareous sandstone is fine to medium grained and includes sparse lenses of coarse grains. These sandstone beds are predominantly sublitharenites, consisting of quartz, chert, carbonate rock fragments, and minor mica. Grains are subangular to subrounded and are moderate to well sorted. Primary sedimentary features include horizontal bedding, small-scale trough cross-bedding, and asymmetrical ripple laminations. Siltstone is muddy, calcareous, indistinctly bedded, and laminated to structureless. Lithic pebble conglomerates contain gray-red to light-gray calcareous siltstone and mudstone fragments, dull-gray carbonate, pale-red-brown chert, and minor quartz. Grains are angular to rounded and range in size from coarse sand to pebbles. Grain sorting is generally poor. Cementation is calcareous and hematitic. Lithic pebble conglomerate is believed to be intraformational because siltstone and mudstone clasts resemble rock types in the Chinle Formation and carbonate clasts may have been derived from pedogenic carbonate. The lithic pebble conglomerates are interpreted to represent the cannibalization of floodplain and lacustrine deposits in the Chinle Formation (Blakey and Gubitosa, 1983).

The upper Chinle contact is placed at the top of a dark-red-brown siltstone in the upper slope-forming unit over which the massive sandstone cliff of the Wingate is present. Locally, the Chinle has an upper ledge-forming unit that overlies the upper slope former. This ledge former consists of thick-bedded to massive, light-brown to red-orange, very fine- to fine-grained sandstone. The sandstone beds are generally horizontally laminated and are interbedded with pale-red to red-brown siltstone and mudstone.

Chinle Formation outcrop thicknesses in the Merrimac Butte quadrangle range from 280 to 400 feet (85-122 m). Finch (1954) measured 297 feet (90 m) of Chinle Formation at the Shinarump No. 1 mine in section 27, T. 24 S., R. 20 E. The Tiger Oil No. 12-11 State well, NW1/4 section 11, T. 24 S., R. 20 E., penetrated 850 feet (259 m) of Chinle Formation in a Salt Valley rim syncline in the north part of the quadrangle. In the Moab area the formation was deposited primarily in alluvial-channel and floodplain environments (Dubiel, 1994).

Jurassic Rocks

Wingate Sandstone (Jw)

The Lower Jurassic Wingate Sandstone generally forms a prominent gray-pink to red-brown smooth cliff near the top of the escarpment southwest of the Moab fault. It is also exposed along the margin of Salt Valley in the northeast corner of the quadrangle. It is the lowermost formation of the Glen Canyon Group (Gregory and Moore, 1931). In places, the Wingate cliff is streaked and stained dark brown or black by desert varnish and is locally horizontally banded.

The formation is a relatively homogeneous unit that consists of gray-orange to gray-orange-pink and moderate-orange-pink to pale-red-brown, very fine- to fine-grained sandstone. Sandstone is quartzose and subarkosic, containing quartz, feldspar, traces of chert, and accessory minerals (Lohman, 1965; Cater 1970). Sand is moderately to well sorted and grains are subangular to rounded, with commonly frosted quartz grains, suggesting eolian transport. Sandstone is calcareous and siliceous and commonly stained with iron-oxide desert varnish. The Wingate is moderately to well indurated.

The Wingate Sandstone generally weathers to a massive cliff. This cliff is less well developed adjacent to salt anticlines where the unit is damaged by fracturing induced by salt dissolution. In such places the unit is generally shattered and ledgy.

The contact with the overlying Kayenta Formation is an irregular sharp surface that locally is erosional with scouring and cut-and-fill features. A cap of lighter sandstone, as much as 10 feet (3 m) thick, is locally found at the top of the Wingate. Nation (1990) and Blakey (1994) interpreted the contact as unconformable and Baker and others (1936) interpreted it as conformable and gradational. A limited extent hiatus seems likely. At outcrops, Kayenta beds are more red or pale purple and lithologically more heterogeneous than Wingate outcrops, and contain fluvial sedimentary features. The Wingate-Kayenta contact can be difficult to identify where the unconformity or lighter beds are not obvious; in this case, the contact is placed where the vertical cliff ends and is replaced by thick ledges.

The Wingate Sandstone is 250 to 400 feet (76-122 m) thick in the Arches National Park area (Doelling, 1981). The thickness range holds true in both surface measurements and in drill holes. A measurement of 286 feet (87 m) was obtained at Little Valley at the south end of the quadrangle. An incomplete section of 305 feet (93 m) was measured on the southwest escarpment of Salt Valley, section 5, T. 24 S., R. 21 E. The Wingate Sandstone in the Merrimac Butte quadrangle is eolian dune and interdune sediments deposited in erg environments that covered this part of the Colorado Plateaus in the Early Jurassic (Blakey and others, 1988; Nation, 1990; Blakey, 1994).

Kayenta Formation (Jk)

The Lower Jurassic Kayenta Formation commonly forms ledgy bare-rock surfaces, mostly in the southwest part of the quadrangle. It is the middle formation of the Glen Canyon Group. In the northeast corner of the quadrangle, the Kayenta dips moderately away from the Salt Valley anticline. The Kayenta consists mostly of fluvial sandstone lenses, with subordinate eolian sandstone, intraformational conglomerate, siltstone, shale, and mudstone. Rare gray limestone beds are locally present. The unit is primarily red, but the color of individual lenses and beds varies considerably; some beds are purple, lavender, red, tan, orange, or white. Most of the sandstone lenses are moderate orange pink and the shale and mudstone beds are dark red brown to gray red. In outcrop the Kayenta is ledge or step-like with thick-bedded lenses of sandstone, between the more massive and cliffy Wingate and Navajo Sandstones. Sandstone in the Kayenta Formation exhibits both high-angle and low-angle cross-bedding. Some lenses display channeling, current-ripple marks, and rare slump features. The grain size is more variable than in the Wingate and Navajo, ranging mostly from fine to medium. Sand grains are mostly quartz, but mica and minor quantities of darker minerals and feldspar have been noted. The cement is generally calcareous, but locally iron oxide or silica are present. Siltstone, shale, and intraformational conglomerate appear as partings or are interlayered with sandstone. These finer grained horizons and intraformational conglomerate beds are rare in the lower part of the formation and increase in abundance and thickness in the upper part.

The contact with the overlying Navajo Sandstone is conformable. The uppermost Kayenta bed is a gray-pink, thick-bedded to massive ledge that commonly is lighter than the beds above and below it. The upper surface of the ledge is sharp and nearly horizontal. The ledge is 10 to 20 feet (3-6 m) thick, and is preferentially cemented, ranging from friable to well indurated.

The Kayenta Formation ranges from 220 to 340 feet (67-104 m) thick in the quadrangle. A measurement of 279 feet (85 m) was obtained in the NW1/4 NW1/4 section 8, T. 25 S., R. 20 E. In the northeast corner of the quadrangle, on the southwest flank of the Salt Valley salt-cored anticline, the Kayenta is also about 280 feet (85 m) thick.

The Kayenta was predominantly deposited in a fluvial system derived from the ancestral Rocky Mountains of eastern Utah and western Colorado (Luttrell, 1987). Eolian strata near the top of the formation indicate a gradual change in climate and depositional environment (Blakey, 1994).

Navajo Sandstone (Jn)

The Navajo Sandstone is exposed mostly in the southwest part of the quadrangle, but an outcrop band is also mapped in the northeast corner. The lower part of the Navajo consists of interbedded sets of flat- and cross-bedded sandstone exposed in a cliff, while the upper part consists of massive beds of large-scale, cross-bedded sandstone that weather to rounded monuments and domes. The exposures are largely bare rock, but hollows are filled with loose sand. The Navajo Sandstone, a classic example of an eolian-deposited unit, is the uppermost formation of the Lower Jurassic Glen Canyon Group.

The Navajo is mostly orange to light-gray, fine-grained, well-sorted, massive sandstone. Partings, where present, occur at the contacts of cross-bed sets, which are as much as 20 feet (6 m) thick. High-angle cross-beds are as much as 30 degrees from the true attitude of the unit. Slight variations in grain size form laminae along the cross-beds. Sandstone cementation is partly calcareous and partly siliceous and is not as uniform as that in the Wingate Sandstone, allowing the cross-beds to be etched in relief in response to weathering. Locally, gray to pink-gray, thin, hard, lenticular limestone beds of lacustrine origin are also found in the unit, and are interpreted to have developed in oases, playas, or interdune lakes (Stokes, 1991). Limestone beds locally contain small nodules of authigenic jasper (red chert). Limestone beds grade laterally into red sandstone or siltstone that form bounding surfaces between large cross-bed sets. The cherty limestones commonly form resistant benches covered with dark sandy or rubbly soil (Qer).

The J-2 unconformity of Pipiringos and O'Sullivan (1978) marks the contact of the Navajo Sandstone with the overlying Dewey Bridge Member of the Entrada Sandstone. In the Merrimac Butte quadrangle the unconformity displays considerable relief, varying to as much as 80 feet (24 m). The lower part of the Dewey Bridge Member fills low areas in the irregularly eroded upper surface of the Navajo. The irregular upper surface of the Navajo is best displayed in Courthouse Pasture, though the contact itself is locally difficult to place. Commonly, both the Navajo and the lower part of the Dewey Bridge are fine-grained sandstone of the same color. Angular white chert is common immediately above the contact in the Dewey Bridge Member.

Paleo-erosion of the upper Navajo is extensive in the quadrangle. The Navajo Sandstone is about 250 feet (76 m) thick between Monitor Butte and the North Fork of Sevenmile Canyon. North of Corral Canyon it is only about 165 feet (50 m) thick. In the northeast corner of the quadrangle, on the southwest flank of the Salt Valley salt-cored anticline, the Navajo is 226 feet (69 m) thick. However, in the subsurface, at the Ladd No. 1, Salt Valley well, NW1/4 section 15, T. 24 S., R. 20 E., the unit is more than 500 feet (152 m) thick. At the Ari-Mex, No. 1-7 Skip Federal, SW1/4 section 7, T. 25 S., R. 21 E., the Navajo is about 800 feet (244 m) thick. And at least 700 feet (213 m) thick in the axial trough of the Kings Bottom syncline along the Colorado River in the Moab 7.5´ quadrangle about 5 miles (8 km) to the southeast (Doelling and others, 1995).

The Navajo Sandstone was deposited in an eolian environment (Peterson and Pipiringos, 1979; Blakey and others, 1988; Blakey, 1994) characterized by dune (cross-bedded sandstone) and interdune (cherty, sandy limestone and horizontally bedded sandstone) deposits.

Entrada Sandstone

The Middle Jurassic Entrada Sandstone of the Merrimac Butte quadrangle consists of three members, in ascending order: the Dewey Bridge, Slick Rock, and Moab Members. The full thickness of the Entrada Sandstone ranges from about 400 to 530 feet (122-162 m). Differences in thickness are due to the paleo-relief on the underlying Navajo Sandstone. Note: In early 2000, Doelling determined that the Dewey Bridge Member should be returned to its original classification as a member of the Carmel Formation, and that the Moab Member should be redefined as a member of the Curtis Formation. These changes are planned for further publications.

Dewey Bridge Member (Jed): Dewey Bridge Member strata were formerly mapped as the Carmel Formation (Dane, 1935; McKnight, 1940), but Wright and others (1962) proposed a change based on lithologic criteria. However, outcrops of the Dewey Bridge are laterally continuous and correlative with the Carmel Formation to the west (Doelling, 1993).

In the Merrimac Butte quadrangle the Dewey Bridge Member can be subdivided into upper and lower parts (not mapped). The lower part of the member is dominated by yellow-gray, planar- (flat-) bedded, fine-grained sandstone. The beds are generally medium to thick and resistant. Angular, white and gray chert fragments are commonly embedded in the sandstone immediately above the lower contact (figure 2). In some areas the lower member is color banded, with pink to red-brown sandstones between the dominantly yellow-gray beds.

The upper part of the member is mostly dark red-brown, muddy, fine-grained sandstone, with irregular, contorted to "lumpy" bedding. One or two horizontally planar, white, well-indurated, fine-grained, calcareous sandstone beds appear at irregular intervals in the upper part. Some of these beds contain angular fragments of white and gray chert that litter the outcrops. Commonly, especially in the Courthouse Pasture area, orange-brown, fine-grained, massive sandstone crops out below the upper contact. This orange-brown sandstone resembles the overlying Slick Rock Member. This fine-grained massive sandstone is locally banded orange-brown and white. Its contact with the "lumpy," dark-red-brown sandstone below is commonly

Figure 2. Sandstone at the base of the Dewey Bridge Member of the Entrada Sandstone. The white fragments embedded in the sandstone are chert. The 8.5 x 11-inch (22 x 28-cm) notebook provides the scale. The photo was taken at the southeast end of Courthouse Rock.

contorted.

The upper contact is placed at the top of a prominent, dark-red-brown siltstone parting, best displayed in the Courthouse Pasture area. Above the parting is the massive, orange-brown, vertical cliff of the Slick Rock Member. The thickness of the Dewey Bridge Member is extremely variable in and near the quadrangle, ranging from 120 to 226 feet (37-69 m) (table 1).

Table 1.
Dewey Bridge Member thickness in and near the Merrimac Butte quadrangle.

Location	Lower Part feet	Upper Part feet	Total thickness feet
Merrimac Butte	84	142	226
Monitor Butte	71	59	130
Mill Canyon	52	94	146
Courthouse Rock	80	138	218
Salt Valley Northeast	(not divided)		121
Klondike Bluffs	77	62	139
Arches Visitor Center	20	84	104
Garden of Eden	15	75	90

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).

Slick Rock Member (Jes): The Slick Rock Member forms nearly vertical cliffs in the Merrimac Butte quadrangle and forms mesas and buttes in the area surrounding Courthouse Pasture (figure 3). It is also exposed in the lower part of Sevenmile Canyon and along the lower part of Courthouse Wash. Additional outcrops, largely buried by self-derived sand, occur in the northeast part of the quadrangle.

The Slick Rock Member is composed of massive, red-orange to brown sandstone. The sandstone is very fine to fine grained with sparse medium to coarse sand grains; it displays distinct high-angle cross-stratification and planar bedding. The sandstone is well indurated with calcareous and iron-oxide cement. Coloration is locally banded.

The upper contact with the Moab Member of the Entra-

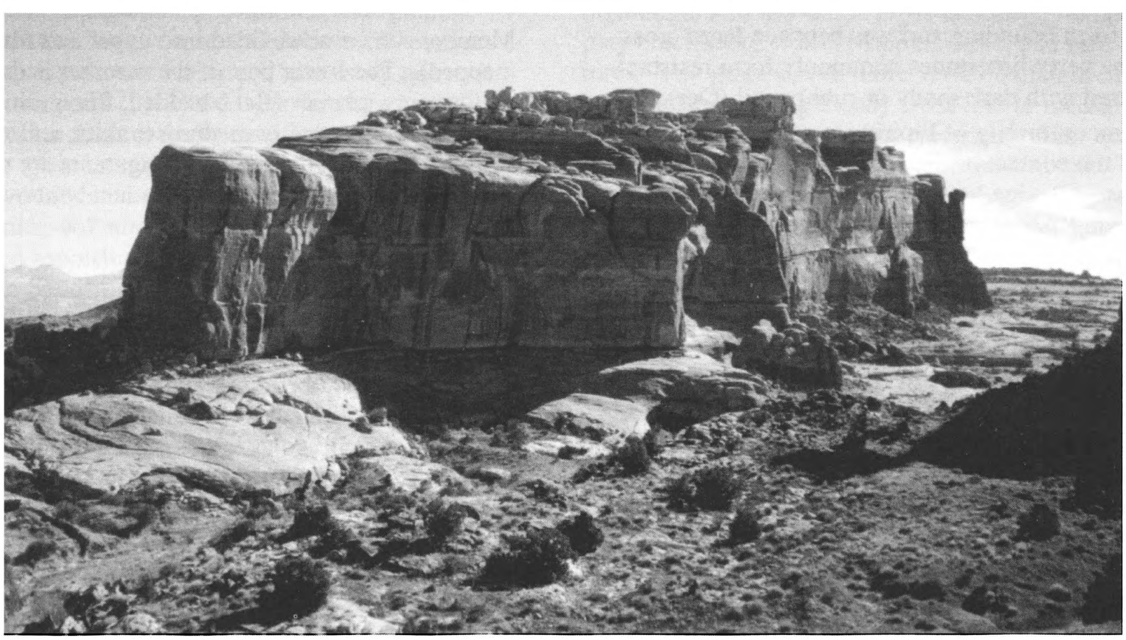

Figure 3. Courthouse Rock, a butte of Entrada Sandstone, as viewed from the northwest. The basal sandstone, below the dark notch, is the Dewey Bridge Member. Most of the vertical cliff is the Slick Rock Member. The uppermost layer is the Moab Member.

da Sandstone is the J-3 unconformity of Pipiringos and O'Sullivan (1978). In the Merrimac Butte quadrangle the contact is found at the top of the massive red-brown sandstone of the Slick Rock and below the mostly white or gray-white sandstone of the Moab Member. In the west part of the quadrangle a recess appears in the cliff a few feet above the base of the white sandstone. In the east part only the color change is manifested, however, the truncation of cross-beds in the Slick Rock is readily apparent. The Slick Rock Member ranges from about 180 to 400 feet (55-122 m) thick in the quadrangle, and about 190 feet (58 m) thick adjacent to Mill Canyon. In the Ari-Mex No. 1-7 Skip Federal well, SW1/4 section 7, T. 25 S., R. 21 E., the Slick Rock Member is 300 feet (91 m) thick. Base map elevation contours of the Slick Rock cliff in the southeast part of the quadrangle indicate that it may be as much as 400 feet (122 m) thick.

The Slick Rock Member was deposited by wind and the rock exhibits high-angle cross-bedding like the Wingate and Navajo Sandstones. The Slick Rock Member forms smooth outcrops similar to the Wingate Sandstone because cross-bed laminae do not etch out well upon weathering as they do in the Navajo Sandstone and Moab Member of the Entrada Sandstone.

Moab Member (Jem): The Moab Member of the Entrada Sandstone is a conspicuous, resistant sandstone that forms the capping surface of the Entrada cliffs in the east part of the quadrangle and at the top of the few buttes and mesas in the west-central part of the quadrangle. The Moab Member correlates with the Curtis Formation of the San Rafael Swell and western Grand County (Doelling, 1993).

The Moab Member is a pale-orange, gray-orange, pale-yellow-brown, or light-gray, fine- to medium-grained, calcareous, massive, cliff-forming sandstone. It generally appears white or gray white above the orange-brown Slick Rock Member. The sandstone is typically well indurated, exhibits low-angle cross-stratification, and is generally highly jointed in outcrop. The sandstone resembles the Navajo in color, cementation, and in the differential etching of cross-bed laminae.

The Moab Member ranges from 70 to 110 feet (21-34 m) thick in the quadrangle. In the west a deep indentation, 15 to 25 feet (4.5-7.5 m) thick, is present a few feet (<1 m) above the base. The indentation exposes thin beds of fine-grained sandstone of varying resistance and alternating gray-white and red-brown color. This indentation is the easternmost representation of the Curtis Formation in the Grand County area. The indentation is too thin to be mapped in the Merrimac Butte quadrangle. No such indentation is present at eastern exposures in the quadrangle. The upper contact is sharp and drawn where the light sandstone of the Moab Member is overlain by the red-brown sandstone of the Summerville Formation. The base of the Summerville commonly consists of a few inches to a foot (5-30 cm) of reworked Moab Member sandstone.

The source of the sand incorporated to form the Moab Member was to the southeast (McKnight, 1940). The environment of deposition for the Moab Member is unclear; the sand was probably deposited in a nearshore continental environment. Dane (1935) suggested possible subaqueous deposition, but McKnight (1940) indicated that only the west edge of the Moab Member was deposited under subaqueous conditions and the remainder of the unit was deposited under continental conditions.

Summerville Formation and Tidwell Member of the Morrison Formation, undifferentiated (Jsmt)

The Summerville Formation and Tidwell Member of the Morrison Formation appear as one unit on the geologic map (plate 1). They are too thin to map separately at the 1:24,000 scale, but are easily divisible in the field. The combined unit forms a prominent reddish outcrop band between the Moab Member of the Entrada Sandstone and the Salt Wash Member of the Morrison Formation (figure 4) that extends from north to south in the east half of the quadrangle. Other outcrops are found near Courthouse Spring and in the Moab splay fault zone.

The Middle Jurassic Summerville consists of thin- to medium-bedded, light-tan to brown, ledgy sandstone and slope-forming red, sandy siltstone that form a steep slope capped by a prominent thin- to medium-bedded blocky to platy sandstone ledge. Several thin ledges of sandstone are fine to medium grained, well sorted, and quartzose. A reworked zone of yellow-gray sandstone generally marks the base. Locally, dinosaur footprints can be identified in the reworked zone. The upper ledge of sandstone is commonly ripple marked.

The upper contact of the Summerville Formation is the J-5 unconformity (Pipiringos and O'Sullivan, 1978; O'Sullivan and Pipiringos, 1983; O'Sullivan, 1984). It is placed at the base of thin, gray limestone beds or maroon to lavender siltstone of the Tidwell Member. The thickness of the Summerville ranges from 6 to 28 feet (2-8.5 m) in the quadrangle, thinning southward. McKnight (1940) interpreted the Summerville as delta deposits marginal to a shallow sea which lay to the west.

Most of the Tidwell Member consists of siltstone weathering red, maroon, lavender, or light-gray. Discontinuous beds of light-gray limestone are interspersed throughout the siltstone, but are more common at the base and top of the unit. In several places in the Merrimac Butte quadrangle, large, mostly white chert concretions are found immediately above the lowermost limestone bed. Some of these concretions are as much as 6 feet (2 m) in diameter and a few contain irregular red and brown patches of jasper.

The upper contact of the Tidwell Member with the Salt Wash Member of the Morrison Formation is gradational and locally intertonguing. We placed the contact below the first significant thick, light-gray, yellow-gray, or light-brown sandstone lens or bed of the Salt Wash Member. The Tidwell is 25 to 50 feet (7.6-15 m) thick in the Merrimac Butte quadrangle. The Tidwell was probably deposited in a nearly flat area as fluvial overbank deposits and in lakes.

Morrison Formation

The Upper Jurassic Morrison Formation is divided into three members in southern Grand County. They are, in

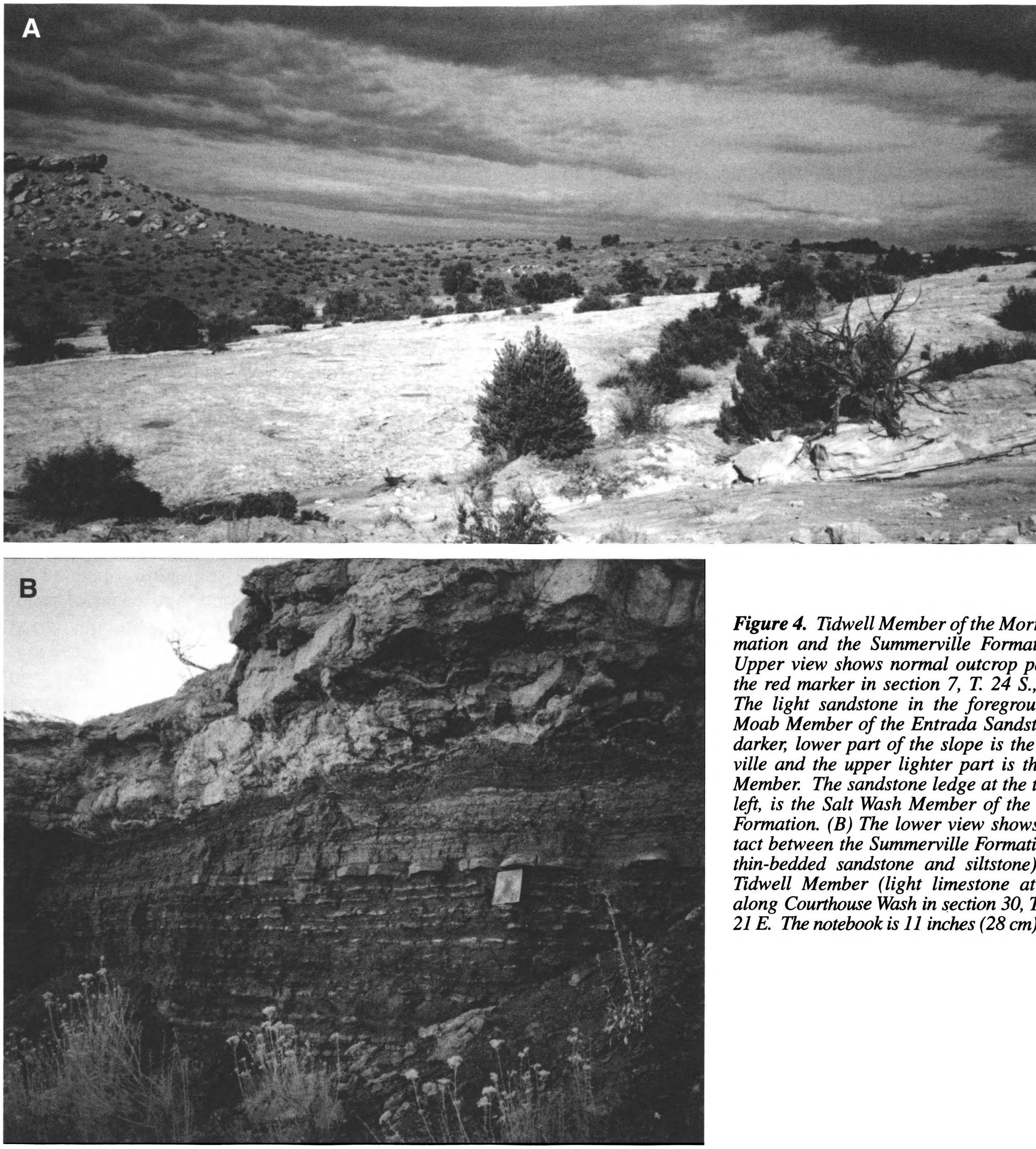

Figure 4. Tidwell Member of the Morrison Formation and the Summerville Formation. (A) Upper view shows normal outcrop pattern for the red marker in section 7, T. 24 S., R. 21 E. The light sandstone in the foreground is the Moab Member of the Entrada Sandstone. The darker, lower part of the slope is the Summerville and the upper lighter part is the Tidwell Member. The sandstone ledge at the top, to the left, is the Salt Wash Member of the Morrison Formation. (B) The lower view shows the contact between the Summerville Formation (lower thin-bedded sandstone and siltstone) and the Tidwell Member (light limestone at the top) along Courthouse Wash in section 30, T. 24 S., R. 21 E. The notebook is 11 inches (28 cm) in height.

ascending order, the Tidwell Member, Salt Wash Member, and Brushy Basin Member. In the Merrimac Butte quadrangle the combined thickness probably ranges from 550 to 650 feet (168-198 m). The Upper Jurassic Morrison Formation was deposited in fluvial and related lacustrine environments (Dane, 1935). The Tidwell Member was discussed in previous paragraphs.

Salt Wash Member (Jms): The Salt Wash Member consists of interbedded and interlensed, ledge-forming sandstone and slope-forming mudstone. The unit forms benches and cliffs exposed in a wide outcrop band in T. 24 S. and makes up the rocks immediately east of the Moab fault in the south half of the quadrangle.

The Salt Wash Member is composed of 25 to 40 percent gray and brown sandstone lenses alternating with 60 to 75 percent red and green mudstone. Thickness of sandstone lenses generally increases upsection with a corresponding decrease in the mudstone intervals. Typically, there are six or seven thick, vertically stacked sandstone lenses in the Salt Wash Member.

Quartzose sandstone in the Salt Wash is cross-bedded, fine to coarse grained, moderately to poorly sorted, and calcareous. The well-indurated sandstone forms resistant ledges that are generally light gray, yellow gray, or light brown, but weather to various shades of brown. Lens thickness ranges to 20 feet (6 m), but most are 2 to 4 feet (0.6-

1.2 m) thick. The mudstone intervals consist of red, green-gray, maroon, and lavender siltstone and fine-grained, clayey sandstone. Thin limestone beds and nodules are locally present in the Salt Wash Member mudstones.

The upper contact of the Salt Wash Member is at the top of an interval dominated by light-gray sandstone lenses and below dark-colored conglomeratic sandstone lenses and brightly banded mudstone of the Brushy Basin Member. Salt Wash sandstone is quartzose whereas Brushy Basin sandstone is commonly more lithic, gritty, and conglomeratic. Salt Wash mudstone is predominantly red whereas Brushy Basin mudstone is variegated maroon, orange, green, gray, and lavender. Sand is more common in Brushy Basin mudstone than in Salt Wash mudstone. The Salt Wash Member ranges from 140 to 250 feet (43-76 m) thick in the Merrimac Butte quadrangle.

Brushy Basin Member (Jmb): The Brushy Basin Member of the Morrison Formation is predominantly silty and clayey mudstone and muddy sandstone interbedded with a few local conglomeratic sandstone lenses. The steep-sloped outcrops are banded in various shades of maroon, green, gray, and lavender. Most of the rock is indistinctly bedded, and has a high clay content as is evident from "popcorn"-weathered surfaces. Many of the mudstone beds are probably decomposed volcanic tuff beds. The sandstone is commonly cross-bedded, coarse grained to gritty, and has local pebblestone and conglomerate lenses. The sandstones locally form ledges, and less commonly cliffs. About 75 percent of the unit is mudstone. The sandstones and conglomerates are generally found near the base of the unit. Because of the clay content, the Brushy Basin Member is prone to landsliding and outcrops are generally replete with slumps. Dinosaur bone and petrified wood are found locally in the member.

The upper contact is an unconformity at the base of a persistent cliff-forming sandstone of the Cedar Mountain Formation that is 10 to 30 feet (3-9 m) thick (Molenaar and Cobban, 1991). West of the quadrangle, near Green River and in the Henry Mountains region, the Buckhorn Conglomerate Member of the Cedar Mountain Formation rests unconformably upon the Brushy Basin Member (Trimble and Doelling, 1978; Peterson and others, 1980). Stokes (1950a, 1950b, 1952), who named the Buckhorn (Stokes 1944), suggested the hiatus is not great.

The unit is about 350 to 400 feet (107-122 m) thick in the Merrimac Butte quadrangle. Yeats (1961) measured 385 feet (117 m) of Brushy Basin north of Courthouse Wash.

Cretaceous Rocks

Cedar Mountain Formation (Kcm)

The Lower Cretaceous Cedar Mountain Formation is exposed in the northwest quadrant of the Merrimac Butte quadrangle where it forms a cap on the steep slopes of the Brushy Basin Member of the Morrison Formation. The Cedar Mountain consists of a lower cliff-forming sandstone and a slope-forming silty mudstone containing lenses of sandstone. The unit is similar to the Brushy Basin Member of the Morrison Formation, but a dull green coloration dominates the silty mudstone. The lower sandstone unit is mostly light to dark brown, weathering to a darker hue. The grain size may be fine, medium, coarse, gritty, or conglomeratic. The mudstone is silty and contains sandstone intervals. Locally, nodular gray limestone is present with sporadic chert nodules. Locally, the Cedar Mountain contains chalcedony fragments and petrified wood.

The upper boundary is an unconformity. The contact is placed at the base of a white claystone of the Dakota Formation. The unconformity represents a hiatus of about 4 million years (Molenaar and Cobban, 1991). The thickness of the Cedar Mountain Formation ranges from 120 to 200 feet (37-61 m) on the quadrangle. Yeats (1961) measured a section of 187 feet (57 m) northeast of Corral Canyon.

Dakota Formation (Kd)

The Dakota Formation is exposed along the trough of the Courthouse syncline in the northwest corner of the quadrangle. It is divided into five units, in ascending order: white siliceous claystone and limestone, carbonaceous shale, yellow-gray conglomeratic sandstone, gray slope-forming shale, and yellow-brown and yellow-gray sandstone.

The white siliceous claystone and limestone forms a steep white slope, is laminated, and is thin to medium bedded. It breaks into blocky chunks. This unit may not be present at the southernmost Dakota Formation exposure in the quadrangle. The carbonaceous shale forms a continuous slope with the unit below, and is locally clayey and coaly. The yellow-gray sandstone is fine to medium grained, forms ledges, and locally contains conglomerate. It is calcareous, cross-bedded, and forms thick lenses. Pebbles and cobbles are rounded and smooth and range to as much as 2 inches (5 cm) in diameter. The clasts consist of gray, white, or black chert, dense sandstone, and quartzite. The gray slope-forming shale contains a few dark horizons that are carbonaceous. Yellow-brown and yellow-gray sandstone at the top is commonly stained with desert varnish, forms a ledge, and is mostly fine grained.

The upper contact of the Dakota Formation with the Mancos Shale is not observable in the Merrimac Butte quadrangle because of Quaternary cover. The formation is at least 87 feet (27 m) thick in the NE $1/4$ section 8, T. 24 S., R. 20 E. The white siliceous claystone is about 17 feet (5 m) thick, the carbonaceous shale is about 9 feet (3 m) thick, the conglomeratic sandstone is about 20 feet (6 m) thick, the gray shale is 31 feet (9.5 m) thick, and the yellow-brown sandstone at the top is about 10 feet (3 m) thick. The Dakota Formation represents the last terrestrial deposition prior to the transgression of the Mancos Sea (Young, 1960; Fouch and others, 1983; Molenaar and Cobban, 1991). The coaly and carbonaceous deposits suggest deposition in lagoons.

Mancos Shale (Tununk Shale Member) (Kmt)

The youngest bedrock unit in the quadrangle is the Mancos Shale. A small poorly exposed outcrop is present in the northwest corner of the quadrangle. The Mancos Shale in the Merrimac Butte quadrangle is assigned to the Tununk Shale Member. The Tununk consists mostly of light- to dark-gray marine shale and silty shale that weathers pale yellowish brown. It also contains a few thin, fine-grained sandstone beds. Most Tununk bedding is thinly laminated. Perhaps 50 feet (15 m) of the unit are exposed.

Quaternary Deposits

Alluvial Deposits

Modern alluvium (Qal): Modern alluvium is mapped along Courthouse Wash and Sevenmile Canyon. The streams that deposited the alluvium are dry most of the time (ephemeral). They carry flash floods when heavy summer thunderstorms drench the upper drainage basins. The compositions of the deposits reflect the geology of the local source areas and are dominated by sand, silt, and clay, with local lenses of pebble-sized sandstone, chert, and quartzite gravel. The Merrimac Butte quadrangle, as well as the Colorado Plateau in general, is an area primarily undergoing erosion. Therefore, the deposits are relatively thin and temporary in nature. Locally streams fill the washes and flow over hard bedrock thresholds, allowing temporary deposits to accumulate behind them. The maximum thickness is estimated at 15 feet (4.6 m) in the Merrimac Butte quadrangle. The deposits are Holocene in age.

Older alluvium (Qa): Older alluvial deposits, for the most part, are like modern alluvium in composition. Some mapped exposures of older alluvium include deposits of modern alluvium, alluvial fans, and colluvium too small to map separately. Deposits flank the modern alluvium along Courthouse Wash and along the wash in Sevenmile Canyon and occur at several levels as terraces. However, many of these terraces are poorly developed because coarse gravels are not present. The older alluvium also fills tributary wash channels.

The older alluvium is commonly not more than 25 feet (7.6 m) thick. However, deposits are locally as much as 60 feet (18 m) thick (figures 5 and 6). Relatively thick outcrops are found south or upstream of the Moab splay faults in Mill Canyon, mostly in the SW1/4 section 20, T. 24 S., R. 20 E. (figure 5), and upstream or north of the sharp bend in Courthouse Wash, NW1/4 SW1/4 section 30, T. 24 S., R. 21 E. In both areas a free face of thick older alluvium stands nearly vertical, where the modern wash is eroding it. The alluvium is finely laminated to thin bedded, but unconsoli-

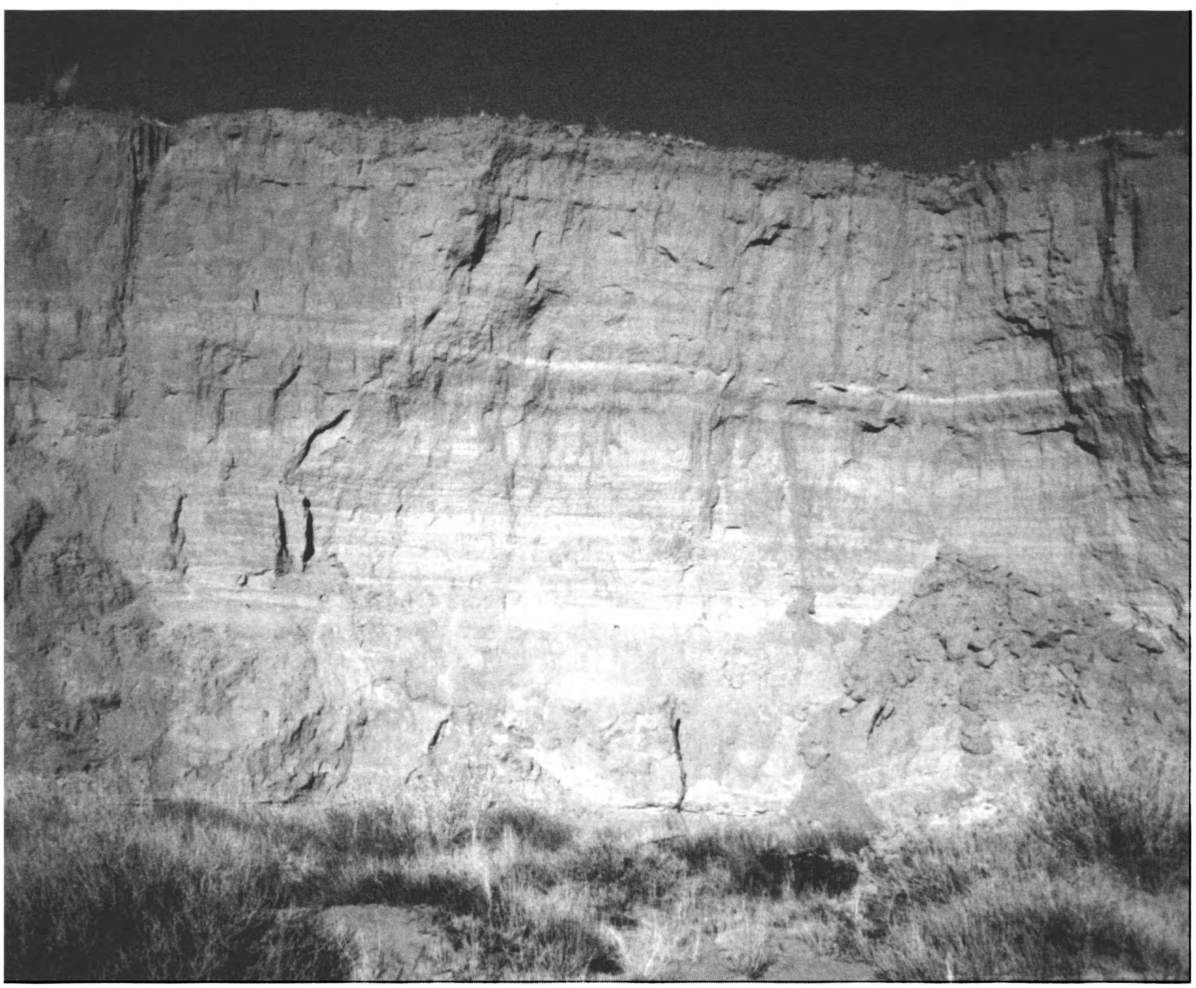

Figure 5. Thick older alluvium (Qa) in Mill Canyon, section 20, T. 24 S., R. 20 E. The branch standing vertically at the base of the exposure is 9 feet (2.7 m) tall. The exposure is about 60 feet (18 m) high. Fresh-water snails were found about 9 feet (2.7 m) above the base. The dark horizon one-third of the way from the top contains a matte of carbonized root debris and overlies vertical root casts (figure 6).

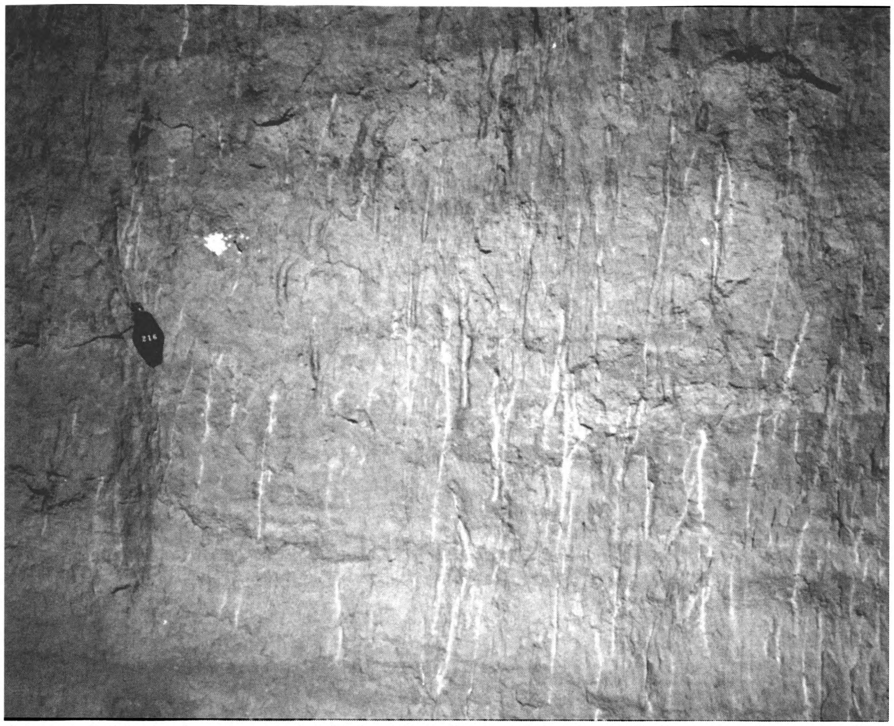

Figure 6. *Vertical root casts in thick older alluvium (Qa) in Mill Canyon. Key tag at left for scale. These roots extend 10 feet (3 m) or more below the matte of carbonized root debris shown in figure 5.*

dated. Locally, small snails occurring along some of the laminae suggest lacustrine or pond environments. In some places the alluvium fills deep channels cut into the surrounding bedrock.

At the Mill Canyon exposure a sample of organic matter was obtained from the middle of the 60-foot (18-m) section and submitted for a radiocarbon date. The test indicated a radiocarbon age of 12,125 ± 1,060 yr B.P. (carbon 13 corrected) for the sample (Geochron Laboratories, May 1996). The deposits are late Pleistocene to early Holocene in age.

Alluvial-fan deposits (Qaf): Gently sloping alluvial fans extend from the foot of the escarpment southwest of the Moab fault. Fan surfaces receive little new material but are not being rapidly eroded. The deposits consist of generally unstratified sand, silt, and pebble-sized sandstone gravel. Boulders are locally common in the proximal (near-cliff) areas of the fans. The distal ends (lower parts) of these fans are shallowly incised by small washes. Locally, these deposits may be as much as 30 feet (9 m) thick. The deposits are probably late Pleistocene to Holocene in age.

Alluvial-terrace deposits (Qat): Gravelly terrace deposits are rare in the Merrimac Butte quadrangle. Most are too small to map. At the south end of section 6, T. 24 S., R. 21 E., terrace gravels cap old slumps (concealed) resting on the Slick Rock Member of the Entrada Sandstone. The gravels are poorly sorted and the material ranges in size from coarse sand to large cobbles. The largest component is 1 to 2 inches (2.5-5 cm) in size. Clasts are in a matrix of poorly sorted sand, silt, and grit and consist mostly of smooth-weathered, subrounded to subangular, black or gray chert and quartzite. Large angular fragments and cobbles of ivory-colored chert containing numerous fresh-water snails, and shellfish are also present. Oviatt (1988) noted that these deposits have been found on both the rim and floor of Salt Valley and show that a drainage system was superimposed across the Salt Valley anticline prior to its collapse. John H. Hanley, U.S. Geological Survey, identified several fossil assemblages in the fossiliferous chert that are reported in Oviatt (1988). He dated them as Eocene, perhaps derived from a now-eroded part of the Green River Formation.

Dyer (1983) regarded the Eocene clast-bearing deposits as late Tertiary in age. Collapsed salt anticlines extant today are related to the uplift of the Colorado Plateau which began in late Tertiary time. However, the gravels overlie slump and slide material derived from erosion of the Morrison and Cedar Mountain Formations, indicating that Colorado Plateau erosion and salt-anticline collapse were well underway. Therefore we believe the deposits to be no older than early Pleistocene in age. Morrison and Cedar Mountain Formation bedrock outcrops now lie 1 to 2 miles (1.6-3.2 km) to the west. The alluvial-terrace deposits are as much as 10 feet (3 m) thick.

Eolian-Sand Deposits (Qes)

Wind-blown sand deposits fill bedrock hollows and topographically low areas and are locally found on the lee (northeast) sides of ledges, cliffs, and small escarpments. They are prevalent on sandstone deposits such as the Navajo, Slick Rock Member of the Entrada Sandstone, and Salt Wash Member of the Morrison Formation. Sand from the latter commonly drapes over the Tidwell Member of the Morrison.

The sand grains are quartzose, fine to medium grained, mostly well sorted, and subrounded to rounded. The deposits occur as thin, discontinuous sheets and dunes and are partially mobile. Locally, they cover older, mixed eolian and alluvial deposits, especially on the higher benches. The maximum thickness is estimated to be about 20 feet (6 m) on the quadrangle. The eolian sand is Holocene in age.

Mass-Movement Deposits

Talus and colluvium (Qmt): Talus and colluvium fringe cliffs and fill steep short canyons as cones and sheets. These deposits are more common than shown on the map; only the more prominent deposits were mapped. They include rock-fall deposits, small slump blocks, creep deposits, slope wash, and the colluvium that develops by weathering and gravity movement along steep slopes. They commonly grade downslope into alluvial-fan deposits or mixed alluvial and colluvial deposits.

Talus and colluvium consist of poorly sorted, angular boulders, cobbles, and smaller rock fragments in a matrix of sand, silt, and clay. Most deposits are structureless. Deposits range from a thin veneer to 15 feet (4.6 m) thick. Talus and colluvium deposits are probably late Pleistocene to Holocene in age.

Landslide and slump deposits (Qms): Landslides and slumps are common on the steep slopes of the Brushy Basin Member of the Morrison Formation. They consist of rotated coherent blocks and deposits where bedrock is completely shattered or obliterated. Some coherent blocks are as much as 100 feet (30 m) across. Slip planes generally occur along the more clayey horizons in the Brushy Basin Member. The hard basal quartzitic sandstone and conglomeratic sandstone of the overlying Cedar Mountain Formation forms part of the debris. Long, open cracks commonly parallel the edges of the cliff formed by the basal Cedar Mountain Formation.

Smaller slide blocks are in the sandy area (Qes) underlain by the Slick Rock Member of the Entrada Sandstone in the northeast corner of the quadrangle. The Salt Wash and Brushy Basin Members of the Morrison Formation and Cedar Mountain Formation make up the materials in these slumps and slides. The more coherent blocks have the younger source formation on their northeast ends, indicating a southwest source. These blocks lie 1 to 2 miles (1.6-3.2 km) east of the present Brushy Basin-Cedar Mountain bluffs and may be preserved in a very shallow syncline presumably formed by subsurface dissolution of salt in the Salt Valley anticline. They are undoubtedly much older than landslide masses resting at the foot of the present Brushy Basin slope. They are presumed to be early Pleistocene in age. The larger blocks along the present cliff are presumed to be mostly late Pleistocene to early Holocene in age.

Mixed Depositional Environment Deposits

Mixed eolian and alluvial deposits (Qea): These deposits mainly consist of fine- to medium-grained sand mixed with silt and sparse lenses of coarse-grained sand, granules, and pebbles. Deposits are somewhat packed and are locally stratified. Eolian horizons commonly alternate with the alluvial. Weak soil development is observable on the tops of some of the Qea deposits. They are commonly slightly darker in color than overlying eolian sand deposits (Qes). The maximum observable thickness is about 20 feet (6 m). The age of the eolian-alluvial deposits in the Merrimac Butte quadrangle is late Pleistocene to early Holocene.

Mixed alluvial and colluvial deposits (Qac): Mixed alluvium and colluvium form gentle to moderate slopes below talus deposits where cliffs have receded significantly from the Moab fault. Locally the alluvium and colluvium fill short narrow canyons. Deposits are poorly sorted, crudely stratified, angular blocks, cobbles, and pebbles in a matrix of red-brown sand, silt, and clay; and vary from clast supported to matrix supported. Clasts are locally derived from the Cutler Formation, Triassic rocks, and the Glen Canyon Group. The deposits are a mixture of sheetwash, debris-flow, rock-fall, and soil-creep materials, as well as alluvium. Mixed alluvium and colluvium grade upward into talus deposits. Deposits are probably less than 30 feet (9 m) thick and are late Pleistocene to Holocene in age.

Mixed eolian and residual deposits (Qer): Thin, sheet-like deposits of windblown fines mixed with weathered bedrock are mapped on the Tidwell Member of the Morrison Formation and are present on small areas of limestone in the Navajo Sandstone. The deposits consist of sand, silt, and angular limestone fragments derived from the underlying bedrock unit. Deposits are yellow, tan, and red orange, dependent on the color of the source materials. Weak petrocalcic soils have developed on some of the deposits. Deposits are mostly less than 3 feet (1 m) thick. The eolian-residual deposits are late Pleistocene to early Holocene in age.

Fill and Disturbed Material (Qf)

Cut-and-fill activities associated with highway and railroad construction have disturbed bedrock and unconsolidated deposits. We mapped only the largest areas. Deep cuts were locally incised to maintain necessary shallow grades, especially along the railroad. We mapped the extracted rock heaped parallel to one of the deepest cuts at the north end of Moab Canyon. We also mapped some of the larger mine dumps between Sevenmile and Corral Canyons.

STRUCTURAL GEOLOGY

Rocks of southern Grand County, including the Merrimac Butte quadrangle, dip gently northward toward the Uinta Basin. However, a strong northwest-trending array of structural features is superimposed on the regional trend. These features include faults, folds, salt diapirs, and joints.

The geologic history of the structures in the Paradox basin (which includes the Merrimac Butte quadrangle) has been postulated and summarized by many authors (Baker, 1933; Dane, 1935; McKnight, 1940; Stokes, 1948; Shoemaker and others, 1958; Cater, 1970, 1972; Doelling, 1988). In summary, salt was deposited in the Paradox basin in Middle Pennsylvanian time and salt moved (flowed) in response to loading and intermittent movement of basement faults mostly from Middle Pennsylvanian to Jurassic time. The shifting of salt greatly affected the thicknesses of units being deposited during those times. All of the bedrock formations in the quadrangle were later folded, faulted, and jointed by post-depositional events generally constrained to the Tertiary Period. Our studies were too general to better constrain the timing of these events. However, Guscott and others (1996) presented evidence that indicates the faulting may be early Tertiary in age.

Faults

Moab Fault

The most prominent structural feature of the quadrangle is the Moab fault. It is a northwest-southeast-trending normal fault with the downthrown block to the northeast. Stratigraphic offset is at least 3,500 feet (1,067 m) near Moab Canyon, in the NW1/4 section 18, T. 25 S., R. 21 E. Here, the upper part of the Honaker Trail Formation is juxtaposed against the Salt Wash Member of the Morrison Formation (plate 1). Northward the stratigraphic offset diminishes. Near Slickensides Arch the Dewey Bridge Member of the Entrada Sandstone is juxtaposed against the Cedar Mountain Formation, indicating a stratigraphic offset of about 1,200 feet (366 m). Along cross-section A-A' (plates 1 and 2) the vertical displacement is less than 200 feet (61 m), indicating that much of the displacement is transferred to the east-west-trending Moab splay faults which abut the main fault at Slickensides Arch.

The strike of the Moab fault averages N. 40° W., but locally bends so that the strike ranges from about N. 15° to 80° W. The fault dips northeast, mostly between 50° and 65°. Slickensides indicate movement was primarily vertical, but rakes locally reach 20° SE. Thick slices of rock are locally found within the fault zone. Two thick slices of the Moab Member of the Entrada Sandstone are observable on the east side of Moab Canyon in the southeast part of the quadrangle. A thick slice of the lower Chinle Formation is exposed at the sharp bend in the fault near the Union Pacific Railroad crossing in Sevenmile Canyon. Locally, gouge can be as much as 25 feet (7.6 m) thick. Small-displacement splays are common along the length of the fault zone and die out a short distance from the main fault. In many places, drag is evident, especially in easily deformed units in the hanging wall.

Moab Splay Faults

Several arcuate faults related to the Moab fault abut the main fault in the vicinity of Slickensides Arch. These normal faults are mostly downthrown to the north and trend nearly east-west along the west margin of the Merrimac Butte quadrangle. West of the quadrangle they bend to the northwest (Doelling, 1993). Most of the faults dip 50° to 80° northward, but at least one is downthrown to the south and dips southward. Exposed slickenlines are nearly vertical (figure 7).

The total offset across the Moab splay faults in the Merrimac Butte quadrangle is about 400 feet (122 m). The northernmost fault has the greatest displacement. It widens to a thick zone from Courthouse to Mill Canyon. In the zone the rocks are steeply tilted to the north, the dips locally paralleling the fault planes. Units identified in this slice include the Moab Member of the Entrada Sandstone, Summerville Formation, and the Tidwell and Salt Wash Members of the Morrison Formation.

Other Faults

Several faults are parallel or subparallel to the Moab anticline and Moab fault in the southeast corner of the quadrangle. Most of these faults have displacements of less than 25 feet (7.2 m), and are related to the joints displayed in the Entrada Sandstone. The joints display a conjugate

Figure 7. *Slickenside exposure along one of the Moab splay faults, near abandoned copper workings on the east side of Mill Canyon, section 20, T. 24 S., R. 20 E. Movement on the high-angle faults was mainly vertical.*

pattern at depth and, where offset, fault blocks are displaced downward on the northeast and southwest sides of faults. Slickenlines are vertical. Most of these faults have been mapped on the southwest flank of the anticline because offset is most noticeable along the contact of the Moab Member and red marker of the Summerville-Tidwell Member map unit. Some of the joints on the northeast flank, only displayed in the Moab Member of the Entrada Sandstone, may be displaced as well. Cruikshank (1993) has noted minor strike-slip movement on some of the joint faults in the area; right-lateral offset on joints trending N. 30° E. and left-lateral offset on joints trending N. 60° E.

Another fault, down to the east, trends approximately north in sections 18 and 19, T. 24 S., R. 21 E. It may also be related to movement along joint planes in the underlying Moab Member. The maximum displacement is about 70 feet (20 m).

Folds

Courthouse Syncline

The Courthouse syncline is a broad fold with an axis parallel to Courthouse Wash, extending from the southeast to the northwest corner of the quadrangle. The axial trace trends N. 15° to 50° W., but averages N. 45° W. It plunges gently to the north. Dips on either flank are gentle, mostly under 5 degrees. The axis of the syncline, at least in the north half of the quadrangle, dies out at the depth of the Triassic Chinle Formation. At that depth a subsurface trough to the east (rim syncline associated with the Salt Valley salt-cored anticline) replaces it (cross-section A-A´, plates 1 and 2).

Moab Anticline

The Moab anticline is subparallel to and is on the east side of the Moab fault as far north as Sevenmile Canyon. It plunges gently northward and is a broad, gentle fold (cross-section B-B´). The Moab anticline is probably underlain by thick salt in the Pennsylvanian Paradox Formation.

Moab Fault Syncline

The Moab fault syncline parallels the Moab fault on the hanging-wall side in the southern third of the quadrangle. The axial trace of the syncline lies 400 to 500 feet (122-152 m) northeast of the fault. Dips are locally steep, approaching 50 degrees, especially where short drainages cross the fault, suggesting salt dissolution as the cause of the structure. Dips on the northeast flank are generally steeper. The syncline has a V-shape where the old highway crosses the fault in the NW1/4 section 18, T. 25 S., R. 21 E.

Kings Bottom Syncline

The Kings Bottom syncline terminates in the southwest corner of the quadrangle. The syncline plunges southeastward toward the Colorado River. In this quadrangle it is very broad and scarcely noticeable. It is better defined to the south in the Gold Bar Canyon and Moab quadrangles (Doelling and others, 1994, 1995).

Salt Valley Salt-Cored Anticline

The Salt Valley salt-cored anticline impinges on the northeast corner of the quadrangle (plates 1 and 2, cross-section A-A'). Wells drilled into the southwest flank indicate the absence of salt in the Paradox Formation in this part of the quadrangle. A deep rim syncline filled with more than 9,000 feet (2,743 m) of Upper Pennsylvanian through Upper Triassic rocks is present in the subsurface (cross-section A-A´). We believe the salt-cored anticline is at least 11,500 feet (3,500 m) tall in the northeast corner of the quadrangle and interpret the wall of the diapir to be steep.

Joints

Joints are common in the brittle rocks of the Merrimac Butte quadrangle and are especially well displayed in the Moab Member of the Entrada Sandstone (Dyer, 1983). The joint network on the southwest limb of the Salt Valley salt-cored anticline is composed of several overlapping domains of differently oriented joints (Cruikshank and Aydin, 1993).

ECONOMIC GEOLOGY

Potash, Halite, and Magnesium

Hite (1960) recognized 29 cycles of salt deposition in the Paradox Formation in the Delhi-Taylor No. 2 well, section 18, T. 25 S., R. 21 E., in the Merrimac Butte quadrangle. In this well the interval between the top of the first halite section and the base of the last is about 7,000 feet (2,134 m). About 78.5 percent of this interval is salt. Hite (1961) indicated that ten of the salt intervals locally contained commercial grades and quantities of potash and eight others contained weakly mineralized intervals. Salt in cycle 5 is currently solution-mined for potash and halite at the Moab Salt Company mine at Potash in the Gold Bar Canyon quadrangle 6 miles (10 km) south of the Merrimac Butte quadrangle. Other salt cycles contain carnallite, a potential source of magnesium. Ritzma (1969) indicated that the three lower cycles were local in nature. The intervals between the salt cycles are known as marker beds and consist mostly of black shale and anhydrite.

The Delhi-Taylor No. 2 well penetrated the thickest interval of salt of the four wells that were drilled through the Paradox Formation in the quadrangle. The Chandler No. 16-9 Federal well, SE1/4 SE1/4 section 9, T. 25 S., R. 20 E., passed through 4,958 feet (1,511 m); the Ladd Petroleum No. 1 Salt Valley well, NE1/4 NW1/4, section 16, T. 24 S., R. 20 E., passed through only 1,686 feet (514 m); and the Tiger Oil No. 12-11 State well, SW1/4 NW1/4 section 11, T. 24 S., R. 20 E., drilled through the Paradox Formation, but encountered no salt. Salt is thick west of the Moab fault and in the southern part of the quadrangle (cross-section B-B´, plates 1 and 2). Salt is thin or missing to the north (cross-section A-A´, plates 1 and 2).

The most common minerals found in the salt beds of the Paradox Formation are halite, carnallite, and sylvite (Ritzma, 1969). Carnallite ($KCl.MgCl_2.6H_2O$) is the most abundant after halite and contains 28.3 percent chlorine, 14.1 percent potassium (equivalent to 16.9 percent K_2O), 8.7 percent magnesium, and 39 percent water. Because of its low potash content, carnallite is presently not considered commercial, but it remains a potentially valuable source of magnesium. Sylvite (KCl) is the commercial potash mineral composed of 52.4 percent potassium (equivalent to 63.1 percent K_2O) and 47.6 percent chlorine.

Potential potash sources in the Merrimac Butte quadrangle are in salt cycles 5, 6, 9, 13, 16, 18, and 19. A brine-bearing marker bed between salt 15 and 16 is also of interest. At Potash the mined horizon in salt 5 is a mixture of sylvite and halite known in the industry as sylvinite (Gwynn, 1984). Variations in grade occur vertically and laterally. The sylvinite in the more interesting salt cycles underlying the Merrimac Butte quadrangle is expected to contain 20 to 35 equivalent percent K_2O.

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

Less is known about the deeper potash-bearing zones. Sylvite in salt 13 may be very thick, but contains considerable insoluble material and carnallite (Hite, 1960). Sylvite in salt 16 is thought to be similar in quality and thickness to that in salt 5. The potash zones at the tops of salts 18 and 19 are identified as sylvite-carnallite zones. These zones may be as thick as 100 feet (30 m) or more and contain 10 to 16 equivalent percent K_2O. The grade is expected to vary locally.

Uranium

Several uranium mines were opened at the base of the Chinle Formation along outcrops southwest of the Moab fault. The more important of these, the Thornburg and Shinarump No. 1 mines, are located between Sevenmile Canyon and Corral Canyon. The Sevenmile Canyon uranium area of the Green River district lies entirely within the Merrimac Butte quadrangle (Doelling, 1982, volume 1, figure 4). Uranium was discovered in 1948; most of the mines were operated by the Thornburg Mining Company from the early 1950s through the mid-1970s, and by the Cotter Corporation until 1985 when the last mine closed. Significant amounts of ore were produced (>1 million pounds U^3O^8, R.W. Gloyn, UGS, July 20, 1998). Remaining ore reserves are thought to be significant (Merrill and McDougald, 1989).

The uranium-producing horizon in the Sevenmile Canyon area is just above the base of the Chinle Formation in contact with the underlying Moenkopi Formation. Mineralization at the Shinarump No. 1 mine is in three zones in the lower 25 feet (7.6 m) of the Chinle Formation: in a basal siltstone, at the top of an overlying limestone-pebble conglomerate, and in a siltstone 5 to 10 feet (1.5-3 m) above the conglomerate (Finch, 1954). Ore-bearing siltstone is generally bleached. The Shinarump No. 1 uranium deposit consists of discontinuous lenticular layers of mineralized rock that generally follow the bedding. Ore minerals, mainly uraninite, impregnate the rock. Uraninite and chalcocite are concentrated in the more poorly sorted parts of siltstones, especially in the presence of carbonaceous matter and clay galls. Identified uranium minerals are uraninite, schroeckingerite, becquerelite, and gummite (?). Other minerals include chalcocite, pyrite, chalcopyrite, bornite, barite, calcite, gypsum, hematite, and quartz (Finch, 1953).

Petroleum

Hydrocarbon shows have been encountered in numerous drill holes in the Merrimac Butte quadrangle, but commercial production has never been established (table 2). The nearest hydrocarbon production is in the Gold Bar Canyon quadrangle where oil and gas was produced from the Mississippian Leadville Formation and is currently produced from the Pennsylvanian Paradox Formation (Doelling and others, 1994).

Oil staining has been reported in sample cuttings of the

Table 2. *Well data, Merrimac Butte quadrangle. Locations are condensed; CSWNW 11-24S-20E may be expanded to center of the SW 1/4 of the NW 1/4 of section 11, T. 24 S., R. 20 E. Elevations and total depths are in feet.*

Map Designation	**More Complete Designation**	**Location**	**Elevation**	**Total Depth**
Tiger Oil 12-11 State	Tiger Oil, No. 12-11 State	CSWNW 11-24S-20E	4,934	12,357
Shell #1 Leggett	Shell Oil, No. 1 Leggett	SWNE 12-24S-20E	4,648	5,600
Ladd #1 Salt Valley	Ladd Petroleum, No. 1 Salt Valley	NENENW 16-24S-20E	4,456	11,330
Union #1 State	Union Oil, No. 1 State	SESWSE 36-24S-20E	4,446	7,534
Ferguson & Bosworth #1 Cullen	Ferguson & Bosworth, No. 1 Cullen	NENE 7-24S-21E	4,855	4,966
Chandler 16-9	Chandler & Associates, No. 16-9 Federal	SESE 9-25S-20E	5,005	9,966
Columbia Crude #1	Columbia Crude Corp., No. 1 Government	SWSE 12-25S-20E	4,700	4,243
Ari-Mex 1-7	Ari-Mex Oil & Expl., No. 1-7 Skip Federal	NESW 7-25S-21E	4,743	2,300
Delhi #2	Delhi-Taylor Oil, No. 2 Utah	NWNWSW 18-25S-21E	4,356	9,425
Samson #1	Samson Resources, No. 1 Arches Federal	SENWSW 18-25S-21E	4,338	8,003

Leadville Formation in the Merrimac Butte quadrangle (Utah Geological Survey and Division of Oil, Gas, and Mining records). Several tests were conducted in the Delhi-Taylor Oil No. 2 well, drilled in 1955, NW1/4 NW1/4 SW1/4 section 18, T. 25 S., R. 21 E., which resulted in the recovery of oil, gas, and water from the Cane Creek shale (marker bed) of the Paradox Formation. Samson Resources offset from the No. 2 well with the No. 1 Arches Federal well in the SE1/4 NW1/4 SW1/4 of the same section in 1983. That well was abandoned after testing gas and water-cut mud from the Cane Creek shale.

Copper

Copper mineralization is evident at various locations along the Moab fault and the Moab splay faults. Small prospects have been dug in the small Salt Wash Member outcrop on the east side of the Moab fault south of Corral Canyon. Other prospects are found in the Moab Member of the Entrada Sandstone in the mesas adjacent to and south of the Moab splay faults.

The most common copper-bearing minerals are malachite, azurite, and chrysocolla. Some black tenorite and metallic cuprite have also been observed. Copper sulfides are rare. The minerals either coat fractures or are disseminated in sandstone. In several places the mineralization follows favorable horizons in the sandstone. Mineralization commonly occurs as replacement of the cement. Copper mineralization is associated with limonitization, which appears to increase where copper minerals are prominent. However, areas of limonitization commonly occur in the Moab Member without copper shows. Some limonite mineralization occurs as mineral fronts. Areas of mineralization are relatively small.

Grab samples have yielded as much as 7 percent copper. A little production was probably realized by handcobbing. Mill Canyon was named after a copper mill built there. This small building is now in ruins. A small pile of coal gives evidence of the fuel used. Workings consist of many pits and a few short adits.

Cryptocrystalline Quartz

Cryptocrystalline quartz is abundant in the Dewey Bridge Member of the Entrada Sandstone, the Tidwell and Brushy Basin Members of the Morrison Formation, and the Cedar Mountain Formation. The cryptocrystalline quartz in these units typically occurs as jasper and agate.

Gray and white angular pieces litter the lower part of the Dewey Bridge Member at outcrops in Courthouse Pasture. They weather from the tops of intramember unconformities and are mostly gray and white. Most have uninteresting patterns, but some pieces resemble dinosaur bone and can be polished into gems.

Large white chert concretions occur in the Tidwell Member of the Morrison Formation near its base. They are locally jasperized. The large white concretions are generally interwoven with limestone, but local red and yellow pieces are suitable for polishing.

The jasper and agate locally found in the Brushy Basin Member of the Morrison Formation and the Cedar Mountain Formation are similar. Dominant colors are red, gray, yellow, and brown. Locally, larger fragments of jasper and agate are abundant in the Cedar Mountain Formation.

Cement Rock

Two relatively large pits have been dug to prospect cement rock in the white beds at the base of the Dakota Formation. These pits are both located in the SW1/4 section 8, T. 24 S., R. 20 E., between the Moab fault and the Courthouse synclinal axis. One is about 70 yards (64 m) long, 16 yards (15 m) wide, and has been dug to a depth of 5 yards (4.5 m). Removed overburden is up to 10 feet (3 m) thick. The total disturbed area is 115 yards by 58 yards (105 x 53 m).

The other pit is 50 yards long (46 m), 20 yards wide (18 m), and 5 yards (4.5 m) deep. The total disturbed area is 122 yards by 33 yards (112 x 30 m). In both areas the strike of the Dakota parallels the Courthouse syncline and dips about 12 degrees northeastward.

The rock of interest is a 17-foot-thick (5 m), white or very light-gray, clayey, muddy, siliceous, carbonate rock. Commonly it is poorly exposed in a white slope. Locally, it is thin to medium bedded, and breaks up into blocky chunks. The upper half is muddier, the lower half is more siliceous. It lies on a green siltstone of the Cedar Mountain Formation and is overlain by about 4 feet (1.2 m) of carbonaceous shale, coaly shale, and gray shale. Typical yellow-gray sandstone and cobble conglomerate of the Dakota overlie the carbonaceous shale.

The rock was prospected and tested in the early 1960s. Production appears to have been limited to test lots. Analyses show 34 to 42 percent CaO (61 to 74 percent $CaCO_3$), 11 to 17 percent SiO_2, 4 to 7 percent R_2O_3, 1.5 to 3.3 percent MgO, and 33 to 36.15 percent LOI (Delhi-Taylor Oil Corporation, 1963, unpublished report). The analytical report indicated that a better product might be produced with selective mining, but that it would be difficult to lower the silica content.

A good Portland cement is made by burning to a clinker a finely ground mixture containing about 75 percent $CaCO_3$ and 25 percent clayey minerals, the latter consisting of 20 percent SiO_2, Al_2O_3, and Fe_2O_3, and 5 percent magnesia, alkalies, and other ingredients. MgO should not exceed 5 percent (Bateman, 1950).

Water Resources

There are no permanent streams in the Merrimac Butte quadrangle. The principal drainages are those of Courthouse Wash and Sevenmile Canyon, which, except for times of flooding, are dry most of the year. Locally, springs issue from bedrock and unconsolidated materials along the floors of the washes. These flow for short distances only to disappear again into the bedrock.

Precipitation in the quadrangle ranges from 6 to 8 inches (15-20 cm) annually, which recharges the sandstone aquifers of the area (Iorns and others, 1964). The best ground-water aquifers include the Wingate Sandstone, Navajo Sandstone, and Moab and Slick Rock Members of the Entrada Sandstone. Springs issue locally from all of these units. Most of these units are replete with joints and fractures which favor recharge. These springs rarely produce more than 10 gallons per minute (37.8 L/min), but are adequate to water livestock. Water may also be present in the surficial deposits that overlie bedrock discharge areas. Phreatophytes, such as willow and tamarisk, generally grow in profusion in areas of shallow ground water where spring discharge occurs.

Water in the Wingate, Navajo, and Entrada Sandstones generally carries less than 220 parts per million total dissolved solids; the water type is calcium bicarbonate or calcium magnesium bicarbonate and is moderately hard to hard (Blanchard, 1990). Water may seep from the sandstones of the Morrison, Cedar Mountain, and Dakota Formations, but the quality is usually not as good. Deep aquifers (Cutler and older formations) may contain much water, but are generally saline (Blanchard, 1990).

GEOLOGIC HAZARDS

Landslides and Fractured Bedrock

Many landslides (Qms) were mapped along outcrops of the Brushy Basin Member of the Morrison Formation. The quadrangle contains little development; presently only roads would be affected by landsliding. Road engineers should be careful to not remove rock debris that supports steep slopes of the variegated bentonitic siltstone and claystone of the Brushy Basin Member. Brittle rocks slide over fine-grained partings, beds, and bedding-plane fractures. Landsliding and slumping are more likely to occur during "wet" seasons and in areas where rocks are highly shattered and fractured.

Large open fractures are evident near the Tiger Oil well and other cliff-top locations in the Cedar Mountain Formation, which overlies the Brushy Basin Member. These are incipient fractures into which water is channeled to clay-rich rock during torrential rainfall. Water commonly exits through "pipes" that develop in the fine-grained rock, thus providing access to more horizons prone to slip. When these horizons become saturated, the overlying load becomes unstable, rotates, and slips.

Rock Falls

Rock falls occur sporadically throughout the rugged topography of southern Grand County. In the quadrangle, rock fragments from the Honaker Trail, Cutler, Moenkopi, Chinle, Glen Canyon Group, Entrada, Morrison, Cedar Mountain, and Dakota Formations produce rock-fall debris. The most susceptible cliffs or slopes are those broken by fractures that subparallel cliff faces.

The high cliffs southwest of the Moab fault are active rock-fall areas. Rock-fall debris may travel great distances downslope by rolling, bouncing, and sliding. The large boulders in Qmt deposits attest to previous rock-fall events. Because the quadrangle is uninhabited, danger is possible only in the transportation corridors and to those using the area for recreational purposes.

Debris Flows, Alluvial-Fan Flooding, and Stream Flooding

Flooding, and erosion and deposition by running water are the most active and potentially damaging hazards in the quadrangle. The sparsely vegetated steep fan slopes (Qaf) and deep, narrow washes (Qal) are subject to flooding and to rapid erosion from waters generated by cloudbursts. Debris flows and floods generally remain confined to stream channels in high-relief areas, but may exit channels and deposit debris where slope gradients decrease or channels are shallow along their travel paths. Easily erodible bedrock, and abundant unstable slope debris (Qmt and Qaf) provide ample material for debris flows. Debris flows and stream floods have damaged roads in the Merrimac Butte quadrangle.

Problem Soils

In the Merrimac Butte quadrangle, clay minerals in the Brushy Basin Member of the Morrison Formation, the Cedar Mountain Formation, Dakota Formation, and Mancos Shale, and in the soils derived from them, are capable of absorbing large quantities of water. The "popcorn" surface of weathering rocks is indicative of the shrinking and swelling nature of these formations.

Fine-grained soils and surficial deposits are prone to piping and gulleying. 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.

Earthquakes

The northern Paradox basin has experienced little recorded natural earthquake activity (Smith and Sbar, 1974). Historical seismicity in the Merrimac Butte quadrangle includes low-level, small- to moderate-magnitude activity with diffusely distributed epicenters (Wong, 1984).

Most events occurring in the region are microearthquakes having Richter magnitudes less than 1.0 and related to potash mining activities south of the quadrangle (Wong, 1984; Wong and Humphrey, 1989). Earthquakes greater than magnitude 4 (large enough to be felt) are uncommon, and no faults cutting Holocene deposits have been found. The quadrangle is in Uniform Building Code zone one, indicating low potential for earthquake damage (International Conference of Building Officials, 1991).

Blowing Sand

Sand blowing across and accumulating on back roads causes local problems. Motorists using the back roads should be cautious when proceeding into areas of sheet or dune sands. Loss of traction in sandy areas becomes more pronounced during the hot summer months when even gentle slopes of sand cannot be traversed in a motor vehicle.

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THE UNITED STATES GEOLOGICAL SURVEY

Base map from U.S. Geological Survey
Merrimac Butte 7.5' Quadrangle, 1985

INTERIOR-GEOLOGICAL SURVEY, RESTON, VIRGINIA-1986

Lori J. Douglas, Cartographer

SCALE 1:24 000

MILES: 1 — 5 — 0 — 1
FEET: 1000 — 0 — 1000 — 2000 — 3000 — 4000 — 5000 — 6000 — 7000 — 8000 — 9000 — 10 000
KILOMETERS: 1 — 5 — 0 — 1 — 2
METERS: 1000 — 0 — 1000 — 2000

CONTOUR INTERVAL 20 FEET

12.33°E
219 MILS

2000 MAGNETIC DECLINATION
AT CENTER OF SHEET

UTAH

QUADRANGLE LOCATION

1	2	3
4		5
6	7	8

1 Valley City
2 Klondike Bluffs
3 Mollie Hogans
4 Jug Rock
5 The Windows Section
6 The Knoll
7 Gold Bar Canyon
8 Moab

ADJOINING 7.5' QUADRANGLE NAMES

GEOLOGIC MAP OF THE MERRIMAC BUTTE QUADRANGLE, GRAND COUNTY, UTAH

by

Hellmut H. Doelling and Craig D. Morgan

2000

UTAH GEOLOGICAL SURVEY
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UTAH DEPARTMENT OF NATURAL RESOURCES
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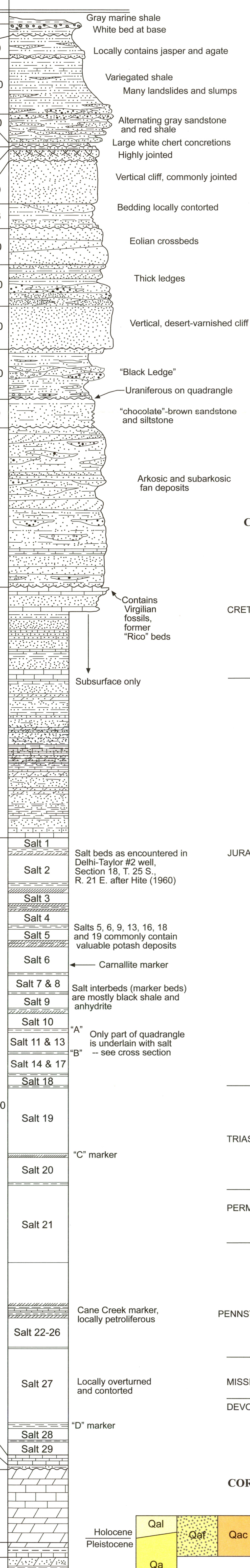
Plate 2
Utah Geological Survey Map 178
Geologic Map of the Merrimac Butte Quadrangle

PERIOD	EPOCH	FORMATIONS AND MEMBERS	SYMBOL	THICKNESS FEET
CRETACEOUS	Late	Mancos Shale - Tununk Shale Mbr.	Kmt	50
		Dakota Formation	Kd	87+
	Early	Cedar Mountain Formation	Kcm	120-200
JURASSIC	Late	Morrison Fm. – Brushy Basin Member	Jmb	350-400
		Morrison Fm. – Salt Wash Member	Jms	140-250
		Morrison Fm. – Tidwell Member	Jsmt	25-50
	Middle	Summerville Formation		6-28
		Entrada Ss. – Moab Member	Jem	70-110
		Entrada Ss. – Slick Rock Member	Jes	180-400
		Entrada Ss. – Dewey Bridge Member	Jed	120-226
	Early	Navajo Sandstone	Jn	165-800
		Kayenta Formation	Jk	220-340
		Wingate Sandstone	Jw	250-400
TRIASSIC	Late	Chinle Formation	TRc	280-850
	Early	Moenkopi Formation	TRm	0-2,500
PERMIAN	Early	Cutler Formation	Pc	0-4,000
PENNSYLVANIAN	Late	Honaker Trail Formation	IPh	0-2,408
	Middle	Paradox Formation	IPp	504-11,500
		Pinkerton Trail Formation		40-70
		Molas Formation		0-86
MISSISSIPPIAN		Leadville Formation	Ml	500±
DEVONIAN	Late	Ouray Limestone	Do	80-140
		Elbert Formation (upper member)	De	167+

LITHOLOGY



DESCRIPTION OF MAP UNITS

Qf Fill and disturbed material -- *Railroad ballast, road fill, and mine dumps; clay- to boulder-sized material mostly derived from local sources; some railroad fill consists of steel-mill slag imported from Colorado; as much as 25 feet (7.6 m) thick; latest Holocene.*

Qal Modern alluvium -- *Mostly sand, silt, clay, and subordinate pebble-sized fragments filling ephemeral stream channels; mostly locally derived; as much as 15 feet (4.6 m) thick; Holocene.*

Qa Older alluvium -- *Mostly sand, silt, clay, and pebble-sized gravel in older channels and in terraces along active washes; locally interbedded with small amounts of lacustrine (pond), alluvial-fan, colluvial, or wind-blown deposits; all material locally derived; locally contains fresh-water snails and soil horizons; as much as 60 feet (18 m) thick; late Pleistocene to early Holocene.*

Qaf Alluvial-fan deposits -- *Sand, silt, and pebble-sized gravel in gently sloping aprons at the base of cliffs; lower parts shallowly incised by small washes; may be as much as 30 feet (9 m) thick; late Pleistocene to Holocene.*

Qat Alluvial-terrace deposits -- *Subrounded to subangular gravel in a matrix of poorly sorted sand, silt, and grit; very local areal extent; contains exotic gravel of rounded black chert and angular cobble-sized, calcareous, fossiliferous chert; deposited on older Quaternary landslide debris; as much as 10 feet (3 m) thick; early Pleistocene (?).*

Qes Eolian-sand deposits -- *Fine- to medium-grained, quartzose sand; typically form thin, discontinuous sheets and small dunes that fill hollows in sandstone bedrock; locally forms thick piles on the lee sides of buttes; as much as 20 feet (6 m) thick; Holocene.*

Qmt Talus and colluvium -- *Angular boulders, cobbles, and smaller fragments commonly in a fine-grained matrix; include rock falls, creep, slope wash, and colluvium; form veneers on slopes below cliffs; commonly grade downslope into alluvial-fan deposits or mixed alluvial and colluvial deposits; as much as 15 feet (4.6 m) thick; late Pleistocene to Holocene.*

Qms Landslide and slump deposits – *Mostly masses of muddy siltstone, derived from the Brushy Basin Member of the Morrison Formation, in which large angular boulders of sandstone, conglomerate, and conglomeratic sandstone "float"; range from coherent blocks to completely "churned" material; long open fractures occur locally in bedrock above the deposits; late Pleistocene and early Holocene, except for remnants preserved on flank of Salt Valley anticline which are probably early Pleistocene (?) in age.*

Qea Mixed eolian and alluvial deposits -- *Mostly fine- to medium-grained sand mixed with silt and sparse lenses of coarser sand, granules, and pebbles; fill sandstone hollows and other protected places; 0 to 20 feet (0-6 m) thick; late Pleistocene to early Holocene.*

Qac Mixed alluvial and colluvial deposits -- *Poorly sorted, crudely stratified, angular blocks, cobbles, and pebbles in a matrix of sand, silt, and clay; vary from matrix to clast supported; mixtures of sheetwash, debris-flow, rock-fall or soil-creep materials, and alluvium; grade upslope into Qmt deposits; 0 to 30 feet (0-9 m) thick; late Pleistocene to Holocene.*

Qer Mixed eolian and residual deposits -- *Thin sheets of eolian silt and fine-grained sand, and weathered angular rubble derived from underlying bedrock units; as much as 3 feet (1 m) thick; late Pleistocene to early Holocene.*

Kmt Mancos Shale (Tununk Shale Member) -- *Gray marine shale; forms slopes; less than 50 feet (15 m) exposed in quadrangle.*

Kd Dakota Formation -- *Yellow-gray, ledge-forming sandstone at the top overlying gray slope-forming shale; yellow-gray conglomeratic sandstone in the middle overlying carbonaceous shale; basal white siliceous claystone and limestone; at least 87 feet (27 m) thick.*

Kcm Cedar Mountain Formation -- *Largely slope-forming green, silty, mudstone; light- to dark-brown resistant sandstone and conglomeratic sandstone, especially near the base, but also in intermediary lenses; 120 to 200 feet (37-61 m) thick.*

Morrison Formation

Jmb Brushy Basin Member -- *Largely varicolored silty and clayey mudstone; green and maroon coloration dominates; contains medium to thick, resistant, brown conglomeratic sandstone and sandstone lenses, especially near the base; 350 to 400 feet (107-122 m) thick.*

Jms Salt Wash Member -- *Light-gray, yellow-gray, or light-brown-weathering, ledge-forming sandstone lenses interbedded with red, green-gray, maroon, or lavender, slope-forming siltstone, and fine-grained, clayey sandstone; 140 to 250 feet (43-76 m) thick.*

Jsmt Summerville Formation and Tidwell Member of the Morrison Formation, undifferentiated -- *Summerville is light-tan to brown, thin- to medium-bedded, fine-grained sandstone, and red siltstone that form a steep slope with ledges; Tidwell Member is red and lavender siltstone with thin beds or nodular horizons of light-gray limestone; commonly displays large, white, siliceous (chert) concretions at the base; units are differentiable in the field, but too thin to show at the map scale; Summerville Formation 6 to 28 feet (2-8.5 m) thick and Tidwell Member 25 to 50 feet (7.6-15 m) thick.*

Entrada Sandstone

Jem Moab Member -- *Mostly pale-orange, gray-orange, pale-yellow-brown, or light gray, fine- to medium-grained sandstone, usually highly jointed in outcrop; thin beds, exposed in a deep notch near the base of the member in western exposures, correlative to the Curtis Formation are included; 70 to 110 feet (21-34 m) thick.*

Jes Slick Rock Member -- *Red-orange to brown, locally banded, cliff-forming, mostly fine-grained sandstone; with few partings; cross-bedded and massive; 180 to 400 (55-122 m) thick.*

Jed Dewey Bridge Member -- *Lower part mostly yellow-gray, flat-bedded (planar) sandstone; upper part mostly dark-red-brown, muddy sandstone, commonly contorted to "lumpy" and capped by orange-brown, Slick Rock-like, banded, massive sandstone; angular gray and white chert at various horizons; 120 to 226 feet (37-69 m) thick.*

Jn Navajo Sandstone -- *Mostly light-hued, fine-grained sandstone; displays eolian cross-beds; massive weathering; lower third commonly weathers to a vertical cliff, the remainder into domes and rounded knolls; locally contains thin, hard, gray limestone beds; 165 to 800 feet (50-244 m) thick, up to 300 feet (91 m) may be exposed.*

Jk Kayenta Formation -- *Red, fine- to medium-grained, medium- to thick-bedded sandstone; generally contains red, slope-forming siltstone in upper third of unit; contains local white and dark-brown sandstone, brown intraformational conglomerate, and rare gray limestone beds; forms thick ledges; 220 to 340 feet (67-104 m) thick.*

Jw Wingate Sandstone -- *Gray-pink to red-brown weathering, fine-grained sandstone; massive, forms vertical cliff along canyon walls; commonly stained dark brown with desert varnish; 250 to 400 feet (76-122 m) thick.*

TRc Chinle Formation -- *Red-brown and green-gray mudstone, siltstone, sandstone, and conglomeratic sandstone; forms steep slope with ledges and cliffs; has local gray-orange-pink to gray-pink gritstone or sandstone and varicolored (mottled) siltstone and mudstone near base; 280 to 850 feet (85-259 m) thick, as much as 400 feet (122 m) exposed.*

TRm Moenkopi Formation -- *"Chocolate"-brown sandstone, silty sandstone, sandy mudstone, fissile siltstone and shale; thin to medium bedded; sandstone is commonly ripple marked; 0 to 2,500 feet (0-762 m) thick, as much as 340 feet (104 m) exposed.*

Pc Cutler Formation -- *Interbedded red to red-orange, subarkosic to quartzose sandstone and red-purple conglomeratic arkosic sandstone; micaceous; fine to medium grained where not conglomeratic; generally resistant, forming ledgy cliffs and slopes; 0 to 4,000 feet (0-1,220 m) thick, as much as 1,100 feet (335 m) exposed.*

IPh Honaker Trail Formation -- *Interbedded gray and brown limestone and subarkosic sandstone exposed; sandstone, siltstone, limestone, and dolomite in subsurface; limestone is fossiliferous and uppermost bed contains Virgilian fusulinids; mostly resistant and cliff forming; 0 to 2,408 feet (0-734 m) thick, only 110 feet (34 m) exposed.*

IPp Paradox Formation (subsurface only) -- *Salt, shale, anhydrite, limestone, and dolomite; 504 to 11,500 feet (154-3,505 m) thick. Additional 40 to 70 feet (12-21 m) of Pinkerton Trail Formation and 0 to 86 feet (0-26 m) of Molas Formation are included in cross sections.*

Ml Leadville Formation (subsurface only) -- *Limestone and dolomite; paleokarst on top; about 500 feet (152 m) thick.*

Do Ouray Limestone (subsurface only; not shown on cross sections) -- *Light- to medium-gray, finely crystalline dolomite and limestone, with sporadic thin green shale stringers; 80 to 140 feet (24-43 m) thick.*

De Elbert Formation (subsurface only; not shown on cross sections) -- *Sandy limestone, dolomite, and minor shale; 200 to 260 feet (62-79 m) thick, greatest well penetration in quadrangle is 167 feet (51 m).*

MAP SYMBOLS

- Contact -- *Dashed where location inferred.*
- Fault -- *Showing dip; dashed where inferred, dotted where concealed; bar and ball on downthrown side; arrows show sense of offset on cross sections.*
- Anticline -- *Trace of axial surface of fold; arrows show direction of plunge; dashed where inferred, dotted where concealed.*
- Syncline -- *Trace of axial surface of fold; arrows show direction of plunge; dashed where inferred, dotted where concealed.*
- Strike and dip of bedding
- Plugged and abandoned petroleum well
- Cement rock prospect or mine
- Adit (blocked, inactive uranium mine)
- Prominent joint -- *Dotted where concealed*

CORRELATION OF BEDROCK UNITS

CRETACEOUS
- Late: Mancos Shale – Tununk Shale Member (Kmt); Dakota Formation (Kd)
- unconformity
- Early: Cedar Mountain Formation (Kcm)
- unconformity

JURASSIC
- Late: Morrison Formation – Brushy Basin Member (Jmb); Salt Wash Member (Jms); Tidwell Member (Jsmt)
- J-5 unconformity
- Middle: Summerville Formation (Jsmt); Entrada Sandstone – Moab Member (Jem)
- J-3 unconformity
- Slick Rock Member (Jes); Dewey Bridge Member (Jed)
- J-2 unconformity
- Early: Navajo Sandstone (Jn); Kayenta Formation (Jk); Wingate Sandstone (Jw)
- J-0 unconformity

TRIASSIC
- Late: Chinle Formation (TRc)
- TR-3 unconformity
- Early: Moenkopi Formation (TRm)
- TR-1 unconformity

PERMIAN
- Early: Cutler Formation (Pc)
- unconformity

PENNSYLVANIAN
- Late: Honaker Trail Formation (IPh)
- Middle: Paradox Formation; Pinkerton Trail Formation; Molas Formation (IPp)
- unconformity

MISSISSIPPIAN
- Leadville Formation (Ml)

DEVONIAN
- Late: Ouray Limestone (Do); Elbert Formation (De)

CORRELATION OF QUATERNARY UNITS