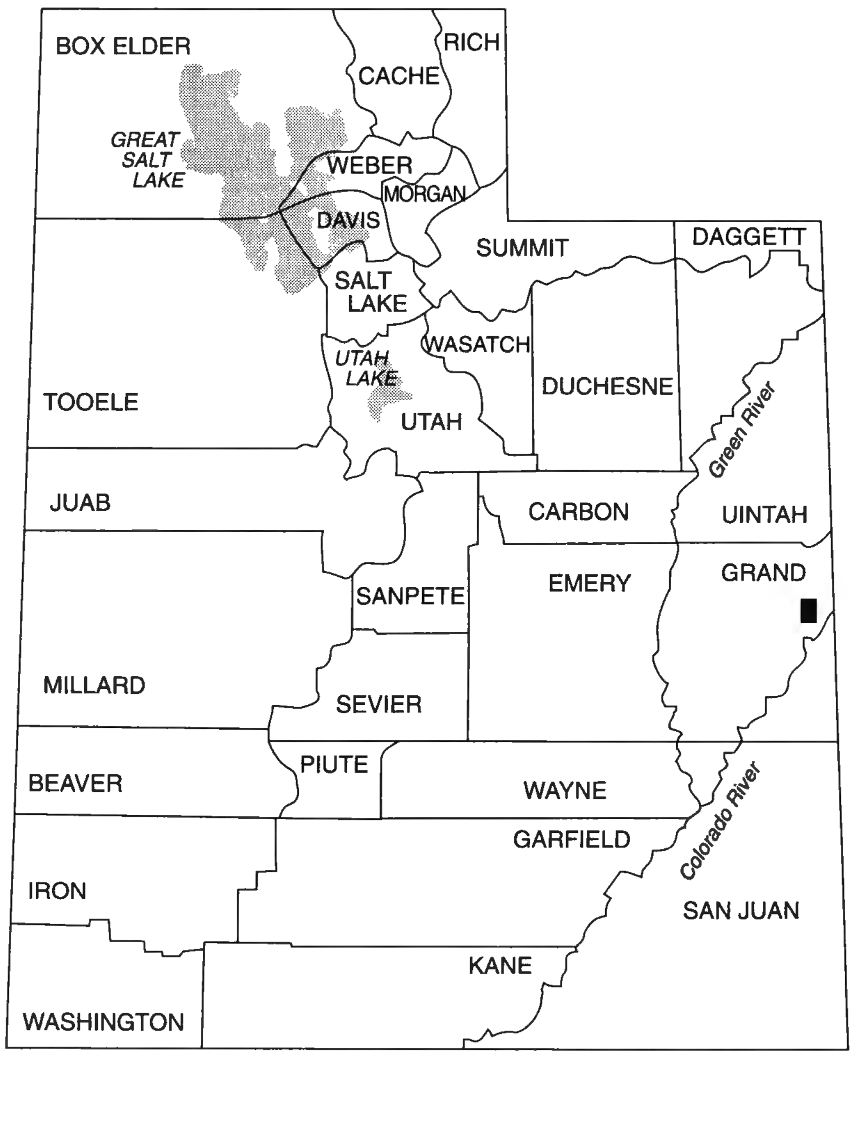
GEOLOGIC MAP OF THE AGATE QUADRANGLE, GRAND COUNTY, UTAH

by
Grant C. Willis, Hellmut H. Doelling and Michael L. Ross



MAP 168 **1996**
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES

UTAH GEOLOGICAL SURVEY

The **UTAH GEOLOGICAL SURVEY** is organized into five geologic programs with Administration, Editorial, and Computer Resources providing necessary support to the programs. The **ECONOMIC GEOLOGY PROGRAM** undertakes studies to identify coal, geothermal, uranium, hydrocarbon, and industrial and metallic resources; initiates detailed studies of these resources including mining district and field studies; develops computerized resource data bases, to answer state, federal, and industry requests for information; and encourages the prudent development of Utah's geologic resources. The **APPLIED GEOLOGY PROGRAM** responds to requests from local and state governmental entities for engineering-geologic and ground-water investigations; and identifies, documents, and interprets Utah's geologic hazards and ground-water resources. The **GEOLOGIC MAPPING PROGRAM** maps the bedrock and surficial geology of the state at a regional scale by county and at a more detailed scale by quadrangle. The **GEOLOGIC EXTENSION SERVICE** answers inquiries from the public and provides information about Utah's geology in a non-technical format. The **PALEONTOLOGY AND PALEOECOLOGY PROGRAM** maintains and publishes records of Utah's fossil resources, provides paleontological recovery services to state and local governments, and conducts studies of environmental change to aid resource management.

The UGS Library is open to the public and contains many reference works on Utah geology and many unpublished documents on aspects of Utah geology by UGS staff and others. The UGS has several computer data bases with information on mineral and energy resources, geologic hazards, stratigraphic sections, and bibliographic references. Most files may be viewed by using the UGS Library. The UGS also manages a sample library which contains core, cuttings, and soil samples from mineral and petroleum drill holes and engineering geology investigations. Samples may be viewed at the Sample Library or requested as a loan for outside study.

The UGS publishes the results of its investigations in the form of maps, reports, and compilations of data that are accessible to the public. For information on UGS publications, contact the Sales Office, 2363 South Foothill Drive, Salt Lake City, Utah 84109-1491, (801) 467-0401.

Printed on recycled paper

3/96

GEOLOGIC MAP OF THE AGATE QUADRANGLE, GRAND COUNTY, UTAH

by
Grant C. Willis, Hellmut H. Doelling, and Michael L. Ross

ABSTRACT

The Agate 7.5′ quadrangle is located on the northwestern flank of the Uncompahgre Plateau and the southeastern edge of the Uinta Basin in eastern Utah. Proterozoic gneiss, amphibolite, and granitoids are exposed near the bottom of Westwater Canyon of the Colorado River in the southeastern part of the quadrangle. These rocks are unconformably overlain by Mesozoic strata. The Upper Triassic Chinle Formation, which overlies the unconformity, is 70 to 110 feet (21-33 m) thick. Jurassic units include, in ascending order, the Wingate Sandstone, 300 feet (90 m) thick; the Kayenta Formation, 200 feet (60 m) thick; the Dewey Bridge Member, 25 to 35 feet (8-11 m) thick, Slick Rock Member, 140 to 150 feet (43-46 m) thick, and Moab Member, 70 to 80 feet (21-24 m) thick, of the Entrada Sandstone; the Summerville Formation, 40 to 55 feet (12-17 m) thick; and the Tidwell Member, 20 to 45 feet (6-14 m) thick, Salt Wash Member, 200 to 250 feet (61-76 m) thick, and the Brushy Basin Member, 380 to 420 feet (116-128 m) thick, of the Morrison Formation. Cretaceous units include, in ascending order, the Cedar Mountain Formation, 60 to 100 feet (18-30 m) thick; the Dakota Sandstone, 90 to 120 feet (27-36 m) thick; and the Mancos Shale, of which 1,800 feet (480 m) are preserved in the quadrangle. The Mancos Shale is divided into the Tununk Shale Member, 150 to 190 feet (45-57 m) thick, which contains the Coon Spring Sandstone Bed, 35 to 45 feet (11-14 m) thick; the Ferron Sandstone, 100 to 130 feet (30-39 m) thick; and the lower part of the Bluegate Shale Member, 1,500 to 1,600 feet (450-480 m) thick.

The topography of the quadrangle has been carved by the Colorado River and its tributaries, and surficial deposits are thin and scattered. Oldest surficial deposits are about 0.8 million years old.

Broad, low-amplitude folds trend northwest across the quadrangle. The Seiber Nose, a steep, northeast-facing, fault-propagated monocline overprinted on a broad anticline parallels the broad folds. The monocline dies out to the northwest, but may deform subsurface strata in the northwestern part of the quadrangle where two small oil and gas fields are located along its trend. The monocline is cored by a high-angle fault (not exposed) that cuts crystalline basement rock and possibly early Mesozoic strata. Mesozoic rocks are attenuated in the fold axis. The folds and fault are probably early Tertiary Laramide structures associated with the development of the Uinta Basin and the Uncompahgre Plateau. The only exposed fault, a small northeast-trending fault in the southern part of the quadrangle, has no more than 20 feet (6 m) of offset.

Thirty-seven petroleum exploration wells have been drilled in the quadrangle. Five wells have produced and several had shows of oil or gas. Primary targets are sandy intervals in the Mancos Shale, Dakota Sandstone, Cedar Mountain Formation, Morrison Formation, and Entrada Sandstone. Coal, humate, stone, and precious metal also have economic potential.

The quadrangle is located along an important transportation corridor and is a popular scenic and recreation area. Geologic hazards of most concern are clay-bearing expansive soil and rock, rock falls, and flash floods. The expansive soil and rock, primarily in the Morrison, Cedar Mountain, and Mancos Formations, cause problems in highway and railroad maintenance. Rock falls are common in steep areas.

INTRODUCTION

The Agate quadrangle is located south of the Book Cliffs in eastern Grand County, east-central Utah (figure 1). This region contains important oil and gas fields (figure 2), transportation routes, and recreation areas. The northwestern part of the quadrangle is in Grand Valley, a broad, low-relief, strike valley eroded into the less-resistant Mancos Shale, and is accented with badland hills, incised arroyos, and terrace and pediment remnants. The southeastern part includes rugged terrain along upper Westwater Canyon of the Colorado River, which is deeply incised into the northwestern flank of the Uncompahgre Plateau. Topographic relief is greatest along Westwater Canyon where the highest point in the quadrangle (5,100 feet [1,554 m] on the canyon rim) and the lowest point (about 4,230 feet [1,269 m] on the river) are just a few hundred horizontal feet apart. Most of the quadrangle lies between 4,300 feet (1,290 m) and 4,600 feet (1,380 m) in elevation. The area is arid, receiving 6 to 8 inches (15-20 cm) of precipitation annually (Waddell and others, 1981). Vegetation consists primarily of sparse grasses, rabbit brush, and saltbush in the northwestern part of the quadrangle, juniper and pinyon pine in rocky areas, and dense thickets of greasewood and tamarisk in the bottoms of washes.

The Seiber Nose and Sage oil and gas fields, two small fields in a cluster of several that make up the Greater Cisco field, are located in the northwestern part of the quadrangle (figure 2).

The quadrangle has been crossed by important east-west transportation routes since prehistoric times, and two perennial streams, Westwater Creek and Cottonwood Creek, were important to early travelers. The Denver and Rio Grande Western Railroad tracks crossed the northwestern corner of the quadrangle for many years until r elocated to more stable ground in the central part of the quadrangle. The old railroad bed can still be seen. The quadrangle was named for the Agate railroad siding and townsite, which is presently (1996) abandoned. The quadrangle is crossed by U.S. Interstate 70, a paved county road that provides access to the Westwater boat-launch on the Colorado River, several graded county roads, and by several unimproved roads. The Kokopelli Trail, a popular bicycle and 4-wheel-drive trail, also crosses the quadrangle.

Geology of the area was first documented by Peale (1878) as part of the U.S. Geological and Geographic Survey-sponsored Hayden Survey. Richardson (1909) made a generalized geologic map of part of the area. Fisher and others (1960) compiled information on the stratigraphy, paleontology, and nomenclature of the eastern Book Cliffs. The quadrangle is included in the Grand Junction 1 by 2 degree (1:250,000 scale) geologic map by Cashion (1973) and surficial geologic map by Whitney (1981), the Westwater 30 by 60 minute (1:100,000 scale) map by Gualtieri (1988), and part is on a 1:50,000 scale map emphasizing coal beds (Ellis and Hopeck, 1985). Case (1991) mapped the Westwater Canyon area at 1:24,000 scale, concentrating on Precambrian rocks.

Young (1955, 1966) studied and described Cretaceous rocks and Molenaar and Cobban (1991) studied the lower part of the Mancos Shale. Fouch and others (1983) summarized the chronology of Cretaceous and early Tertiary formations of eastern Utah, primarily using paleontologic data. O'Sullivan and Pipiringos (1983) described and correlated Jurassic rocks throughout the region. Heyman (1983) and Heyman and others (1986) studied structures along the northwestern flank of the Uncompahgre uplift.

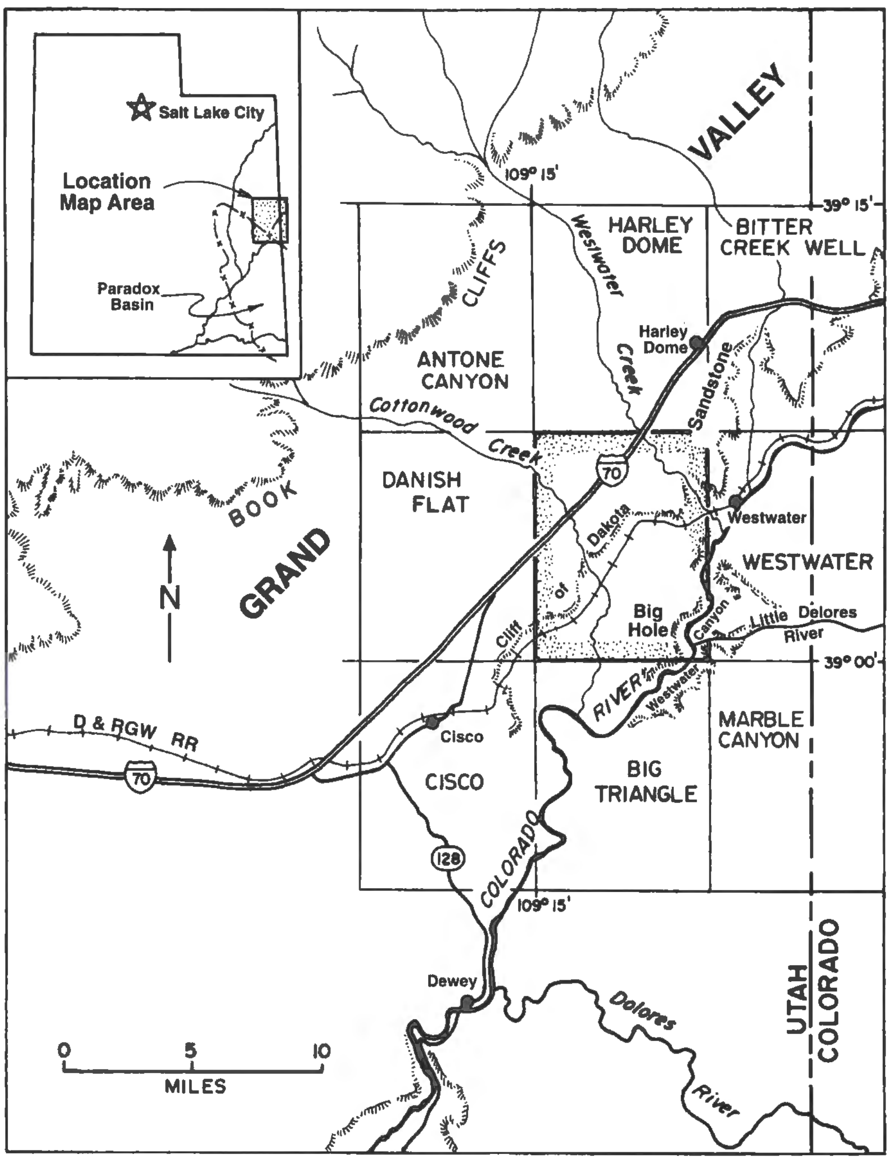


Figure 1. Index map of the Agate quadrangle showing major physiographic features and names of surrounding quadrangles. The Kokopelli Trail (not shown), a popular recreational route, approximately parallels the railroad through the quadrangle.

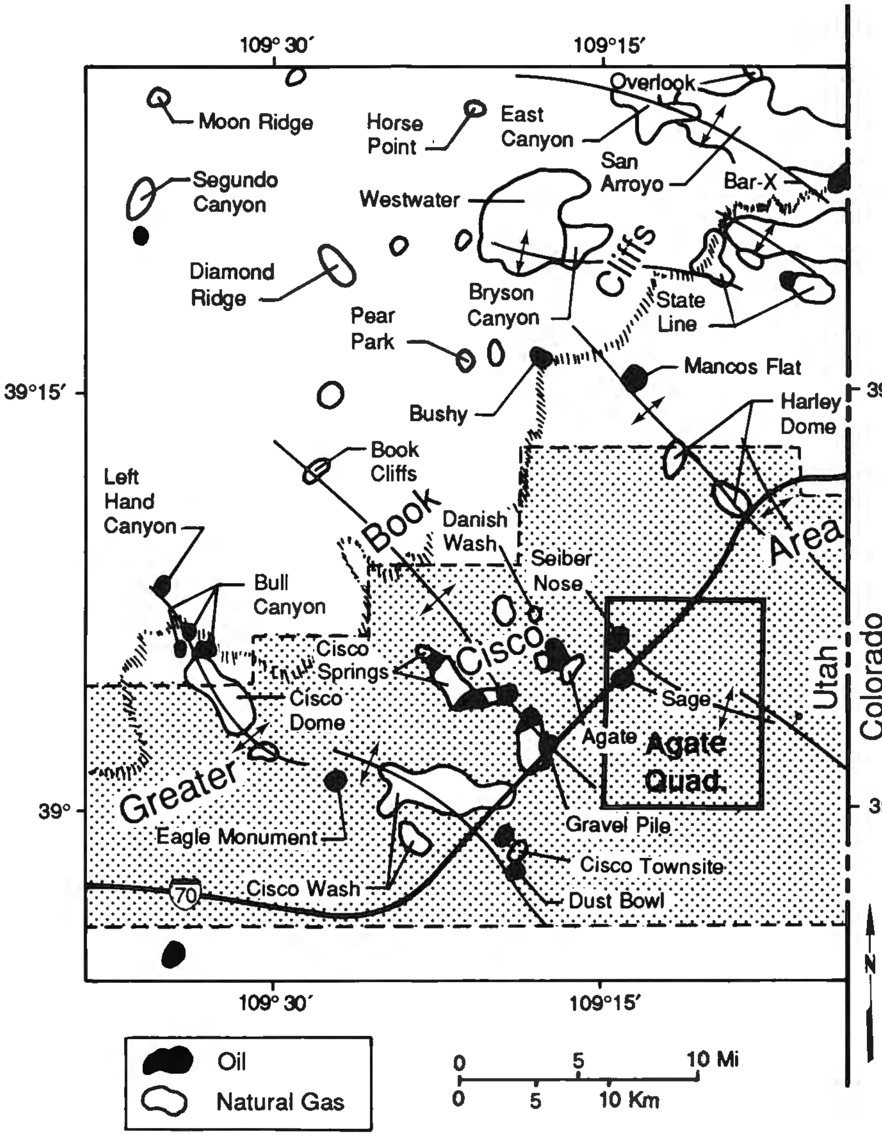


Figure 2. *Location of oil and gas fields and major anticlines in the Agate quadrangle area. Fields in the shaded area are combined to form the Greater Cisco Area field (modified from Utah Geological and Mineral Survey, 1983).*

DESCRIPTION OF MAP UNITS

Proterozoic high-grade metamorphic and intrusive igneous rocks are exposed in Westwater Canyon and underlie the quadrangle. These basement rocks are unconformably overlain by about 1,700 feet (520 m) of Triassic to Late Cretaceous strata exposed in a northwestward-dipping homocline that forms part of the south flank of the Uinta Basin. Thin surficial deposits are scattered across the quadrangle.

Proterozoic

Proterozoic metamorphic and igneous basement rocks form a resistant bench a few hundred feet above the river in Westwater Canyon (figure 3). Hedge and others (1968), Tweto (1987), Gualtieri (1988), and Case (1991) have mapped and described them. These rocks consist primarily of older amphibolite-grade gneiss intruded by younger (possibly late synorogenic) metadiorite to metagabbro plutonic rock that exhibits minor foliation, and a post-metamorphic batholith of quartz monzonite (Case, 1991). Exposures in the quadrangle are mainly of the older gneissic rocks, including feldspathic gneiss, amphibole-rich gneiss and amphibolite, microcline augen gneiss, and biotite-microcline gneiss. Several small bodies of altered mafic/ultramafic rock are also present. All of the gneisses are cross-cut by small quartzo-feldspathic pegmatite and aplite dikes and veins (not mapped). Some dikes may be related to the quartz monzonite batholith. Our mapping and discussion of the Proterozoic rocks is modified from Case (1991). The metamorphic rocks have been isotopically dated as Early to Middle Proterozoic (about 1,700 to 1,450 million years old) and the igneous rocks as Middle Proterozoic (about 1,450 million years old) (Hedge and others, 1968; Case, 1991).

Feldspathic Gneiss (Xfg)

This quartz-plagioclase-biotite gneiss unit forms light-pinkish-gray to black bouldery outcrops. In hand sample, the rock is strongly foliated and fine to medium grained. It has anhedral to subhedral grains and has a gneissic to schistose texture. Coloration is reddish brown to black with a micaceous sheen on foliation surfaces. The primary mineral assemblage is quartz (47-67 percent), plagioclase (8-35 percent), biotite (1-25 percent), and potassium feldspar (1-15 percent) (Case, 1991). Minor amphibole, muscovite, apatite, sphene, garnet, and opaque minerals are present. Common alteration minerals are epidote, sericite, chlorite, and hematite. The rock contains quartzo-feldspathic pegmatite and aplite veinlets and segregations that are parallel to sub-parallel to foliation. Mineral lineations and open-crenulation folds are pervasive and boudinage is common.

Amphibole Gneiss and Amphibolite (Xa)

The amphibole gneiss and amphibolite unit forms dark-gray to black bouldery outcrops. The gneiss is fine to medium grained, equigranular, and strongly to weakly foliated. Rocks are composed of green amphibole (50-75 percent), quartz (17-34 percent), plagioclase (1-15 percent), and potassium feldspar (1-8 percent) with variable relative mineral proportions (Case, 1991).

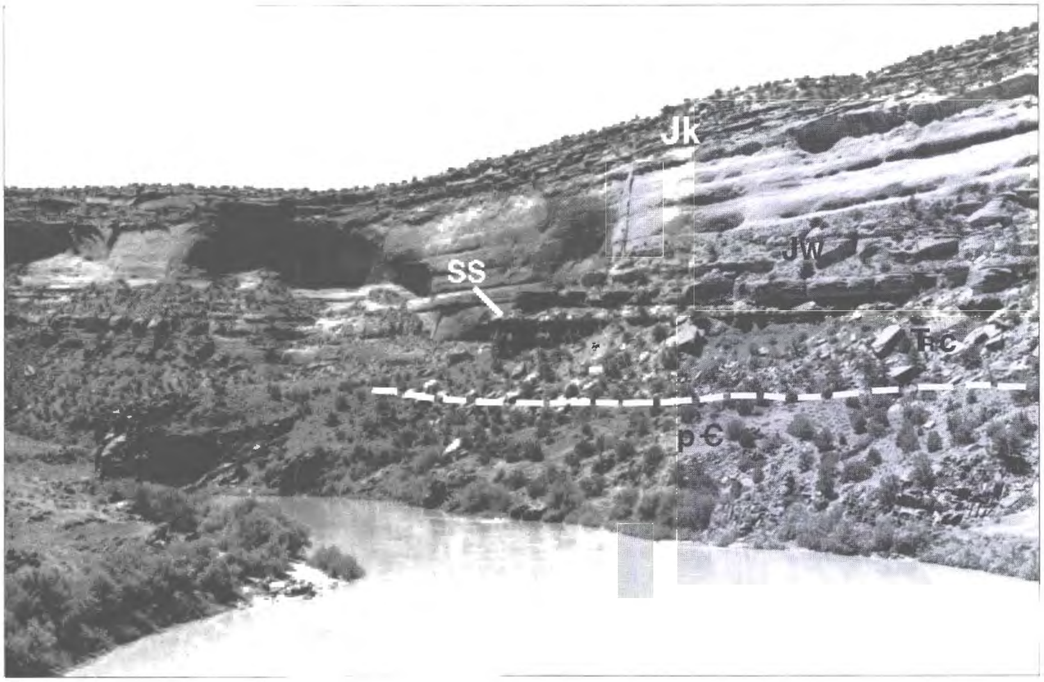


Figure 3. Precambrian high-grade metamorphic and igneous rocks (p€) are well exposed in Westwater Canyon in the southeastern part of the quadrangle. The Chinle Formation (Ŧc) unconformably overlies the crystalline rocks in a slightly irregular contact. A thick-bedded quartzose sandstone lens (SS) at the top of the Chinle is truncated by the Wingate Sandstone (Jw). The contact with the Wingate is sharp in most areas. The Kayenta Formation (Jk) forms the ledgy cliff near the top of the photograph.

Case reported that the gneiss varies from biotite-rich to amphibole-rich with well-lineated prismatic amphibole crystals.

Amphibole-rich gneiss is also present as dark-green to black, dike-like bodies that parallel and crosscut foliation in feldspathic gneiss (Xfg) near its contact with the amphibole gneiss-amphibolite unit (Case, 1991). Case interpreted the bodies as metasomatized mafic to ultramafic rock. The original texture apparently was medium to coarse grained; however, observed samples exhibit extreme recrystallization to an overall fine-grained texture. Local, large crystals are relict amphiboles and pyroxenes in a groundmass of alteration minerals. These mafic rocks are non-foliated and locally are crisscrossed by quartz veinlets. In thin section, the rocks contain epidote, sericite, quartz, hematite, and serpentine, suggesting pervasive alteration.

Microcline Augen Gneiss (Xmag)

Microcline augen gneiss is a distinctive pinkish-gray to salt and pepper-colored rock unit interlayered with amphibole-rich gneiss (Xa) in Westwater Canyon. The distinctive appearance is due to "birds-eye" features that are augen of pink microcline and recrystallized chlorite-sericite-muscovite-quartz aggregates in a fine- to medium-grained foliated to granoblastic groundmass. The rock contains plagioclase (25-40 percent), microcline (15-35 percent), quartz (15-30 percent), biotite (10-20 percent), and minor muscovite. In less deformed areas, coarse-grained (0.2-1.0 in; 0.5-2.5 cm), subhedral to euhedral microcline augen are wrapped in a weakly foliated groundmass. The long axes of some feldspar laths are subparallel to parallel to the foliation (Case, 1991). In more deformed areas, the groundmass is strongly foliated and augen of very fine-grained chlorite, sericite, muscovite, and quartz are folded and sheared. These textural relations suggest the microcline megacrysts are porphyroclasts that were shortened, recrystallized, and sheared to form the augen in the strongly deformed rock.

Case (1966, 1991) named this rock porphyroblastic microcline gneiss and indicated that microcline was a late-stage metamorphic recrystallization mineral (porphyroblast). Yet Case also suggested that the microcline might be phenocrysts of the protolith that have been rotated into parallel orientation and sheared by protoclastic flowage. Our observations support the latter interpretation.

Biotite-Microcline Gneiss (Xbm)

Biotite-microcline gneiss is a highly deformed, thinly layered, well-foliated rock with classic gneissic light and dark banding that forms dark, bouldery outcrops. The gneiss locally is migmatitic, exhibiting irregular quartzo-feldspathic veins, segregations, and dikelets (Case, 1991). The quartzo-feldspathic segregations are slightly coarser grained than the fine- to medium-grained biotite-rich layers, giving the gneiss a bimodal grain size. Grains have an overall granoblastic texture. The mineral assemblage contains quartz (30-45 percent), microcline (9-35 percent), biotite (10-30 percent), and plagioclase (12-20 percent) (Case, 1991). We also noted minor amounts of muscovite and garnet. Some layers are locally amphibole rich and Case (1991) reported sillimanite. Alteration minerals include muscovite, epidote, sericite, and chlorite. The biotite-microcline gneiss has a sharp contact with the amphibole gneiss/amphibolite unit (Case, 1991).

Altered Mafic and Ultramafic Rocks (YXm)

Several small, irregular bodies of dark-greenish-black to dark-brownish-black rock crosscut the gneissic rocks in Westwater Canyon. Outcrops are dark colored with rusty and pitted surfaces. Numerous prospect pits have been dug in and around the outcrops. These non-foliated rocks are strongly metasomatized and have a generally equigranular, fine-grained texture overprinting fragmented medium- to coarse-grained relict amphibole and pyroxene. The fine-grained groundmass consists predominantly of quartz with lesser chlorite, serpentine, carbonate, hematite, and other clay minerals. Abundant veinlets of alteration minerals crisscross hand samples. Case (1991) mapped these bodies as metapyroxenite, which we feel is too specific given that the original mineralogy and chemistry is extremely altered.

Triassic

Chinle Formation (℞c)

The Chinle Formation forms moderate to steep, reddish-brown ledgy slopes below the vertical cliffs of the overlying Wingate Sandstone in Westwater Canyon (figure 3). Stratigraphic and nomenclature problems for the upper members of the Chinle in east-central and southeastern Utah are discussed at length in O'Sullivan (1970) and Stewart and others (1972). In east-central Utah, the Chinle strata consists of beds assigned to the Church Rock Member (Stewart and others, 1972) or the equivalent informal "red siltstone" member (Poole and Stewart, 1964; Stewart and others, 1972). Individual members of the Chinle cannot be readily recognized in the Agate quadrangle.

The Chinle Formation in the quadrangle consists of reddish-brown mudstone interbedded with moderate-reddish-brown, grayish-red, pale-red, and pale-brown thin lenses and beds of siltstone, fine-grained sandstone, and lithic pebble conglomerate. A few beds of very pale-green siltstone and reddish-brown to pale-green silty limestone are present. Siltstone is calcareous and moderate to well indurated. Bedding in the thin beds ranges from horizontal to wavy, and from thinly laminated to structureless. At some locations, such as Little Hole (section 33, T. 20 S., R. 25 E.), some of the uppermost siltstone beds exhibit vertical burrows with bleached margins. Sandstone is fine grained, moderately sorted, calcareous, and well cemented. A few of the thin-bedded sandstones have ripple laminations and small-scale trough cross-stratification. Pebble conglomerate is calcareous cemented and clast supported. It contains subangular to rounded, reddish-brown mudstone, siltstone, and limestone pebbles in a poorly sorted, silty, sand matrix. The pebbles are similar in composition to other lithologies of the Chinle, suggesting the conglomerates are intraformational. Discontinuous channel lenses are stacked up to 15 feet (4.5 m) thick at the base of the formation. In addition to the sedimentary pebbles, the basal conglomerate also contains abundant angular to subrounded Precambrian metamorphic and granitic rock fragments up to 5 inches (13 cm) in diameter and coarse quartz and feldspar grains.

The nonconformity at the base of the Chinle, the ℞-3 unconformity of Pipiringos and O'Sullivan (1978), has an overall level appearance from a distance. However, there is up to 20 feet (6 m) of local relief on the gently irregular surface. Basal gravels or muddy siltstone overlie the erosional surface and Precambrian rocks beneath the nonconformity are generally deeply weathered.

The contact between the Chinle and the overlying Wingate is the J-0 unconformity of Pipiringos and O'Sullivan (1978). From a distance, the contact between the Chinle and the massive cliffs of the overlying Wingate Sandstone looks sharp and horizontal. It is placed at the base of the first thick- to massive-bedded, mature, fine-grained sandstone above which only cliff-forming sandstone is present (figure 3). Generally, the upper Chinle consists of a thin sequence (about 2 feet; 0.6 m) of silty mudstone and ripple-laminated siltstone that is distinct from the more typical underlying blocky weathering siltstone. Elsewhere, the uppermost part of the Chinle is a thick-bedded lens of quartzose sandstone with sand grains that are calcareous cemented, moderately sorted, subrounded, and fine to medium grained, that fills lenticular channels as much as 5 to 10 feet (1.5-3 m) deep. The Wingate-Chinle contact truncates the channel lenses. However, locally the contact appears gradational; in the uppermost Chinle Formation there are thin eolian sand-sheet deposits similar to the sands of the Wingate Sandstone (Lohman, 1965).

Chinle thickness varies from 70 to 110 feet (21-33 m). Stewart and others (1972) measured 78 feet (23 m) near the head of Westwater Canyon and Dane (1935) measured 107 feet (32 m) at Big Hole (just south of the Agate quadrangle). The Chinle has been assigned to the Late Triassic in the Colorado Plateau province (Stewart and others, 1972).

Jurassic

Wingate Sandstone (Jw)

The Wingate Sandstone forms massive cliffs or massive step-like benches along Westwater Canyon and other canyons east and southeast of the quadrangle (figure 3). The lower part weathers to a rough, blocky appearance, whereas the upper part weathers to a smoother, rounded appearance. Commonly, the cliff face has a patchy veneer of dark-rusty-red to black desert varnish.

The Wingate consists of grayish-orange-pink, moderate-orange-pink, and light-brown, very fine- to fine-grained sandstone. Sand grains are subangular to rounded and well sorted. Many grains are frosted, suggesting eolian transport. The subarkosic sandstone is composed of 50 to 60 percent quartz, 15 to 20 percent feldspar, 15 to 20 percent clay matrix and voids, and a trace to 15 percent calcite cement (Lohman, 1965, table 4). The Wingate is very thick bedded to massive, and exhibits both horizontal bedding and medium- to large-scale cross-bedding, with generally high-angle foresets. These bedding features and frosted grains are consistent with eolian deposition. The basal beds of the Wingate consist of interbedded, flat-bedded sandstone and siltstone with local symmetrical ripple marks and laminations. Basal bed thickness varies from thinly laminated to thick bedded.

The contact with the overlying Kayenta Formation varies from gradational and intertonguing to erosional, and from subtle to distinct (figure 3) (Dane, 1935; Lohman, 1965; Cater, 1970; Luttrell, 1987). We placed the contact at the base of the lowest lenticular bed that is generally thinner bedded, better indurated, and coarser grained than the less resistant, massive sandstone of the Wingate. Along the cliffs, the vertical position of this contact varies in a gentle undulatory manner up to 40 feet (12 m). At some outcrops, the contact is distinct with basal beds of the Kayenta channeled into the Wingate sandstones. When viewing the contact along the cliffs of Westwater Canyon, thinner beds assigned to the basal Kayenta merge laterally with massive sandstones that would be better included in the top of the Wingate. Gradational contacts and intertonguing of the formations and limited evidence of erosion indicates relatively continuous deposition.

The estimated thickness of the Wingate Sandstone is about 300 feet (90 m). Lohman (1965) estimated the Wingate in the area of Colorado National Monument to be 315 to 370 feet (95-111 m) thick, thinning to the southeast. The Wingate Sandstone is Early Jurassic in age based on paleontological and stratigraphic studies in southern Utah and northwestern Arizona (Peterson and Pipiringos, 1979; Peterson, 1988). The Wingate Sandstone is the basal formation of the Glen Canyon Group, which includes the Kayenta Formation and the Navajo Sandstone.

Kayenta Formation (Jk)

The Kayenta Formation consists of thin to thick, wedge-shaped to tabular sandstone beds and minor conglomerate lenses that form irregular, step-like, ledgy cliffs and slopes. It is exposed in numerous drainages and benches on the mesa west of Westwater Canyon; elsewhere Quaternary sand deposits cover large areas of the formation.

The Kayenta is primarily sandstone interbedded with minor conglomerate and siltstone. Sandstone and siltstone beds are grayish red purple, pale red, pale red purple, pale reddish brown, bluish white, and very light gray. All conglomerate beds are shades of reddish purple. At numerous locations, the Kayenta consists of normally graded, fining upward, conglomerate to siltstone sequences. Each sequence begins with a reddish, mudstone-, siltstone-, and carbonate-clast-bearing intraformational conglomerate that fills scours. They are capped by whitish-gray, medium-grained, cross-bedded sandstone that grades into fine-grained sandstone and siltstone. Each sequence is commonly 6 to 10 feet (1.8-3 m) thick.

Sandstone in the Kayenta is calcareous to siliceous, very fine to medium grained, and generally moderate to well sorted. Grains are primarily subangular to subrounded quartz and feldspar. The majority of the Kayenta sandstone is classified as lithic arkose to feldspathic litharenite (Luttrell, 1987). Bedding ranges from thinly laminated to thick bedded. Cross-bedded and horizontal to low-angle laminated sandstone are common and are indicative of a fluvial origin. Some cross-bedding is large scale and high angle (30-40°), suggesting eolian deposition. Out-of-phase, sinuous-crested, asymmetrical ripple marks were found on some sandstone bedding surfaces. Finely laminated and locally ripple-laminated, very fine-grained sandstone and siltstone is interbedded with thin mudstone.

Conglomerate is poorly sorted and varies from clast-supported to matrix-supported. Clasts are subangular to rounded and polymodal, with sizes ranging from granules to small cobbles; pebbles are predominant. Clast types are fine-grained sandstone, siltstone, mudstone, and carbonate. Lithology and coloration suggest the clasts are intraformational. The gravels are generally lags on scour surfaces or form beds up to 3 feet (1 m) thick. Crude cross-bedding was observed in the thicker lenses.

In the Agate quadrangle, the Kayenta is truncated by the J-2 unconformity (Pipiringos and O'Sullivan, 1978; O'Sullivan and Pipiringos, 1983), a major unconformity that separates Lower Jurassic from Middle Jurassic strata. The erosion surface appears to be relatively flat with only small irregularities and is generally sharp (figure 4). In eastern Utah, strata beneath the unconformity were tilted gently to the west and beveled (Peterson, 1988). The Navajo Sandstone, the upper formation of the Glen Canyon Group, is completely eroded from the quadrangle area. The J-2 unconformity is recognized and mapped with good certainty in the quadrangle by locating scattered chert pebbles that are characteristic of the basal beds of the overlying Entrada Sandstone.

Overall, the Kayenta Formation thins from about 300 feet (90 m) near Moab, Utah (Doelling and others, 1994) to about 60 feet (18-30 m) in places near Colorado National Monument (Lohman, 1965). The northeastward thinning is, in part, related to truncation by the J-2 unconformity. Some workers suggested that it is also depositional thinning (Luttrell, 1987; Peterson, 1988). The estimated thickness of the Kayenta in the quadrangle is about 200 feet (60 m). Dane (1935) estimated it to be 150 feet (45 m) thick at Big Hole (figure 1). Dickerson and others (1988) estimated it to be about 110 feet (33 m) thick in the nearby Black Ridge Canyons and Westwater Canyon wilderness study areas.

The Kayenta Formation is Early Jurassic in age based on paleontological and stratigraphic studies in southern Utah and northwestern Arizona (Peterson and Pipiringos, 1979; Peterson, 1988).

Entrada Sandstone

Dewey Bridge Member (Jed): The Dewey Bridge Member of the Entrada Sandstone is reddish-brown, silty sandstone interbedded with grayish-orange sandstone that form thick and irregular rounded ledges (figure 4). The ledges commonly contain numerous small recesses. Within the thick ledges the bedding is deformed into convoluted irregular folds of various sizes, and indistinct areas of contorted and disturbed laminae that are characteristic of the Dewey Bridge Member (Wright and others, 1962). Within the quadrangle the Dewey Bridge is exposed near the eastern part of the Seiber Nose structure and in the southern part of the quadrangle along a tributary drainage to Cottonwood Wash. The Dewey Bridge Member was defined and named by Wright and others (1962).

Figure 4. *Contact between the Kayenta Formation (Jk) and the Dewey Bridge Member (Jed) of the Entrada Sandstone. The thick ledge near the middle of the photograph is the basal sandstone of the Dewey Bridge Member. This quartzose sandstone commonly contains chert pebbles. Photographed in section 5, T. 21 S., R. 25 E..*

Silty sandstone of the Dewey Bridge is generally moderate reddish brown or pale reddish brown to light brown, generally very fine to medium grained, and poorly to moderately sorted. Sand grains are subangular to rounded and calcareously cemented. The matrix is locally muddy and the rock is moderately indurated.

Interbedded sandstone is very pale orange, grayish orange, pale yellowish orange, and grayish orange pink. In most areas the sandstone and silty sandstone exhibit a mottled appearance. The sandstone is very fine to fine grained, subrounded to rounded, moderately sorted, calcareous, and poorly cemented. Detrital mineral percentages reported in Wright and others (1962) indicate that the sandstone is subarkosic arenite. Black specks of residual oil are common in the yellowish-orange sandstones throughout the formation. The occurrence of residual oil staining in sandstone beds immediately above and below the J-2 unconformity suggests a relationship between the unconformity and oil migration pathways.

The basal part of the Dewey Bridge is a horizontally bedded sandstone 2 to 10 feet (0.6-3 m) thick (figure 4). Locally, it is infolded in soft-sediment deformation structures with the uppermost bed of the Kayenta Formation, despite being separated by an unconformity. The basal sandstone is generally light gray, though locally it is mottled with residual oil specks. It is moderately sorted and fine to medium grained. Some stringers of coarse-grained quartz and chert, detrital chert granules, pebbles, and a few cobbles up to 6 inches (15 cm) in diameter are present in the lower part of the basal sandstone. The chert pebbles are widespread, but locally absent, and are generally found in distinct clusters. Chert clasts are angular to rounded and are shades of gray, cream, and pale brown. According to Pipiringos and O'Sullivan (1975), the chert pebbles were derived from cherty limestone beds in the Navajo Sandstone to the southwest. The basal sandstone bed is interpreted as reworked detritus from the Navajo and possibly the Kayenta Formations (Wright and others, 1962).

The upper contact of the Dewey Bridge Member with the Slick Rock Member is an undulating bedding surface with a distinct change in overall character, appearance, and color. In general, the Dewey Bridge is poorly bedded, mottled, reddish-brown, silty sandstone and sandstone and the overlying Slick Rock is thick-bedded, large-scale cross-bedded, buff to light-gray, fine-grained sandstone.

The Dewey Bridge Member is from 25 to 35 feet (7.5-10.5 m) thick in the quadrangle. Reported thicknesses in the area range from 33 to 38 feet (10-11 m) (Wright and others, 1962; O'Sullivan and Pipiringos, 1983).

Stratigraphic studies indicate that the Dewey Bridge Member of the Entrada Sandstone is in part equivalent to, but lithologically different from, the Middle Jurassic Carmel Formation to the west in central Utah (Wright and others, 1962; O'Sullivan, 1981; Peterson, 1988).

Slick Rock Member (Jes): The Slick Rock Member of the Entrada Sandstone is exposed in discontinuous patches in the south-central to east-central part of the quadrangle. In most areas, the rocks are covered with unconsolidated sand that was probably weathered from the Slick Rock Member and that has undergone slight to moderate eolian and alluvial reworking. In most exposures the Slick Rock is very friable or earthy, especially near locations where surficial cover can hold moisture close to the rock, indicating that the weak cementation is readily destroyed by weathering. At well-exposed localities the Slick Rock forms smooth and rounded bare-rock cliffs (figure 5).

The Slick Rock Member is mostly very light-pinkish-gray to yellowish-gray, light-brown, or pinkish-orange, massive-bedded, very fine- to fine-grained quartzose sandstone. Coarse grains are common along cross-bed laminae. Grains are frosted and equant. Cementation is calcareous and hematitic. The unit is generally more resistant in the lower and upper parts where it is also lighter colored, possibly reflecting stronger calcareous cementation. It is generally redder and slightly less resistant in the middle; however, the variations are gradational. The Slick Rock is cross-bedded with long, sweeping, locally steep foresets. Major cross-sets are commonly 20 to 40 feet (6-12 m) thick; however, major set boundaries cannot be traced for more than a few hundred feet. Locally, cross-beds are complexly intermeshed and some sets contain slump features and local autobreccias. In spite of the primary sedimentary structures, weathered surfaces are smooth and rarely display bedding features. Thick color banding is locally prominent. This banding is nearly horizontal and generally cuts across the sedimentary structures, but locally follows the major set boundaries.

From a distance the upper contact is identifiable by a marked color change from the light-brown, orange, or pink of the Slick Rock, to the white or very light-gray of the Moab Member (figure 5). The contact is a nearly flat erosional surface with little relief. The sweeping cross-beds of the Slick Rock are all truncated at the upper contact. Sandstone of the Moab Member displays horizontal laminations or medium- to large-scale cross-beds, is typically more resistant, and typically weathers to a sugary rather than a smooth surface. We believe this contact may be the J-3 unconformity of Pipiringos and O'Sullivan (1978), though in a correlation diagram of the area, O'Sullivan and Pipiringos (1983) did not show an unconformity in this position.

The Slick Rock Member is 140 to 150 feet (43-45 m) thick in the Agate quadrangle. We measured 147 feet (45 m) 0.5 mile (0.8 km) south of the Denver and Rio Grande Western Railroad tracks starting in the SW¼SW¼NE¼ section 16, T. 20 S., R. 25 E., and ending in the NE¼SE¼NW¼ of the same section. This corresponds well with a 148-foot (45-m) section of the Slick Rock measured in section 5, T. 21 S., R. 25 E. about 1.5 miles (2.4 km) southwest of Cottonwood Creek by Dane (1935, p. 97-98). The Slick Rock Member is late Middle Jurassic (early Callovian) in age (Hintze, 1988, p. 47).

Moab Member (Jem): White, bare-rock outcrops of the Moab Member of the Entrada Sandstone trend northeasterly across the Agate quadrangle near the Seiber Nose structure. The unit is intermittently covered by unconsolidated surficial sand and locally forms massive cliffs or is exposed in the bottom of washes. The upper surface commonly exhibits distinctive, 10- to 50-foot (3-15-m), polygonal joints that form a "biscuit" pattern.

The Moab Member is white, yellowish-orange, or light-pinkish-gray, fine-grained sandstone with irregular yellow and pale-red patches. The grains, which are mainly quartz, are frosted, subangular to subrounded, and equant. The unit is cemented with calcite and minor hematite. Cementation varies from friable to indurated, but generally the Moab Member is more resistant and cliff forming than the underlying Slick Rock Member. The Moab Member also differs from the Slick Rock Member in that it has a greater percentage of low-angle to horizontal surfaces. Cross-bed bounding surfaces in the Moab Member are prone to weathering, forming prominent indentations in outcrops and weathered surfaces that appear sucrosic rather than smooth.

The upper contact of the Moab Member with the Sum-

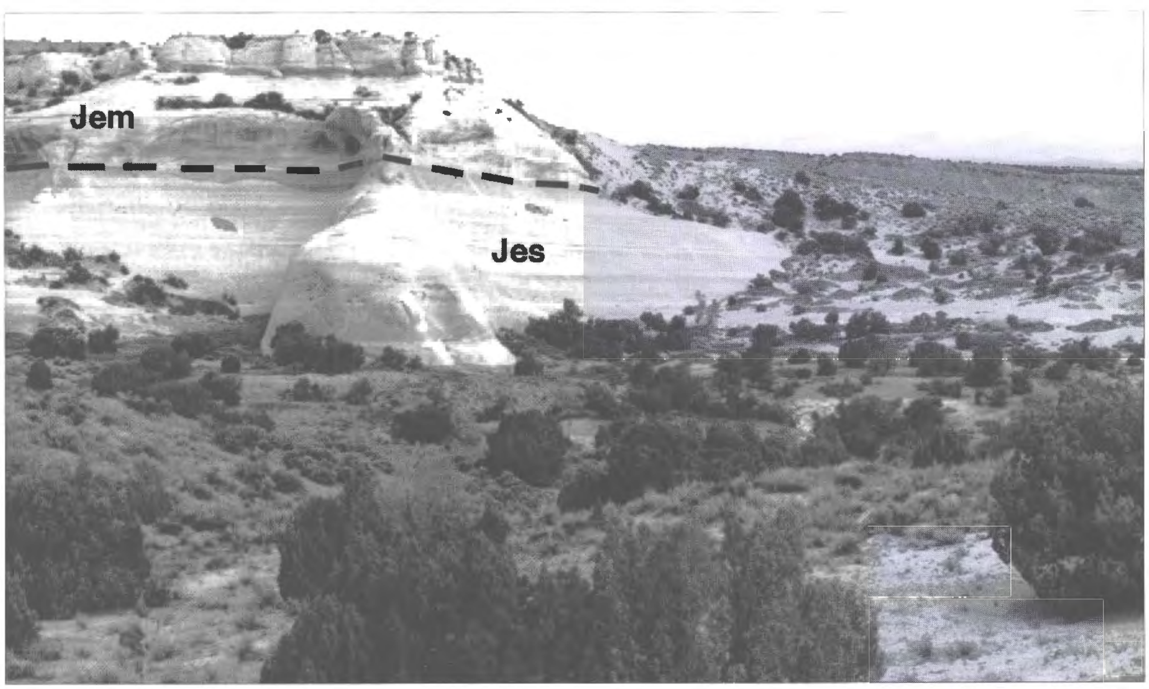


Figure 5. The Slick Rock Member (Jes) of the Entrada Sandstone forms smooth, rounded, salmon-colored cliffs while the Moab Member (Jem) forms rough, jointed, white cliffs. Photographed in NW¼ section 21, T. 20 S., R. 25 E..

merville Formation is easy to recognize. It is a nearly flat erosional surface overlain by a resistant, 6- to 18-inch (15-45-cm) bed of light-colored, reworked sandstone and several thinner, well-bedded sandstone beds. The erosional surface may be of local extent as Pipiringos and O'Sullivan (1978) did not show an unconformity in this position.

The Moab Member is 70 to 80 feet (21-24 m) thick in the Agate quadrangle. It is 77 feet (23.5 m) thick in the NW¼SW¼SW¼ section 10, T. 20 S., R. 25 E. Dane (1935, p. 97) measured 74.5 feet (22.7 m) northwest of Cottonwood Spring in section 5, T. 21 S., R. 25.

Regionally, the Moab Member pinches out within the Curtis Formation in western Grand County (Doelling, 1993). In the San Rafael Swell area the Curtis Formation overlies the Entrada Sandstone above the J-3 unconformity (Pipiringos and O'Sullivan, 1978). The Moab Member is late Middle Jurassic (Callovian) in age (Peterson, 1988).

Summerville Formation (Js)

The Summerville Formation forms a discontinuous band of outcrops extending from the southwestern corner of the quadrangle to the east-central part of the map area. We map the base of the Summerville following the criteria of Dane (1935, p. 102-106) and Gualtieri (1988), but we placed some strata that they mapped as part of the Summerville Formation in the Tidwell Member of the Morrison Formation. O'Sullivan and Pipiringos (1983) did not identify Summerville Formation in the Agate area and included this section of strata in the Tidwell Member.

The Summerville Formation is thin, but is easily recognized. It has four parts in the quadrangle, in ascending order: (1) a thin-bedded sandstone interval, (2) a reddish-brown, slope-forming siltstone interval, (3) an alternating greenish-gray and reddish-brown, slope-forming siltstone interval, and (4) a ledge-forming, thin-bedded sandstone interval.

The thin sandstone beds of the lowest part contain fine- to medium-grained, well-sorted quartz grains. The sandstone is nearly white, though weathered surfaces are stained reddish brown or light brown by thin, reddish siltstone partings. The thin beds locally contain ripple-marks. The basal bed of the lowest part is reworked sandstone from the Moab Member, is about 6 inches (15 cm) thick, and locally contains dinosaur tracks (figure 6). The lowest part is 4 to 10 feet (1.2-3 m) thick and forms a slight ledge.

The second part weathers to a conspicuous earthy red slope. Digging exposes crudely stratified siltstone that breaks into angular fragments. The weathering and outcrop pattern of the third part is similar to the second, but it is more sandy toward the top. The second and third parts have a combined thickness of 30 to 40 feet (9-12 m); however, the thickness of each varies considerably in the quadrangle.

The fourth part is similar to the first, but the sand grains are mostly subangular quartz. Sandstone beds are 0.5 inch to 2 feet (2.5-61 cm) thick, but the thicker beds are sparse. Thicker beds weather into flat, angular slabs and blocks while the thinner beds exhibit platy weathering. The sandstone beds are separated by thin, light-gray siltstone, some of which is sandy. Siltstone beds commonly show ripple-marks and locally exhibit mudcracks and bioturbation. The interval becomes more indurated and calcareous toward the top. Locally, yellow-gray, chippy-weathering, very thin beds of soft sandstone with siltstone partings continue for as much as 5 feet (1.5 m) above the ledge before the Tidwell Member is reached. The upper interval is normally 4 to 10 feet (1-3 m) thick.

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 typically poorly exposed in the Agate quadrangle, but is placed at the base of maroon to lavender siltstone of the Tidwell Member. In most places the contact is mapped directly above the upper ledge of the Summerville Formation. However, the contact is placed above the yellow-gray, chippy-weathering, soft sandstone where it is present.

The Summerville Formation, as mapped, is 40 to 55 feet (12-17 m) thick in the Agate quadrangle. We measured 51 feet (15.5 m) in the SE¼SE¼SE¼ section 8, T. 20 S., R. 25 E., 49 feet (15 m) in the SE¼NW¼NW¼ section 21, T. 20 S., R. 25 E., and 40 feet (12 m) in the NE¼NW¼NE¼ section 1, T. 21 S., R. 24 E. The Summerville Formation is late Middle Jurassic (Callovian) in age (O'Sullivan, 1981).

***Figure 6.** Theropod dinasaur tracks in the basal sandstone bed of the Summerville Formation in NE¼ section 1, T. 21 S., R. 24 E..*

Morrison Formation

The Morrison Formation forms low, ledgy hills in the middle part of the quadrangle and is 650 to 700 feet (198-213 m) thick. The thickness variation is due to difficulty in picking the upper contact and to erosional truncation of the upper surface.

In this area the Morrison consists of the Tidwell, Salt Wash, and Brushy Basin Members. Thicknesses of the individual members depends upon placement of member contacts, which are gradational and laterally variable.

The age assignment for the Morrison Formation has been shifted by geologists throughout the years (Kowallis and others, 1991). Simpson (1926), employing fossil evidence, concluded that the Morrison is Jurassic. Dane (1935, p. 113) tentatively assigned the Morrison to the Lower Cretaceous. Stokes (1952) placed the Morrison in the Late Jurassic. Kowallis and Heaton (1987) obtained Cretaceous fission track ages on volcanic ash in the Brushy Basin Member. However, Kowallis and others (1991) obtained well-constrained $^{40}Ar/^{39}Ar$ radiometric ages of 153 to 145 ± 2 Ma (Late Jurassic Kimmeridgian to Tithonian) from the Brushy Basin Member that refute the Cretaceous fission track ages. They noted that the Cretaceous fission track ages were determined from a stratigraphically complex section and are unreliable. Thus, the Morrison Formation is now considered Late Jurassic in age, though the age of the uppermost part of the formation remains poorly constrained.

Tidwell Member (Jmt): The Tidwell Member forms a gentle dip slope with scattered thin beds of limestone and large chert concretions in the central to southwestern part of the quadrangle. The Tidwell Member weathers like the underlying Summerville Formation, but is generally poorly exposed because resistant beds are sparse. Most of the Tidwell is lavender, maroon, or light-gray weathering siltstone and very thin beds of fine-grained, light-gray, calcareous sandstone. Bedding is indistinct on unweathered surfaces, but color bands are evident. Discontinuous zones of small, light-gray carbonate nodules are interspersed throughout the siltstone but are more common at the base and top of the unit. Locally, thin limestone beds less than 1.5 feet (0.5 m) thick are present. In the southwestern corner of the quadrangle and locally elsewhere, the lower limestone of the Tidwell is cherty or is completely replaced by large, white, siliceous concretions, some 3 to 6 feet (1-2 m) in diameter (protruding into overlying beds). Less common are siliceous concretions with irregular red and brown patches of jasper.

The upper contact of the Tidwell is generally placed at the base of the first thick, resistant lens of yellow-gray or light-brown sandstone. However, this lens is not present locally. At these locations the contact is placed above the typical lavender or pinkish hues of the Tidwell siltstone and below the mostly greenish-gray siltstone of the Salt Wash. In the SE¼ section 8, T. 20 S., R. 25 E. sandstone lenses are absent and limestone is found in the lower part of the Salt Wash Member. However, the Salt Wash limestone is medium gray whereas the Tidwell limestone is generally light gray. Both limestones are very fine to finely crystalline.

The Tidwell Member is 20 to 45 feet (6-14 m) thick in the Agate quadrangle. We measured 41 feet (12.5 m) in the SE¼SE¼ section 8, T. 20 S., R. 25 E.; 39 feet (12 m) in the SE¼NW¼ section 21, T. 20 S., R. 25 E., and only 20 feet (6 m) in a gravel-capped knoll in the NE¼NW¼NE¼ section 1, T. 21 S., R. 24 E. In most localities the thickness is 30 feet (9 m) or greater.

Salt Wash Member (Jms): The Salt Wash Member is interbedded, ledge-forming sandstone and slope-forming mudstone; 25 to 40 percent sandstone lenses alternate with 60 to 75 percent red and green mudstone. It forms a low, partly covered outcrop belt 0.5 to 0.75 miles (0.8-1.2 km) wide southeast and south of the Denver and Rio Grande Western Railroad tracks. Sandstone lenses are 2 to 10 feet (0.6-3 m) thick, but most are 2 to 4 feet (0.6-1.2 m) thick. Sandstone thickness generally increases up section with a corresponding decrease in the mudstone intervals. Typically, there are six or seven thick sandstone lenses in the Salt Wash Member. Sandstone in the Salt Wash is cross-bedded, fine to coarse grained, moderately to poorly sorted, quartzose, calcareous, and well indurated. The sandstones are generally white or yellow gray, but weather to various shades of brown. Small pieces of silicified wood and dinosaur bone are found locally. The mudstone intervals are red, greenish gray, maroon, and lavender interbedded mudstone, siltstone, and fine-grained clayey sandstone. Thin limestone beds and nodules are present in the Salt Wash Member mudstones, especially near the bottom of the section.

The upper contact with the Brushy Basin Member is placed at the top of an interval of predominately light-gray sandstone lenses and at the base of an interval containing dark conglomeratic sandstone lenses and brightly colored, banded mudstone. In the Agate quadrangle, the Salt Wash Member was distinguished from the overlying Brushy Basin Member by texture and composition of their sandstone beds, coloration of the mudstone, and relative percentage of sand in the mudstone. Salt Wash sandstones are quartzose and only rarely gritty or conglomeratic, whereas Brushy Basin sandstones are lithic and are commonly gritty and conglomeratic. Salt Wash mudstone is predominantly red whereas Brushy Basin mudstone is variegated purple, green, maroon, and gray. The percentage of sand is greater in the Brushy Basin mudstone relative to the Salt Wash mudstone. The Salt Wash forms a dip slope of low irregular hills while the Brushy Basin forms a smooth slope near the base of a large cuesta.

The Salt Wash Member is 200 to 250 feet (61-76 m) thick in the Agate quadrangle. A complete 205-foot (62 m) section was measured in the SE¼ section 8, T. 20 S., R. 25 E., near the Seiber Nose monocline. An incomplete section of 231 feet (70 m) was measured in the S½ section 36, T. 20 S., R. 24 E.

Brushy Basin Member (Jmb): The Brushy Basin Member is exposed in the lower part of a steep slope held up by the cuesta-forming Dakota Sandstone north and northwest of the Denver and Rio Grande Western Railroad tracks (figure 7). The brightly colored, distinctly banded unit is easily recognized. It is predominantly maroon and greenish-gray mudstone and minor grayish-green, fine-grained, muddy, conglomeratic sandstone, interbedded with local resistant, cross-bedded, conglomeratic sandstone lenses. The mudstone is brightly colored, indistinctly bedded, and contains smectite clay minerals as evident from "popcorn" weathered surfaces. Light- to medium-brown nodules and thin beds of limestone are common and produce brown rubble that accumulates on gentler slopes. The limestone nod-

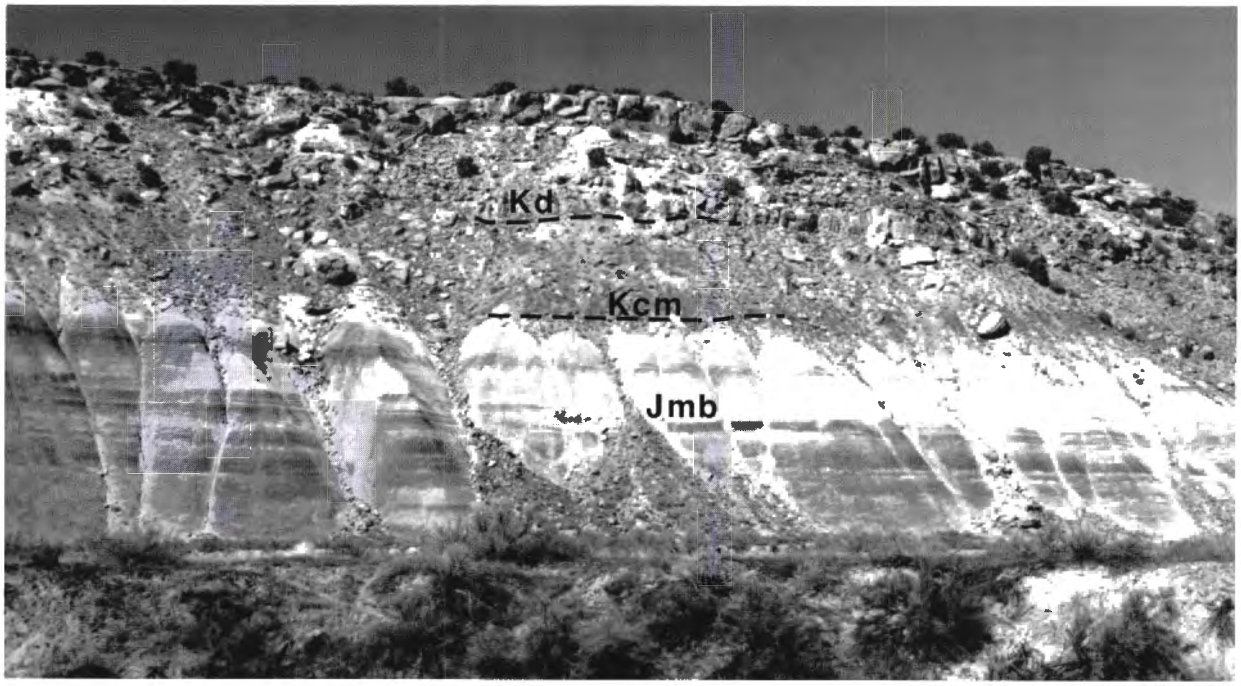


Figure 7. *Rubble-covered, slope-forming, greenish-gray Cedar Mountain Formation (Kcm) resting on the variegated Brushy Basin Member (Jmb) of the Morrison Formation and overlain by channel sandstone and conglomerate of the cliff-forming lower part of the Dakota Sandstone (Kd). Photographed in section 3, T. 20 S., R 25 E..*

ules commonly have interiors of acicular crystalline aragonite or brown, yellow, and red jasper. The lenses of conglomeratic sandstone are very well indurated, dark weathering, and form scattered resistant ledges that interrupt the steep slope. The lenses are generally less than 1,000 feet (305 m) wide and as much as 30 feet (9 m) thick and are interpreted as fluvial channels. The sandstone is generally medium to coarse grained, and calcareous. Fresh surfaces are light gray to light brown, but weather to dark brown, dark gray, and even black. Cross-bed surfaces in the sandstone are lined with grit, pebbles, and small cobbles.

The upper contact with the Cedar Mountain Formation is in the upper part of the steep slope and is probably the K unconformity (Pipiringos and O'Sullivan, 1978). In most areas, mudstone beds are common both above and below the contact. However, the Brushy Basin beds are generally brighter, are banded, and contain abundant small, light-brown limestone nodules. A distinctive orangish-red-weathering mudstone interval 2 to 5 feet (0.6-1.5 m) thick overlies the contact. Though missing in a few areas, it is more continuous than other beds near the contact. Locally, poorly sorted, medium- to thick-bedded, siliceous, ledge-forming sandstone lenses are present along the contact. To the west, 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 and to the south the Burro Canyon Formation unconformably overlies the Brushy Basin Member (Stokes, 1944, 1952; Trimble and Doelling, 1978; Peterson and others, 1980).

The Brushy Basin Member is 380 to 420 feet (116-128 m) thick in the Agate quadrangle. It is 417 feet (127 m) thick where measured just north of the Denver and Rio Grande Western Railroad tracks in the SW¼SW¼ section 10, T. 20 S., R. 25 E. It is 390 feet (119 m) thick in the SW¼ section 25, T. 20 S., R. 24 E.

Cretaceous

Cedar Mountain Formation (Kcm)

The Cedar Mountain Formation forms a grayish-green, thin, laterally continuous steep slope with a few scattered ledge-forming sandstone lenses just below the cliff-forming Dakota Sandstone (figure 7). The steep slope is continuous with the slope formed by the Brushy Basin Member of the Morrison Formation. However, in most places the grayish-green Cedar Mountain contrasts with the more brightly banded Brushy Basin Member of the Morrison Formation. Also, the Cedar Mountain is less smectitic as evident from less "popcorn" weathering.

The dominant lithology of the Cedar Mountain Formation is grayish-green, greenish-gray, or gray siltstone. Some mudstone and greenish-gray, very fine- to fine-grained sandstone is also present. The siltstone weathers to angular pebble-size detritus that locally litters the steep slope. At the base of the Cedar Mountain is a conspicuous orangish-red mudstone that may be a paleosol. At some localities the paleosol is very siliceous and hard, forms ledges, and weathers to rubble. Locally, it contains hard, siliceous, lavender-gray limestone nodules. A few well-indurated, sandstone lenses are present in the Cedar Mountain Formation. They are dark-brown to brownish-gray weathering and form small but prominent ledges in the steep slope. They are similar in lithology to sandstone lenses in the Brushy Basin Member of the Morrison Formation except they have altered chert pebbles and abundant kaolinitic matrix in most localities.

The Cedar Mountain Formation is 60 to 100 feet (18-30 m) thick in the Agate quadrangle; the variation is due to scouring by the overlying Dakota Sandstone and to difficulty in placing the lower contact. The upper contact is placed at the top of the greenish siltstone and at the base of broad channels of cliff-forming conglomeratic sandstone or conglomerate in the Dakota Sandstone (figure 7). The upper contact is an unconformity with a hiatus of about 4 million years (Molenaar and Cobban, 1991).

The Cedar Mountain Formation is Barremian to middle Albian in age (Fouch and others, 1983; Kirkland, 1992). Tschudy and others (1984) found late Albian palynomorphs, and Willis and Kowallis (1988) reported fission track ages of 99 to 108 million years (Albian) in the Cedar Mountain Formation in central Utah.

Dakota Sandstone (Kd)

The Dakota Sandstone forms a resistant cuesta and a gentle, broad, dip slope that trends from southwest to northeast across the quadrangle (figure 7). It is divisible into three parts: (1) a lower conglomerate and sandstone interval, (2) a middle carbonaceous shale, coal, and sandstone interval, and (3) an upper sandstone interval (appendix A). The lower part generally forms a resistant ledge or cliff. The middle part is less resistant and forms a recess between cliffs of the lower and upper parts and low swells on dip slopes. The upper sandstone forms thin ledges or cliffs, depending upon bed thickness. These three parts were mapped as informal members in the Harley Dome quadrangle (Willis, 1994), but the member contacts are less distinct in the Agate quadrangle, making it impractical to continue the informal subdivisions.

The lower part typically comprises as much as 50 percent of the formation, but locally it thins to only a few feet, forming a thin ledge between the green slope of the Cedar Mountain and the slope-forming middle part of the Dakota. Interbedded pebble conglomerate, conglomeratic sandstone, sandstone, and mudstone are the predominant lithologies in the lower part. The conglomerate is pale gray, pinkish gray, and yellowish gray, varies from matrix to clast supported, and is poorly to moderately cemented. Pebbles are up to 2 inches (5 cm) in diameter, though most are 0.25 to 0.5 inches (0.6-1.2 cm). Lithic pebbles are gray, white, or black chert, dense sandstone, and quartzite; and are moderately to well sorted and are subrounded to rounded. The sandstone is mostly medium grained, calcareous, cross-bedded, and forms thick lenses interlayered with the conglomerate beds. Most cross-bed sets are 0.5 to 3 feet (0.15-0.9 m) thick, but a few are thicker. The lower part varies in thickness from a few feet to about 50 feet (15 m). It is 32 feet (9.8 m) thick in SE¼SE¼ section 33, T. 19 S., R. 25 E.

Locally, the lower part consists of broad fluvial channels incised into the Cedar Mountain Formation (figure 7). A large channel is visible in the cliffs on both sides of Westwater Creek in section 3, T. 20 S., R. 25 E.. It is resistant gray conglomerate with a matrix of medium-grained sandstone. The conglomerate is moderately sorted with an average clast size of 1 to 2 inches (2.5-5 cm). Overlying it is a white to pink, medium- to coarse-grained, smooth-weathering, bleached sandstone up to 20 feet (6 m) thick. It in turn is overlain by a light-brown, cliff-forming, gritty conglomeratic sandstone that weathers medium grayish brown and is as much as 15 feet (4.5 m) thick.

The middle part of the Dakota Sandstone is interbedded carbonaceous shale, mudstone, coal, fine- to medium-grained sandstone, and kaolinitic clay, and is of deltaic origin. It is relatively nonresistant and is commonly covered by sandstone debris. Where exposed, it forms gray to black slopes. Zones of interbedded coal, impure coal, and bone coal are as much as 5 feet (1.5 m) thick (appendix B). The kaolinitic clay beds, which are altered volcanic ash, are 2 to 12 inches (5-30 cm) thick. Plant fossils are common near the base of some of the ash beds. Locally, thick channel sandstone beds cut out most of the shale and mudstone beds of the middle part. An east-west-trending channel is exposed from the W½ of section 3 to the E½ of section 4, T. 20 S., R. 25 E. The middle part of the Dakota is 64 feet (19 m) thick in SE¼ section 33, T. 19 S., R. 25 E., which is near the maximum thickness in the area.

The upper part of the Dakota Sandstone is composed primarily of resistant, thick-bedded to massive sandstone with local carbonaceous shale and mudstone partings and is of delta-front and tidal-channel origin. The sandstone is yellowish orange, very fine to medium grained, locally pebbly, and rounded to subrounded. Bedding is planar to lenticular, with ripple laminations. The upper part is 16 feet (5 m) thick in section 33, T. 19 S., R. 25 E., but varies from 0 to about 25 feet (0-7.5 m).

The upper contact of the Dakota in this area is an unconformity, and is a hummocky to channeled surface with up to 10 feet (3 m) of relief. The contact is commonly sharp, and is placed at the change from yellowish-orange sandstone to reworked yellowish-gray sandy mudstone that grades rapidly upward into gray mudstone and shale. The thin zone of reworked sandy mudstone is included with the overlying Tununk Member of the Mancos Shale.

The Dakota is 90 to 120 feet (27-36 m) thick in the quadrangle (appendix A). It is middle to late Cenomanian in age, and represents terrestrial and transitional deposition during the transgression of the Mancos sea (Young, 1960; Fouch and others, 1983; Molenaar and Cobban, 1991).

Mancos Shale

The Mancos Shale is exposed in the northwestern third of the quadrangle where it forms a broad valley with low "badland" hills and cuestas of slightly sandier beds. Vegetative cover is sparse to absent, and, where present, is supported by a thin mantle of alluvial or colluvial cover. The Tununk Shale, the Ferron Sandstone, and the lower part of the Bluegate Shale Members are present in the quadrangle. The Tununk contains a sandy interval, informally called the Dakota silt (Munger, 1965), that Molenaar and Cobban (1991) named the Coon Spring Sandstone Bed. The strata between the top of the Ferron Sandstone and the base of the Castlegate Sandstone have been informally called the main body (Hintze, 1988; Molenaar and Cobban, 1991) or the upper shale member of the Mancos Shale (Gualtieri, 1988). We use the name Bluegate Shale Member, an eastward extension of a name well-established in the area west of the San Rafael Swell (Peterson and Ryder, 1975; Hintze, 1988). In eastern Utah and western Colorado the Prairie Canyon Member of the Mancos Shale (formerly the Mancos B unit -- Cole and Young, 1991; Cole, Young, and Willis, in preparation) divides the Bluegate Shale Member into lower and upper parts (map units Kmbl and Kmbu of Willis, 1994). Only the lower part of the Bluegate Shale Member is preserved in the Agate quadrangle.

The Mancos Shale is 3,400 to 3,600 feet (1,040-1,200 m) thick (excluding the Buck Tongue, which is above the Castlegate Sandstone) in drill holes north and northwest of the quadrangle, but the maximum preserved thickness in the quadrangle is only about 1,800 feet (540 m).

The ages of the Mancos Shale members have been determined through detailed studies of fossils, primarily ammonoids and bivalves, combined with isotopic dating of biotite and sanidine from volcanic ash and bentonitic clay beds (Kauffman, 1977; Fouch and others, 1983; Kauffman and others, 1987; Cole and Young, 1991; Molenaar and Cobban, 1991). In this area the lower part of the Tununk Shale Member is late Cenomanian to early Turonian, the Coon Spring Bed contains early middle Turonian fauna, and the upper part of the Tununk is mostly or entirely late middle Turonian in age. The Ferron Sandstone Member is late Turonian in age. The lower part of the Bluegate Shale Member is Coniacian to Santonian in age.

Tununk Shale Member (Kmt): The Tununk Shale Member forms a strike valley between the cliff-forming Dakota Sandstone and the cuesta-forming Ferron Sandstone Member of the Mancos Shale. The Tununk contains the Coon Spring Sandstone Bed, which we mapped as a marker bed (shown as a single line on plate 1) (figure 8).

The Tununk is primarily medium- to dark-gray shale and silty shale that weathers pale yellowish brown. Pale-yellowish-gray bentonite beds up to a few inches thick are common. The lower 20 feet (6 m) of the Tununk contain an interval with abundant oyster fossils (*Pycnodonte newberryi*). The upper part of the Tununk Member forms a mostly covered slope that rises up to the base of a cuesta formed by the more resistant Ferron Sandstone Member.

The basal contact of the Tununk, which is an unconformity (Molenaar and Cobban, 1991), is sharp, marking an abrupt change from clean fluvial and tidal sandstone of the Dakota Sandstone to marine mudstone of the Tununk. The marine transgression is marked by a few inches of reworked sandstone and sandy mudstone.

The total thickness of the Tununk is 150 to 190 feet (45-57 m). In section 33, T. 19 S., R. 25 E., it is 151 feet (45 m) thick (appendix A) and in NW¼, section 35, T. 20 S., R 24 E., it is 190 feet (58 m) thick.

Coon Spring Sandstone Bed (Kmtc): The Coon Spring Sandstone Bed of the Tununk Member was named by Molenaar and Cobban (1991) with the type section northwest of Green River, Utah. In the Agate area, the Coon Spring Bed is about 100 feet (30 m) above the base of the Tununk Member. It is slightly to moderately fossiliferous silty shale with several thin, platy sandstone beds, an interval of large, rounded sandstone concretions up to 6 feet (2 m) in diameter, and scattered calcareous concretions up to 2 feet (0.6 m) in diameter (figure 8). The two types of concretions appear similar from a distance. The sandstone is medium yellowish brown to pale gray, very fine grained, and forms beds up to 3 inches (8 cm) thick. Fossils include bivalves *Exogyra, Pinna,* and *Inoceramus* (Kauffman, 1977; Molenaar and Cobban, 1991). The only well-exposed part of the unit is the sandstone concretions. The upper and lower contacts are gradational and the thin sandstone beds are only locally exposed. In the southwestern part of the quadrangle, the sandstone concretions zone is missing or is not exposed and the bed is recognized

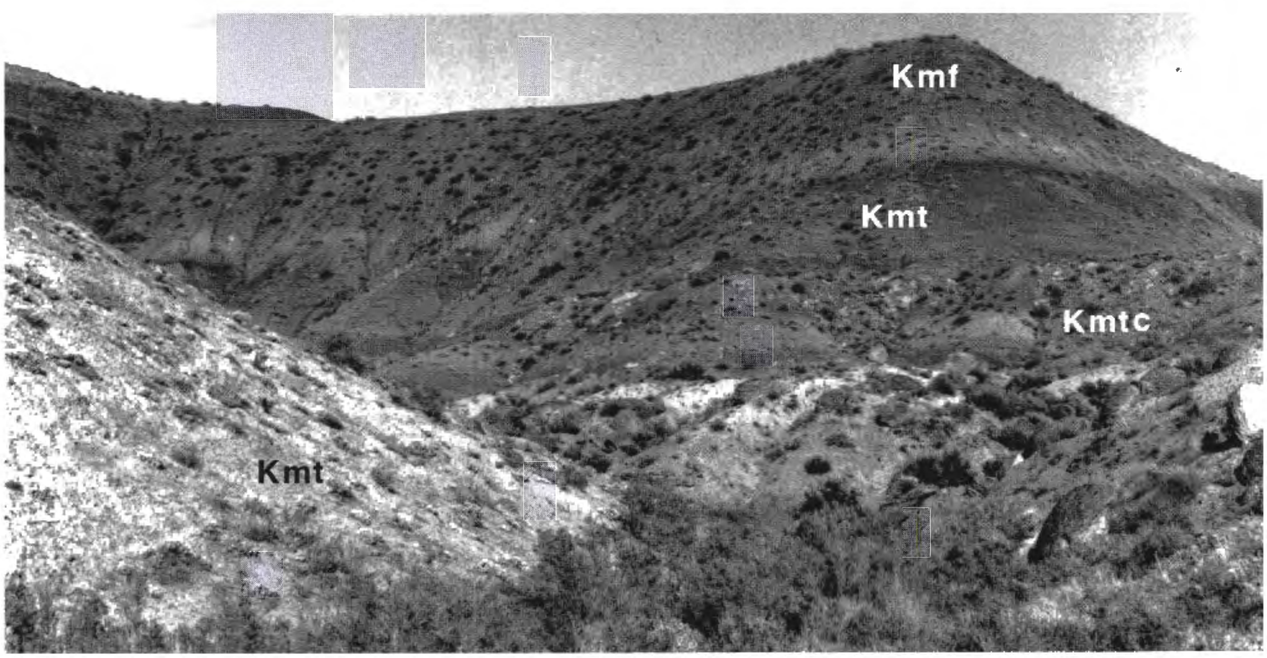


Figure 8. *The Tununk Shale Member (Kmt) of the Mancos Shale is exposed in the lower half of the photograph. Rounded boulders are concretions from the Coon Spring Bed (Kmtc). The upper slope is the Ferron Sandstone Member (Kmf). Photographed in section 33, T. 19 S., R. 25 E..*

only by thin, platy sandstone float. In that area the contact is drawn using poorly exposed calcareous concretions that are typically about 15 feet (45 m) lower in the bed. The Coon Spring Sandstone Bed is 35 to 45 feet (11-14 m) thick in the quadrangle.

Ferron Sandstone Member (Kmf): A relatively resistant sandstone interval in the lower part of the Mancos Shale forms a low but prominent cuesta throughout east-central Utah. This interval is the Ferron Sandstone Member of most published maps and reports (Cashion, 1973; Gualtieri, 1988; Hintze, 1988). However, Molenaar and Cobban (1991) argued that the beds exposed in eastern Utah correlate directly with the Juana Lopez Member in the San Juan basin of northwestern New Mexico and not with the Ferron Sandstone of central Utah. We disagree because the eastern Utah strata are equivalent in age and stratigraphic position to the upper part of the fluvial-deltaic Ferron Sandstone Member at its type section (Ryer and McPhillips, 1983; Molenaar and Cobban, 1991). They were deposited directly east and offshore of the Ferron deltaic deposits of central Utah and are likely the distal equivalent of the deltaic beds. The Ferron beds have been eroded in the uplifted San Rafael Swell area between central and eastern Utah such that direct correlation cannot be made.

The Ferron forms a persistent double cuesta that stands about 80 feet (24 m) above the surrounding topography. It consists of fissile sandy shale, silty shale, coaly siltstone, and sandstone. The medium-brown quartzose sandstone is well sorted, very fine grained to fine grained, and is laminated to thin bedded, forming intervals 5 to 10 feet (1.5-3 m) thick. Thin, platy sandstone and silty shale form alternating intervals 10 to 20 feet (3-6 m) thick. Rounded concretions 1 to 3 feet (0.3-1 m) in diameter, commonly cored with siderite and calcite, are common in the lower part of the Ferron. Fossils are abundant, and Molenaar and Cobban (1991) identified oysters (*Lopha lugubris*), bivalves (*Inoceramus dimidius and I. perplexus*), and ammonites (*Prionocyclus macombi, P. wyomingensis* and two or three species of *Scaphites*).

The base of the Ferron is marked by a scoured surface locally overlain by lenticular lag deposits of pebbly, medium- to very coarse-grained sandstone. The lag deposits form widely separated, small, ledgy outcrops 1 to 3 feet (0.3-1 m) thick, up to 30 feet (9 m) long, and up to 1 mile (1.6 km) apart. Small pebbles, mostly less than 0.25 inch (0.6 cm) but as much as 0.75 inch (1.8 cm) in diameter, are locally present in the lag, and small fish teeth are sparsely scattered throughout. Though sparse and laterally discontinuous, the resistant sandstone lag deposits are the key to mapping the basal contact. This basal unconformity is a major sequence boundary between the Greenhorn cyclothem (below) and the Niobara cyclothem (above) (Van Wagoner and others, 1990; Molenaar and Cobban, 1991).

The Ferron is 124 feet (37.8 m) thick in section 33, T. 19 S., R. 25 E., and is 125 feet (38 m) thick in section 35, T. 20 S., R. 24 E (appendix A). The top was eroded or is covered at both sites, but the measurements are believed to be near complete. Molenaar and Cobban (1991) calculated thicknesses of 80 to 100 feet (24-30 m) in wells a few miles north of the quadrangle. The variation is due to selection of different horizons for the indistinct upper contact.

Lower part of the Bluegate Shale Member (Kmbl): The thickest and most widely distributed unit in the quadrangle is the lower part of the Bluegate Shale Member, of which about 1,500 feet (460 m) is preserved in the Agate quadrangle. This interval is primarily medium- to dark-gray shale, silty shale, and mudstone that is variably sandy. Fresh surfaces are dark brownish gray to brownish black. Macro-fossils are rare, and bioturbation is rare to common. A few thin beds of very fine-grained sandstone and several thin layers of altered volcanic ash are scattered throughout the unit. Two prominent sandstone beds were mapped as marker beds M_1 and M_2. The ash beds are white to pale yellow and contrast sharply with the dark-gray shale. Except for rare sandstone beds, the entire interval is nonresistant and forms a broad lowland between the more resistant Ferron Sandstone and the Prairie Canyon Member (exposed north of the quadrangle) (Willis, 1994). The unit is commonly covered with a thin veneer of alluvial or eolian deposits and exposures are deeply weathered, obscuring most sedimentary structures. Beds that are slightly sandy take on a yellowish hue, producing a subtle striped appearance when viewed from a distance. To the north, the lower part is 1,600 to 1,800 feet (490-550 m) thick (Willis, 1994), of which about 1,500 feet (460 m) is preserved in the quadrangle.

Quaternary

The quadrangle is in an area that is undergoing relatively rapid downcutting and erosion, and surficial deposits are mostly thin and scattered. Older surficial deposits are limited to eolian and alluvial deposits on protected benches, pediments, and terraces. All surficial deposits in the quadrangle are probably Quaternary in age (first letter in the map symbol). The surficial deposits are herein categorized by predominant interpreted environment of deposition (second letter in the map symbol), then by subenvironment or grain size (generally the third letter in the map symbol), and then, where necessary, by relative age (number subscript or "o" for older in the map symbol).

We have differentiated several active and inactive alluvial surfaces in the area into eight levels. Deposits on active alluvial surfaces (the lowest level) are mapped as alluvial deposits (Qal_1 and Qas). Successively older deposits are remnants on pediments and terraces and have higher numbers, the oldest unit being Qat_8. Numbering is continued from mapping in the adjacent Harley Dome quadrangle (Willis, 1994) and not all levels are present in the Agate quadrangle. Deposits not directly correlative to the pediments and terraces are not numbered. They are generally farther from major drainages, and probably have a broader age range (Correlation of Surficial Deposits and Correlation of Pediment and Terrace Deposits charts, plate 2).

Ages and correlation of surficial deposits were estimated by comparing pedogenic soil carbonate development, lithology, degree of preservation, height of deposits above nearby drainages graded to the Colorado River, and by correlation with deposits in the Harley Dome quadrangle (Willis, 1992, 1994; plate 2).

The elevations of alluvial-deposit remnants above major tributaries of the Colorado River can be used to estimate age of the deposits. The Colorado River and its tributaries have been eroding the Colorado Plateau for several million years. Willis (1992, 1994) calculated an average downcutting rate for the river of 0.6 feet (0.18 m) per thousand years for the past 620,000 years. The rate was calculated using the present height of an exposure of Lava Creek B volcanic ash preserved at a site in the Harley Dome quadrangle about 360 feet (110 m) above nearby tributaries of the river. The Lava Creek B ash erupted from a volcanic caldera in the Yellowstone Park area 620,000 years ago (Izett and Wilcox, 1982). Similar downcutting rates have been determined by Hunt (1956) and Biggar (1987). Constructed profiles of river tributaries in the quadrangle show that larger streams rapidly adjust to changes in river base level and serve as reliable base level indicators.

Pedogenic carbonate (caliche) is derived from windblown dust and accumulates near the top of the soil profile at a measurable rate (Machette, 1985; Birkeland and others, 1991), and thus the amount of accumulated carbonate can be used to estimate age of surficial deposits or topographic surfaces. Some eolian sand deposits, older alluvial deposits, and bedrock surfaces in the quadrangle have well-developed carbonate horizons and may be as old as 800,000 years (Correlation of Pediment and Terrace Deposits chart on plate 2).

Alluvial Deposits

Terrace gravel deposits of the Colorado River (Qat_2-Qat_8): Terrace gravel deposits from the Colorado River are preserved as isolated remnants in Westwater Canyon. They consist of moderately to well-sorted sand and gravel. Clasts are primarily metamorphic and igneous rocks that were transported 20 miles (32 km) from the closest possible source, and many clasts may have been transported over 100 miles (160 km). Clasts up to about 1 foot (0.3 m) in diameter are present, but clasts average 2 to 6 inches (5-15 cm). Deposits are divided into five map units based on elevation above the present river (plate 2), labeled Qat_2 to Qat_8 (levels three and five are not preserved in this quadrangle). Terrace deposits range up to about 40 feet (12 m) thick.

Sand and gravel deposits of the Colorado River (Qas): Sand and gravel bars at normal water level in the active channel of the Colorado River are similar in composition and depositional environment to the older terraces deposits of the river (Qat_2-Qat_8). They consist of moderately to well-sorted sand and gravel. They are similar in age to map unit Qal_1 but have a different composition. They are reworked during heavy spring runoff and therefore are transitory in nature.

Pediment- and terrace-mantle deposits (Qap_3, Qap_4): Pediment- and terrace-mantle deposits consist of a thin veneer of poorly to moderately sorted sand and gravel, and boulders with minor silt and clay that cover gently inclined erosional surfaces developed on older bedrock. Most clasts are less than 2 feet (0.6 m) in diameter but a few larger boulders are present. These deposits are mapped only in the northwestern part of the quadrangle and in one small remnant in the southwestern part. Most of these surfaces are strath terraces of Westwater and Cottonwood Creeks, but in many locations it is impractical to divide terraces from pediments, thus all are lumped into one category (Willis, 1994). Deposits on beveled surfaces ranging from 20 to 60 feet (6-18 m) above adjacent drainages are mapped as Qap_3. Qap_4 deposits are older and are on several surfaces between 60 and 110 feet (18-34 m) above the creeks.

Stream deposits (Qal_1, Qal_2): Thin deposits of moderately sorted, clay- to boulder-size alluvial materials are present in the channels of Cottonwood and Westwater Creeks. This material differs from undifferentiated alluvial deposits (Qa and Qao) in that it is generally better sorted and contains a higher proportion of material derived from outside the area. Clasts are sedimentary rock fragments derived primarily from the Book Cliffs whereas Qas deposits consist primarily of better-sorted metamorphic and igneous clasts. Younger deposits (Qal_1) are present in or near the bottoms of active channels. The upper surfaces of older deposits (Qal_2) are dissected and are 10 to 30 feet (3-9 m) above active channels. Both units are typically 10 to 30 feet (3-9 m) thick.

Older alluvial deposits (Qao): These deposits are mapped in the central to southwestern part of the quadrangle near Cottonwood Creek where they protrude from beneath eolian deposits. They consist of poorly to moderately sorted mud- to boulder-sized material. Clasts were derived from both within and outside of the quadrangle. The deposits are primarily alluvial, but include minor amounts of colluvial and eolian materials. The deposits are generally older than Qal_2 deposits and are younger than Qap_4 deposits. They are up to 40 feet (12 m) thick.

Alluvial deposits (Qa): This unit consists of poorly to moderately sorted, mud- to boulder-sized material of local origin. It consists mostly of material deposited along small, poorly to well-defined, active drainages, but includes small deposits of older materials too small to map separately. The deposits are poorly defined and gradational with other surficial materials. In some areas they contain minor eolian and colluvial materials. Deposits are generally less than 10 feet (3 m) thick and are frequently reworked by flashfloods and spring runoff. They are mostly Holocene but may be older in some areas.

Eolian Deposits

Eolian sand deposits (Qes): Pale-reddish-orange, well- to very well-sorted, wind-blown sand and silt is common on benches and protected areas throughout the quadrangle. Most deposits are semi-stabilized by vegetation, but locally they are dune-shaped and active. Much of the sand was probably derived from the weathering of friable sandstone formations that it now covers (especially the Entrada Sandstone), but some sand may be from outside the area. The deposits are typically in mounds with steep 20-foot (6-m) margins, and may be as thick as 40 feet (12 m). In many places Qes deposits grade into Qea deposits.

Locally, the Qes deposits have well-developed stage III to IV pedogenic carbonate horizons, indicating an older period of stabilization. The carbonate horizons generally parallel ground slopes and are up to 4 feet (1.2 m) thick. In several areas the carbonate horizons are being eroded and form steep bluffs. In other areas, they are covered by dunes as much as 15 feet (4.6 m) thick.

Mass-Movement Deposits

Landslide deposits (Qms): Small landslides are mapped near the center of the quadrangle and in the northeastern part near Westwater Creek. The deposits consist of very poorly sorted, angular boulders supported in sandy and muddy matrix. They include rotational blocks from the Brushy Basin Member, and colluvium, talus, and shallow weathered bedrock from the Brushy Basin, the Cedar Mountain Formation, and the Dakota Sandstone.

The landslide deposits are dissected and the upper surface is about 80 feet (24 m) above nearby washes, roughly the same elevation as Qap_4 deposits. No evidence was observed to indicate historic landslide movement. The surfaces are hummocky and have local undrained depressions. Erosional windows into the underlying Brushy Basin Member are common. The landslides are mostly less than 20 feet (6 m) thick, but locally are as much as 50 feet (15 m) thick.

Talus deposits (Qmt): Talus deposits are common below cliffs and on steep slopes throughout the quadrangle, but are extensive enough to map in only a few areas. Talus derived from the Dakota Sandstone, the Cedar Mountain Formation, and the Brushy Basin Member are mapped in the central and eastern parts of the quadrangle beneath the Dakota Sandstone cliff (figure 1). Similar deposits are mapped below the Wingate Sandstone cliff and on Precambrian rocks in Westwater Canyon. The deposits consist of very poorly sorted angular boulders up to 20 feet (6 m) in diameter. Talus commonly armors less-resistant formations and gradually weathers out in relief as unprotected parts of the formations are eroded. The deposits range from a few feet up to about 30 feet (9 m) thick.

Mixed-Environment Deposits

Alluvial and colluvial mud and sheet-wash deposits (Qam): Many broad, flat to gently sloping surfaces in the northwestern part of the quadrangle are covered with moderately well-sorted mud, silt, clay, and some sand weathered from nearby outcrops of Mancos Shale or from the middle member of the Dakota Sandstone. The material was derived mostly from in-situ weathering of muddy outcrops and from colluvial processes and has had limited transport. It forms a thin cover that obscures bedrock. Locally, the deposits are mixed with sand or minor gravel- to boulder-sized materials eroded from nearby pediments or outcrops. It grades into deposits Qal_1, Qal_2, Qae, and Qea. Most deposits are less than 20 feet (6 m) thick.

Alluvial and colluvial deposits (Qac): Thin deposits in a few small, steep washes near Westwater Canyon are mapped as mixed alluvial and colluvial deposits. The alluvial deposits were transported along the washes by heavy rainstorms while the colluvial material was derived from steep side slopes along the washes. The material is generally poorly to moderately sorted and is thin and scattered. The unit locally contains some eolian deposits.

Eolian and alluvial deposits (Qea): Many of the broad surfaces and gentle slopes in the quadrangle are blanketed by mixed eolian, alluvial, and residual weathering deposits. Normally, there is little erosion on these surfaces because bordering washes are entrenched and most precipitation sinks into the porous surficial material. Eolian dust and sand gradually accumulate on the deposits. Scattered pebbles and poorly developed drainage patterns indicate a limited amount of alluvial reworking. In addition, thin alluvial gravels are exposed near the base of this unit.

The deposits are composed primarily of moderately well- to very well-sorted sand with minor mud and gravel. Much of the sand is derived from underlying or nearby sandstone bedrock units; the overall color of the deposits and the bedrock are generally similar. The deposits cover large areas, forming smooth, nearly flat to gently rolling or sloping surfaces covered with grass (especially cheat grass) and tumble weeds (Russian thistle). Locally, recent flooding has cut deep rills into this unit, often reaching the bedrock beneath. Where eroded, the walls of the deposit commonly stand nearly vertical, indicating some consolidation and possible cementation by clay particles. Minor soil development is evident. The deposits are mostly less than 8 feet (2.4 m) thick, but locally fill depressions as much as 20 feet (6 m) deep.

Alluvial and eolian deposits (Qae): These deposits consist primarily of moderately to well-sorted clay to fine sand, but locally contain gravel. They are primarily alluvial, but include some eolian material, and locally, some colluvial material. The unit is common on broad slopes and in low areas with minor drainages and limited runoff. Slope wash and small washes are the dominant process in most areas. Locally, the unit is crossed by small washes that contain deposits similar to Qa but that are too small to map. The unit is up to 20 feet (6 m) thick.

Artificial Fill (Qf)

Fill and disturbed areas are common in the quadrangle, but are generally too small to map. These include fill for construction of Interstate 70, railroad beds, local roads, and small dams on ephemeral streams. The three mapped fill deposits are large and obscure important stratigraphic relationships. Two are fill emplaced during railroad construction; one in the center and another near the eastern edge of the quadrangle. The other is a dam that was constructed across Cottonwood Creek in the west-central map area. It is an engineered structure that had rock facing, a wood-framed headgate structure, and a spillway. We do not know exactly when the dam was constructed, but it has been breached by the creek.

STRUCTURE

The Agate quadrangle is located on a gentle dip slope between the northwestern flank of the Uncompahgre Plateau and the southeastern flank of the Uinta Basin. The Paradox basin is located about 20 miles (36 km) to the southwest. The structural history of the quadrangle can be divided into: (1) Proterozoic deformation and intrusion, (2) late Paleozoic and early Mesozoic offset on the Uncompahgre fault, (3) gentle folding and minor faulting of probable early Tertiary age, and (4) late Tertiary uplift of the Colorado Plateau.

Structure of Proterozoic Crystalline Rocks

Basement rocks were complexly folded and metamorphosed during multiple episodes of deformation and intrusion in the Proterozoic (Case, 1991). The earliest recognizable episode was characterized by development of metamorphic foliation and lineation, and by folds with axial traces that trend north, northeast, and northwest. A later Proterozoic episode refolded the early structures (Case, 1991) but no features related to this later event were recognized in the Agate quadrangle.

Metamorphic foliation, lineation, and large folds of the early episode are exposed in Westwater Canyon (figure 3). The foliation is mostly steep to nearly vertical, but strike directions vary, rotating with the large, open folds. The large folds are best defined by patterns of contacts between competent rock units such as the feldspathic gneiss, amphibole gneiss and amphibolite, and microcline augen gneiss. The less competent, thinly layered, biotite-microcline gneiss is characterized by smaller scale isoclinal and disharmonic folds. The most obvious basement fold in the quadrangle is the Little Dolores River synform. The axial trace of the nearly isoclinal synform trends east and northeast and the axis plunges steeply eastward. The steeply northeast-plunging antiformal nose of the north and northeast-trending Westwater Canyon antiform can be seen just south of the Little Dolores River synform. North of the Little Dolores River synform, the Snyder Mesa antiform is a broad, steeply southeast-plunging antiform defined by rock unit patterns and foliation trends.

Uncompahgre Fault

The Agate quadrangle is located about 20 miles (32 km) northeast of the buried Uncompahgre fault, which bounds the southwestern margin of the ancestral Uncompahgre Plateau (figure 9). The Uncompahgre fault is a northwest-trending, down-to-the-southwest, reverse fault with about 20,000 feet (6,000 m) of vertical displacement and more than 30,000 feet (10,000 m) of horizontal offset (Frahme and Vaughn, 1983). It was active primarily in the late Paleozoic. Several thousand feet of Proterozoic and early to middle Paleozoic rocks were probably eroded from the uplifted highland (including from the Agate quadrangle) prior to the Late Triassic. Much of the eroded material was deposited in the adjacent Paradox basin to the southwest (White and Jacobsen, 1983). The Upper Triassic Chinle Formation was the first unit deposited across the Uncompahgre uplift.

Structure of Stratified Rocks

Most strata in the Agate quadrangle dip 3 to 7 degrees to the northwest, but are gently warped by two broad synclines and a broad anticline. Locally, beds are steeply tilted by a northwest-trending monocline. The broad anticline and the monocline are jointly referred to here as the Seiber Nose structure. The folds have been important in oil and gas accumulation throughout the area (figures 2 and 9). Only one minor fault is exposed in the quadrangle. Locally, joint sets are prominent and several unconformities with possible structural implications are present.

Gentle Folds

The axial traces of two gentle synclines trend generally northwest across the quadrangle. The Danish Flat syncline crosses the northern part, and an unnamed syncline crosses the southern part. Both of these structures are broad, open folds that plunge gently to the northwest and are difficult to detect in the field. They are separated by the Seiber Nose structure, a tight monocline superimposed on a broad anticline (the axial trace of the monocline and anticline approximately coincide and both structures are shown on the map by one monocline symbol). The anticline is indicated on the map by the broad curvature of the structural contours between the two synclines (where not overprinted by the tight monocline). It is also indicated on cross section B-B′ by the slight change in dip between the southwest and northeast ends of the section (away from local deformation caused by the monocline).

Seiber Nose Structure

The Seiber Nose structure is one of several monoclines draped over northwest-trending, high-angle basement faults in the northwestern part of the Uncompahgre Plateau (Lohman, 1965; Jamison and Stearns, 1982; Heyman, 1983; Young, 1983). It is called a "structure" because it is a compound fold consisting of a low amplitude, broad anticline overprinted (refolded?) by a fault-propagated monocline. We interpret the anticline to be slightly older than the monocline though ages relationships are unclear and the structures may have formed simultaneously. Both probably formed during the early Tertiary (see discussion of age of tectonic deformation in Geologic History section).

The conspicuous monocline is well exposed in the east-central part of the quadrangle where headward erosion from the Colorado River has cut a narrow canyon for about 1 mile (1.6 km) along the limb of the monocline (figure 10). The monocline trends N. 65-70° W. and plunges gently to the northwest.

Exposed Lower and Middle Jurassic strata in the monocline dip 50 to 70 degrees to the northeast. The rocks in the steep northeastern limb are intensely fractured and attenuated, but bend downward almost at a right angle without obvious faulting of the rocks. The Kayenta Formation and the Dewey Bridge and Slick Rock Members of the Entrada Sandstone are estimated to be attenuated 20 to 50 percent in the hinge. The Wingate Sandstone is incompletely exposed in the intensely fractured zone, but also appears to be significantly thinned. Heyman (1983), who studied several folds in the area, indicated that the Wingate, Kayenta, and Entrada Formations are typically attenuated as much as 30 percent along fault-propagated monoclines, and Jamison and Stearns (1982) found that the Wingate Sandstone thinned about 20 percent over similar structures in the Colorado National Monument. They noted that flexure and attenuation of the Wingate Sandstone occurred through micro-

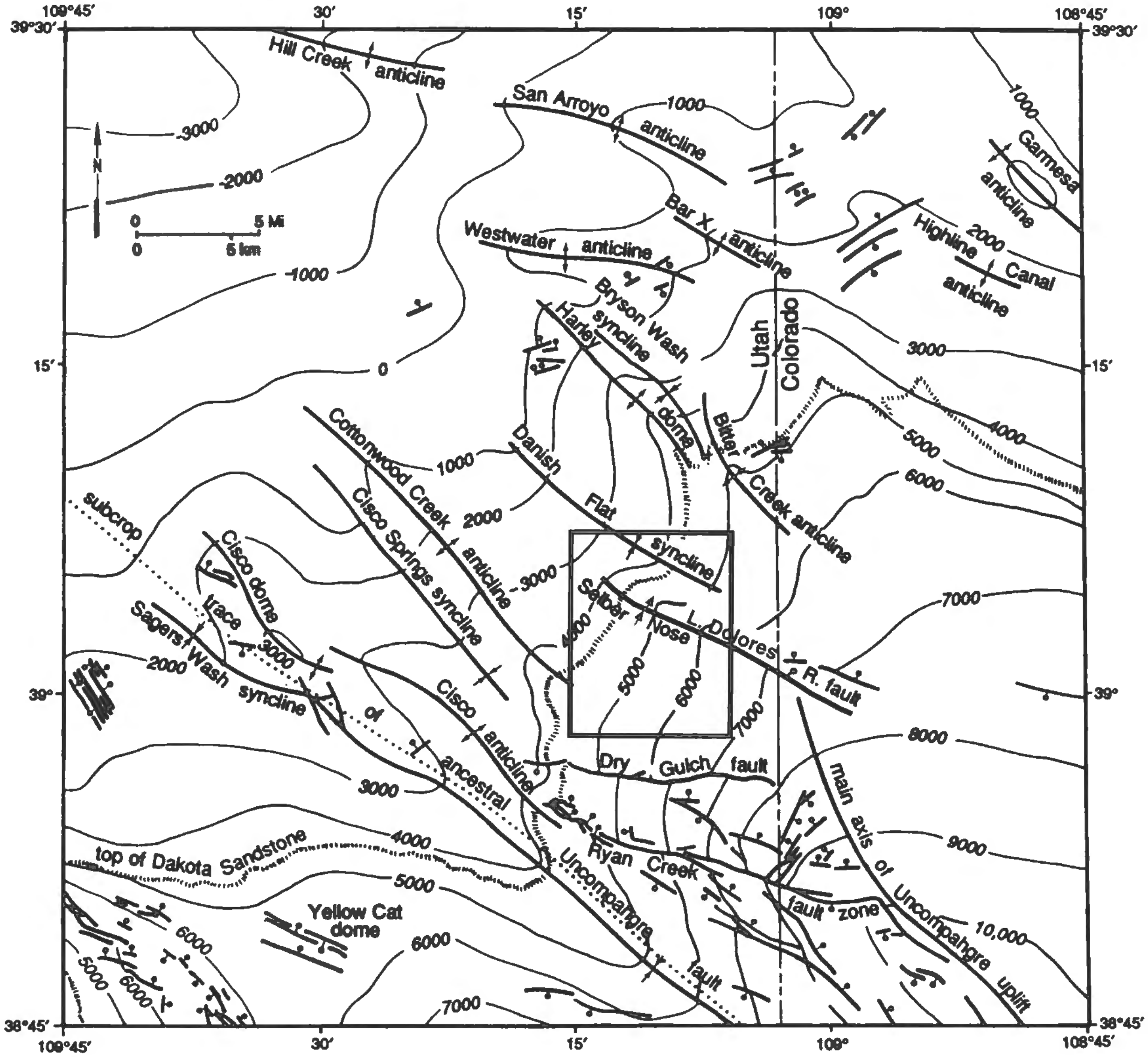


Figure 9. Simplified structural contour map showing the regional setting of the Agate quadrangle. One-thousand-foot (300 m) contours are drawn on the top of the Dakota Sandstone, the outcrop of which is indicated by the hachured line (modified from Williams, 1964 and Cashion, 1973). Heavy line indicates area of quadrangle.

faults, Riedel shear zones, fault zones, and fractures. In the fold hinge in the quadrangle, anastomosing networks of microfaults and fractures cut the Wingate Sandstone, Kayenta Formation, and Dewey Bridge and Slick Rock Members of the Entrada Sandstone.

No clearly discernible large fault or fault zone is visible along the monocline in the quadrangle. However, the fault is well exposed to the east, across the Colorado River, along the trend of the monocline (Cashion, 1973; Gualtieri, 1988). There, the Little Dolores River fault juxtaposes the Kayenta and Entrada Formations against the Proterozoic basement for an offset of about 700 feet (215 m). Heyman (1983) reported slickensides dipping 80 to 85° southwest along the fault and indicated that it is a high-angle reverse fault.

Cross section B-B′ shows our subsurface interpretation of the structure with the Little Dolores River fault offsetting the Proterozoic basement, Chinle Formation, and lower part of the Wingate Sandstone, and also force-folding the monocline. The estimated offset in the Precambrian rocks in the subsurface at section B-B′ is 700 to 800 feet (213-244 m). Case (1991) interpreted the Little Dolores River fault as a northeast-dipping, high-angle normal fault, but cited no field evidence on which to base this interpretation.

The Little Dolores River fault parallels foliation in the Proterozoic metamorphic rocks and numerous aplitic veinlets, brecciation, and possible mylonitization are found near it, suggesting that it may be a reactivated Proterozoic fault zone (Case, 1991). Young (1983) also suggested that northwest-trending faults in the area are probably reactivated Proterozoic structures.

The surface expression of the monocline decreases to the

Figure 10. *Fault-propagated monocline of the Seiber Nose structure near the Colorado River showing attenuated Kayenta Formation (Jk), and Dewey Bridge (Jed) and Slick Rock (Jes) Members of the Entrada Sandstone. No discrete fault is recognized at the surface in this area.*

northwest; the Dakota Sandstone and Ferron Sandstone Member in the center of the quadrangle are only moderately warped. Though not apparent in exposed rock, drill hole information (table 1 and plate 1) shows a flexure in the Dakota Sandstone beneath the northwestern part of the quadrangle, along the monoclinal trend. Keebler (1956) showed the Dakota Sandstone as faulted in this part of the quadrangle, but Quigley (1961) showed only a fold. The Dakota is not faulted where exposed in sections 7 and 8, T. 20 S., R. 25 E., just to the southeast. We believe the Little Dolores River fault only offsets Proterozoic basement and possibly older Mesozoic strata in that part of the quadrangle, similar to our interpretation in section B-B′ (plate 2).

Small Faults

The only exposed fault is in the south-central part of the quadrangle in section 36, T. 20 S., R. 24 E., and in section 31, T. 20 S., R. 25 E. It trends east-northeast, is down-to-the-south, and has up to 20 feet (6 m) of offset. Its relationship with other structures in the area is unclear. Gualtieri (1988) mapped a fault in the Entrada Sandstone in the southeastern part of the quadrangle; however, we found that the bedrock is not offset and the feature is a large joint.

Joints

Joints are locally prominent in the outcrops of thick to massive sandstone near the Seiber Nose structure and in outcrops of Dakota Sandstone and the Moab Member of the Entrada Sandstone throughout the quadrangle. Most major joint sets are nearly vertical and parallel the major northwest structural trend in the area and are assumed to have formed at the same time. Conjugate sets are not common. Some jointing may be younger and related to uplift and unloading due to denudation of the Colorado Plateau.

GEOLOGIC HISTORY

Precambrian gneissic rocks of the Uncompahgre Plateau are part of a complex of meta-sedimentary and meta-igneous gneisses of late Early Proterozoic age exposed throughout the central and southern Rocky Mountains. This Early Proterozoic gneissic terrain abuts the southern margin of the Archean Wyoming province. The sedimentary and igneous (volcanic) protoliths of the gneisses probably accumulated in an oceanic island-arc environment (Tweto, 1987). The protoliths were metamorphosed and deformed during a pre-1,700 million-year event and underwent a second period of deformation and intrusion of igneous rock about 1,700 Ma (Tweto, 1987; Case, 1991). The slightly foliated to non-foliated metadiorite-metagabbro of the Little Dolores River pluton and a gneissic granodiorite intrusion (not located in the quadrangle) were probably emplaced syndeformationally at this time (Tweto, 1987; Case, 1991). The numerous small unmapped pegmatites and granitic dikes and dikelets in the Westwater Canyon area that crosscut most metamorphic rock types may be related to a post-deformation quartz monzonite intrusion emplaced about 1,443 ± 22 Ma (Case, 1991). This non-foliated granitoid intrusion postdates metamorphism and deformation and is believed to be part of the Vernal Mesa quartz monzonite batholith (Tweto, 1987; Case, 1991). No record of subsequent tectonic or depositional events until the late

Paleozoic are preserved in the northwestern Uncompahgre Plateau.

The ancestral Uncompahgre uplift developed during Pennsylvanian to Permian tectonism in western North America (Cater, 1970; White and Jacobson, 1983). The uplift was a pronounced northwest-southeast-trending topographic high bounded on the southwest by the Paradox basin and on the northeast by the central Colorado trough (Cater, 1970). Erosion eventually beveled the highland to a relatively even surface on the crystalline basement (Cater, 1970; Mack and Rasmussen, 1984). Detritus from this episode of erosion, which removed at least 2,000 feet (600 m) of Paleozoic sedimentary rocks, and a large, but unknown, thickness of Precambrian metamorphic and igneous rocks from the upthrown block, filled syntectonic basins on both flanks of the uplift. The Paradox basin was filled with up to 20,000 feet (6,000 m) of clastics, carbonates, and evaporites. By Late Triassic time the fault was inactive and the topography was subdued enough to allow deposition across the uplift. The upthrown block continued to exert some influence on deposition throughout the Mesozoic, causing noticeable thinning and pinchouts of several formations that extend onto the block (Heyman and others, 1986).

Late Triassic redbeds of the Chinle Formation were the first sediments to be deposited across the uplift. The Chinle consists of stream and floodplain deposits that contain vertebrate, invertebrate, and trace fossils at various locations in eastern Utah (Stewart and others, 1972; Dubiel, 1994). Unconformably overlying the Chinle is a thick sequence of Early Jurassic sandstone. The basal unit of the sequence is the eolian Wingate Sandstone, which was deposited in a sandy desert environment. The Wingate grades upward into the fluviatile Kayenta Formation. The Kayenta represents a period during the Early Jurassic in which through-flowing drainage networks existed in eastern Utah. Overlying the Kayenta in much of eastern and southern Utah is the eolian Navajo Sandstone. However, in this quadrangle and adjacent areas, the Navajo has been removed by erosion at the J-2 unconformity that separates Lower Jurassic from Middle Jurassic strata (O'Sullivan and Pipiringos, 1983). The erosional truncation of the Navajo may reflect a positive area over the ancestral Uncompahgre uplift. The Dewey Bridge Member of the Entrada Sandstone was deposited in a paralic sandy mudflat environment about 50 to 75 miles (80-120 km) east of a shallow Middle Jurassic seaway (Craig and Shawe, 1975). The overlying Slick Rock and Moab Members are interpreted as eolian dune and interdune deposits of a sandy desert environment (Craig and Shawe, 1975). Strata from the Chinle through the Entrada thin in the area of the ancestral Uncompahgre uplift, suggesting the area remained somewhat positive relative to surrounding regions. The Summerville Formation represents shallow marine to tidal flat deposition. It is probably conformable with the Moab Member and is separated from the Morrison Formation by the J-5 unconformity (Pipiringos and O'Sullivan, 1978). The Morrison Formation was deposited in fluvial to lacustrine settings and represents later-stage infilling of a middle Mesozoic basin centered far to the west (O'Sullivan, 1984; Yingling, 1987). It is very bentonitic, reflecting widespread volcanism along the western continental margin of North America. The Cedar Mountain Formation contains sediment shed from Cretaceous uplift during the Sevier orogeny far to the west (Young, 1973; Yingling, 1987). The Dakota Sandstone is interpreted as the earliest near-shore coastal and paludal deposits associated with the western advance of the Late Cretaceous epicontinental sea (Young, 1960, 1973; Molenaar and Cobban, 1991). Current directions suggest deposition by east- to northeast-flowing fluvial systems. The Mancos Shale was deposited in an epeirogenic sea and reflects continued uplift and a vast sediment supply to the west. The Agate quadrangle is in the distal part of a foreland basin formed during the Sevier orogeny. Sand intervals such as the Coon Spring Sandstone Bed and the Ferron Sandstone were deposited far offshore but during periods of sea level regression (Ryer and McPhillips, 1983; Molenaar and Cobban, 1991).

No rocks from middle Cretaceous to middle Pleistocene are preserved in the quadrangle. Thus, interpretations of this interval are based on regional observations. The Laramide orogeny began to deform strata in the area during the Late Cretaceous (Johnson and Finn, 1986; Lawton, 1986). Major deformation that created the Uinta and Piceance Creek basins, Douglas Creek arch, and Uncompahgre uplift, and associated faults was primarily during the Paleocene and Eocene (Gries, 1983; Johnson, 1985, 1989; Johnson and Finn, 1986). The small folds and faults in the quadrangle are assumed to have formed contemporaneously with these larger structures. However, Johnson and Finn (1986) found evidence suggesting that normal faulting in the Douglas Creek arch to the northeast is post-Laramide, possibly occurring around 25 million years ago.

Regional uplift of the Colorado Plateau began about 10 million years ago (Hunt, 1956; Gable and Hatton, 1983; Johnson and Finn, 1986). The Colorado Plateau was uplifted 7,000 to 10,000 feet (2,000-3,000 m) while the Uncompahgre Plateau was lifted up to 3,000 feet (900 m) more, forming a structural high (Sinnock, 1981; Heyman and others, 1986). Since then, the history of the quadrangle has been one of erosion, and probably more than 10,000 feet (3,000 m) of Tertiary and older strata have been eroded from the area. The Colorado River was a meandering river that crossed a broad plain before 10 million years ago and was superimposed on the present surface (Hunt, 1956). In contrast, tributaries to the Colorado River in the quadrangle show young, immature development, and are controlled by downcutting of the river, not superimposition. The oldest surficial deposits in the quadrangle are probably small, isolated terrace gravel remnants (Qaf_8) about 460 feet (140 m) above the nearby Colorado River that are about 800,000 years old. The broad surface cut across the Kayenta and other formations in the southern part of the quadrangle has stage IV pedogenic carbonate that may be of similar age.

ECONOMIC GEOLOGY

Oil and Natural Gas

The Agate quadrangle has two small producing oil and gas fields (Seiber Nose and Sage) that are part of a cluster of several fields in eastern Grand County (figure 2 and table 1). The Utah

Table 1.
Oil and gas wells of the Agate quadrangle. Tops of the Dakota Sandstone, Entrada Sandstone, and the Precambrian were determined from well logs where available; others were extracted from driller logs (d symbol) and are unverified. The reported log pick for the top of the Dakota is a marker bed 20 to 30 feet (6-9 m) above the actual contact. This marker is used because it has a consistently strong kick on gamma ray and resistivity logs, while the upper part of the Dakota varies lithologically and the upper contact is not represented consistently on logs. Measurements are in feet. Abbreviations: BBLO - barrels of oil, MCFG - thousands of cubic feet of gas, BBLW - barrels of water. Status codes: oil - completed oil well, gas - completed gas well, S.I. - shut-in, D&A - dry and abandoned, O - oil show, G - gas show, W - water show.

Map Location Number	Location (Sec.-T.-R.)	Operator and Well Name	Completion Date	Total Depth (feet)	Formation at TD	Elevation Top of: Dakota Sandstone Entrada Sandstone (d-from driller logs)	Producing Formations	Cumulative Production (BBLO, MCF, BBLW)	Status-shows
1	SWNWSE 35-19S-24E	Promontory Oil Seiber Nose-Federal 3	09/14/64	1580	Morrison	3352 —			D&A-O
2	CSESW 35-19S24E	Carter Oil Henroid-Federal-2	10/03/55	1600	Morrison	3356 —			D&A-OG
3	SWSWSE 35-19S-24E	Ute Production Ute-Federal-3	10/23/71	1550	Morrison	3415d —			D&A
4	NESWSE 35-19S-24E	Carter Oil Henroid-Federal-1	04/09/55	2200	Entrada	3454 2625			D&A
5	SENENW 36-19S-24E	Gunnison Drilling Husky-State-1	10/15/68	1523	Morrison	3517 —			D&A-G
6	SWSESE 36-19S-24E	Adams, Frank B State-36-1	12-06-79	1602	Entrada	3885d 3042d			D&A
7	CSESE 30-19S-25E	Reynolds, Paul J Reynolds-Federal-1	04/02/65	965	Morrison	3846 —			D&A
8	CNENE 31-19S-25E	B&W Drilling Govt-2-X	11/02/56	865	Morrison	3880d —			D&A-O
9	CNENE 31-19S-25E	Reynolds, Paul J Federal-2X	04/28/65	870	Morrison	3880 —			D&A-WO
10	SESENW 31-19S 25E[1]	Agate Oil Government-4	06/18/56	2550	Morrison	3820d —			D&A
11	SWSESE 01-20S-24E	Gralapp, Ben Federal-2	08/23/67	630	Morrison	4472d —			D&A-O
12	NWNWSW 01-20S-24E	Clayton Investment Shuttle-2	01/25/82	1223	Dakota	4090 —			D&A
13	SWNWNE 02-20S-24E	Linn Bros. Oil & Gas, Inc. Duchess State 1-A	11/07/70	1338	Morrison	3567 —	Cedar Mtn.	136 0 0	Oil
14	NENESW 02-20S-24E	Cook, Delila 4-C State-1	05/13/73	1260	Morrison	3793d —			D&A
15	SWSWNE 02-20S-24E	Cook, Delila Duchess-2	11/06/70	1300	Morrison	3743d —			D&A
16	NESENW 02-20S-24E	Carter Oil Larsen-State-2	06/21/55	1374	Morrison	3749 —			D&A-O
17	NWSENW 02-20S-24E	Combined Oil and Gas State-1	01-15-77	1750	Morrison	? —			D&A
18	NWSESE 02-20S-24E	Dab Oil Cisco-1	02/03/84	1876	Entrada	3965d ?			D&A
19	NENWNW 02-20S-24E	Linn Bros. Oil & Gas, Inc. State-2 Combined	10/24/78	1590	Summerville	3405 —	Morrison	384 0 1	Oil
20	SENENW 02-20S-24E	McMillan-Johnson State-1	08/12/62	1665	Morrison	3520 —			D&A
21	SWNWNE 02-20S-24E	Cook, Delila A Duchess-1	10/27/70	1311	Morrison	3567 —			D&A
22	NESWNW 02-20S-24E	Larsen Industries State-3	07/11/61	955	Dakota	3677d —			D&A
23	NENENW 02-20S-24E	Linn Bros. Oil & Gas, Inc. Promontory Seiber State-1	12/18/64	1500	Morrison	3418 —	Morrison	90 0 77	D&A-O
24	CNENW 02-20S-24E	Linn Bros. Oil & Gas, Inc. Larsen-State-1	07/15/58	1445	Morrison	3475 —	Morrson	21594 0 6078	Oil-WO

Table 1 (continued)

Map Location Number	Location (Sec.-T.-R.)	Operator and Well Name	Completion Date	Total Depth (feet)	Formation at TD	Elevation Top of: Dakota Sandstone Entrada Sandstone (d-from driller logs)	Producing Formations	Cumulative Production (BBLO, MCF, BBLW)	Status-shows
25	CNENW 02-20S-24E	Carter Oil Larsen-State-1	02/17/55	1439	Morrison	3475 —		see Larsen State-1 above)	Oil
26	NWNENW 02-20S-24E	McMillan-Johnson State-2	08/30/62	1602	Morrison	3399 —			D&A
27	CNENE 03-20S-24E	Carter Oil Larsen-Federal-1	05/14/55	1650	Morrison	3434d —			D&A-OG
28	NENWNE 12-20S-24E	Sundial Exploration Ketchum-Rich-1	07/24/77	700	Morrison	4413 —			D&A-G
29	NENWNE 12-20S-24E	Toles & Toles Larsen-Federal-1	05/04/55	1235	Entrada	4413 3563			D&A-O
30	NENENW 13-20S-24E	Intermountain Petroleum Federal-1	04/22/61	640	Morrison	4483d —			D&A
31	NESWNW 14-20S-24E	Broadhead, Walter D. Broadhead-Federal-1	11/01/66	700	Morrison	4117d —	Dakota	185 0 0	Oil
32	NWSENW 14-20S-24E	Broadhead, Walter D. Broadhead-Federal-3	05/28/68	688	Dakota	4025d —			D&A
33	NENWSW 14-20S-24E	Broadhead, Walter D. Federal-Reina-1	09/21/78	1075	Morrison	4025d —			D&A
34	NENESE 15-20S-24E	Broadhead, Walter D. Broadhead-Federal-2	12/15/67	773	Morrison	4068 —			D&A-O
35	NESWNE 36-20S-24E[1]	Pumpelly, Raphael State-36-33	09/29/63	226	Morrison	— —			D&A
36	NWSENW 36-20S-24E	Goal Resources Goal-State-36-7	09/05/73	1556	Precambrian	— 4103d 3108d (Precambrian)			D&A
37	SESWSW 06-20S25E[2]	F-L Energy Federal Buttes-1-6	09/27/85	976	Entrada	4540 3762			D&A
38	NESENW 06-20S-25E	Viking Oil Government-2	10/25/68	980	Morrison	4133d —			D&A
39	NWNWSE 06-20S-25E	Ute Royalty Corp. Government-1	09/25/55	1300	Entrada	4258d 3438d			D&A
40	NWSWNW 06-20S-25E	Viking Oil South Seiber Nose-8	07/25/68	1309	Summerville	4100d —			D&A
41	NENENW 07-20S-25E	F-L Energy Federal Buttes-1-7	02/01/86	620	Morrison	surface —			D&A

[1]Locations given in state files for wells number 10 and 35 are not correct. Field checking showed no disturbance of ground at either location. The correct locations are not known, thus neither well is plotted on the map.

[2]Standpipe in field is labeled incorrectly but location and well name in this table are correct.

Table 2.
Composite analyses of four samples from coal seams in the Dakota Sandstone (Jackson, 1983)

	Range	Average
Btu/lb	3,000 - 9,000	5,500
Ash	20 - 80%	54%
Moisture	4 - 22%	14%
Sulfur	0.15 - 0.88%	0.44%
Carbon	6 - 32%	18%
Hydrogen	1.3 - 3.8%	2.4%
Nitrogen	0.2 - 0.6%	0.4%
Oxygen	3.3 - 26%	10.6%

Division of Oil, Gas and Mining combines these clustered fields into the Greater Cisco Area field. The fields in the Greater Cisco Area are primarily gas producers, though oil has also been produced. Primary targets are sandstone and sandy siltstone intervals in the Mancos Shale, Dakota Sandstone, Cedar Mountain Formation, Morrison Formation, and Entrada Sandstone (Stowe, 1972). Young (1983) suggested that the gas was derived primarily from carbonaceous material in the Mancos, Dakota, Cedar Mountain, and Morrison Formations whereas the oil was derived from Pennsylvanian strata in the deep Paradox basin about 20 miles (32 km) to the southwest and migrated eastward and up section to reservoirs in the Agate area.

The first recorded well in the quadrangle, the Carter Oil Larsen-State 1, drilled in 1955, flowed 126 barrels of oil per day (Keebler, 1956). After an initial rush of drilling, exploration has been sporadic, with pulses of activity in the mid 1950s, late 1960s, late 1970s, and early 1980s. The most recent well was drilled in 1986 (table 1). Production has been hindered by the presence of carbon dioxide, nitrogen, and helium (R.G. Young, written communication, 1991; Willis, 1994).

The two productive fields in the quadrangle, the Seiber Nose and the Sage (figure 2), are located near the northwestern end of the Seiber Nose (figure 9). The oil reservoir is a thin, lenticular sandstone bed in the upper part of the Morrison Formation (Keebler, 1956; Quigley, 1961). The stratigraphic trap may be enhanced by folding or faulting of strata along the Seiber Nose structure. Though surface strata are not faulted, the structure probably overlies a northwestward extension of the Little Dolores River fault (similar to relationships shown in cross section B-B′).

Coal and Humates

The Dakota Sandstone contains a carbonaceous interval that has been prospected for coal and humates (figure 11). The coal is thin, lenticular, and generally impure. Ellis and Hopeck (1985) reported that no seams greater than 30 inches (75 cm) thick are present in the area. We found no seams thicker than 24 inches (60 cm), and most are less than 12 inches (30 cm) thick. Overburden is 100 feet (30 m) or less over about 9 square miles (23 km^2). Jackson (1983) reported analyses of 3,000 to 9,000 BTU per pound (340-1,020 kg-calories per kg), and a subbituminous C or lower rank for the coal (table 2). A partial analysis of "better" coal yielded 8,850 Btu/lb (MAF) with 25.3 percent ash, 22.8 percent moisture, 21.5 percent oxygen, and 26.1 percent fixed carbon (P/S Associates, 1981, unpublished data). These analyses seem low for Dakota coals and may indicate weathered samples since Doelling and Graham (1972, p. 274) reported analyses of six coal samples from the Dakota Sandstone in southeastern Grand County that ranged from 9,300 to 14,750 BTU per pound (1,064-1,688 kg-calories per kg).

Though the coal in the Dakota Sandstone presently (1995) shows limited economic potential as a fuel resource, the carbonaceous material has generated considerable interest as a source of humates (Jackson, 1983). Humate is a natural carbonaceous substance that is readily soluble in slightly alkaline water. Humates are used in agriculture as a fertilizer and soil conditioner, and are leached to produce mineral-rich liquids for use in health foods. Good humate raw materials should contain at least 25 percent soluble organic matter. Though value per ton is low

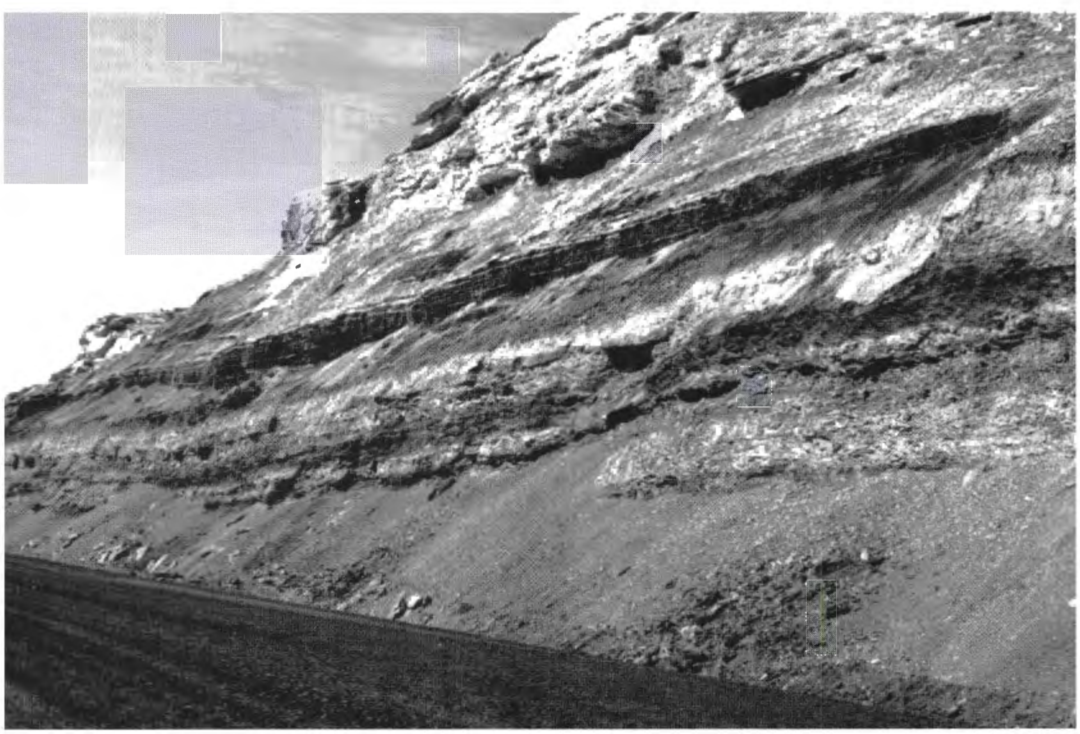


Figure 11. *Outcrop of coal and humates in the Dakota Sandstone in section 33, T. 19 S., R. 25 E..*

compared to coal, humates can be economical when a large tonnage with limited overburden is easily accessible.

In the northern part of the quadrangle, the minable interval is 20 to 30 feet (6-9 m) thick, has thin (typically 0-30 feet; 0-9 m) overburden, and consists of two continuous zones, except where incised by paleochannels or modern drainages. The upper zone is located 15 to 20 feet (4.5-6 m) below the thick sandstone beds of the upper part of the Dakota and is 10 to 20 feet (3-6 m) thick. The lower zone is 30 feet (9.1 m) below the upper zone and is about 7 to 12 feet (2.1-3.7 m) thick.

Three main and a few minor prospects are present in the Agate quadrangle. The prospects were located and tested from 1980 to 1983 and are currently (1996) abandoned. The first is in the SW¼SE¼NW¼ section 9, T. 20 S., R. 25 E., and tested the upper carbonaceous zone. It consists of a disturbed area 135 feet by 60 feet (41 by 18 m) with a highwall of 6 feet (1.8 m) (appendix B, section a). Carbonaceous shale and coal were scraped into piles, most of which is still on location.

The second prospect is in the SW¼SW¼SW¼ section 3, T. 20 S., R. 25 E. Two pits are present; one in each of the two zones. The pit in the upper zone is 90 feet by 75 feet (27 by 23 m) with a 10-foot (3 m) highwall (appendix B, section b); most of the material remains stockpiled on site. The pit in the lower zone is 75 feet by 75 feet (23 by 23 m) and has a highwall of 12 feet (3.7 m) (appendix B, section c). Most of the carbonaceous material remains stockpiled on site.

The third area consists of several scattered prospects in the northwest corner of the quadrangle. The largest prospect is located in NW¼SE¼SE¼ section 27, T. 19 S., R. 25 E., and consists of a triangular-shaped disturbed area of 78 feet by 150 feet (24 by 46 m), with a highwall of 12 feet (3.7 m) (appendix B, section d). A smaller satellite pit, 15 feet (1.5 m) across and 3 feet (0.9 m) deep, is located about 45 feet (14 m) to the east.

A 60-foot by 27-foot (18 by 8 m) oval-shaped pit is in NW¼SW¼SE¼ section 27, T. 19 S., R. 25 E. It is up to 3 feet (1 m) deep. An elongate pit in the NE¼SE¼SE¼ section 27, is partly exposed by an intermittent drainage. It is 69 feet by 45 feet (21 by 14 m) in size with a highwall of 4 feet (3.7 m). In the NW¼NE¼NE¼ section 34, T. 19 S., R. 25 E. carbonaceous shale was scraped up in an area of 75 feet by 30 feet (23 by 9 m) in the lower part of the upper zone. The upper part of the zone is eroded off.

Uranium and Vanadium

Uranium and vanadium are commonly associated with the sandstone lenses and channels in the Salt Wash Member of the Morrison Formation. Even though claim markers were found that indicate that much of the area was staked during past uranium "booms," no prospect workings were found during our mapping. Favorable conditions for uranium and vanadium mineralization were not observed in the Agate quadrangle. Such conditions include fossil carbonized vegetal trash in sandstone lenses at least 25 feet (7.6 m) thick, commonly at the top of the Salt Wash Member (Doelling, 1969). Some carbonized vegetal trash is present in the quadrangle, but almost all the sandstone lenses are less than 25 feet (7.6 m) thick. Some uranium mineralization in the area was located in a carbonaceous mudstone near the base of the Brushy Basin Member (R.G. Young, personal communication, 1993), but none was mined in the quadrangle.

Metals

Placer gold deposits in gravel bars and terraces along the Colorado River have been known for many years (Utah Geological and Mineralogical Survey, 1966), and mineralization associated with Precambrian rocks of the Uncompahgre uplift has been prospected since the turn of the century. The U.S. Bureau of Mines and the U.S. Geological Survey conducted studies to assess mineral resource potential of the Westwater Canyon Wilderness Study Area, which includes the southeastern part of the Agate quadrangle (Chatman, 1987; Dickerson and others, 1988). Of 273 rock, placer, stream sediment, and panned concentrate samples, approximately 165 were collected in the Agate quadrangle. Analytical results are published in Chatman (1987).

Placer gold workings along the Colorado River in the Agate quadrangle are known as the Pussycat claims (sections 22, 23, 26, and 27, T. 20 S., R. 25 E.). The workings on the unpatented claims consist of numerous open cuts, prospect pits, and a couple of trenches. The workings are in narrow, discontinuous gravel terraces (map unit Qat_2) that extend for about 1,400 feet (427 m) along the east riverbank and that rest on Precambrian rocks about 20 to 30 feet (6-9 m) above the current stream channel. The alluvial deposits consist of well-rounded cobbles and pebbles in a sandy matrix. The gold usually occurs as small, thin flakes less than 0.02 inches (0.5 mm) in diameter (Chatman, 1987). Analytical data indicate the Precambrian rocks beneath the placers cannot account for the gold concentrations in the placer deposits (Dickerson and others, 1988). Estimated gold reserves from the placer and placer tailings amount to about 24 ounces of gold for this 5,000 cubic-yard (3,800 m^3) deposit (Chatman, 1987). Some gold may have been produced from the Pussycat claims, but there is no known production record. Samples from thin gravel terrace remnants exposed at slightly higher elevations (Qat_4 and Qat_6) on the Pussycat claim yield negligible amounts of gold (Chatman, 1987).

Several small prospect pits and a caved shaft are located in and around the metapyroxenite body at the southern end of the Pussycat placer claims. Workings explore altered areas of hematite- and chlorite-epidote-rich rocks with abundant quartz veins. Other bedrock prospect pits on the Pussycat claims are located in biotite-microcline gneiss and amphibolite. Sample analyses from prospect pits and altered fractures in this immediate area indicate slightly elevated concentrations of gold, copper, and barite (Chatman, 1987).

Additional workings south of the Little Dolores River, presumably for precious metals, consist of three adits in Precambrian rocks in section 3, T. 21 S., R. 25 E. near the contact between amphibolite and biotite-microcline gneiss. An adit on the west side of the Colorado River and another one almost directly across the inner gorge of the canyon explore a 2-foot-wide (0.6 m) shear zone that strikes northeastward parallel with the metamorphic foliation (Chatman, 1987). Clay gouge and quartz samples from the shear zone contain anomalous gold and copper values. A third adit ("Outlaw Cave") just downstream is associated with a granitic dike; analytical results from the weakly altered rocks indicate they are sparsely mineralized.

Gravel and Road Fill

Pediment- and terrace-mantle deposits in the quadrangle are an important source of fill and gravel for railroad and highway construction. Interstate 70, former U.S. Highway 6 and 50, and graded gravel roads were constructed using fill material from the deposits. Test results from a pit in NE¼ section 11, T. 20 S., R. 24 E. in deposits mapped as Qal_2 are reported in table 3. Pits have also been opened in section 29, T. 19 S. R. 25 E. They have not been tested but are compositionally similar to pits in section 20, T. 19 S., R. 25 E., in the Harley Dome quadrangle (Willis, 1994).

Pediment- and terrace-mantle deposits in the quadrangle are mostly sand and silt with abundant gravel- and boulder-sized clasts of sandstone, dense oolitic and algal limestone, and chert. Sorting is poor to moderate with boulders ranging up to about 4 feet (1.2 m) in diameter. No estimates have been made of the volume available in the quadrangle, but deposits are up to 50 feet (15 m) thick and average 20 to 40 feet (6-12 m) thick. They are thickest in the northern part of the quadrangle.

Terrace gravels along the Colorado River contain abundant clean, well-sorted gravel and cobble deposits. Materials are primarily igneous and metamorphic clasts derived from Precambrian rock exposures. The deposits are difficult to access and are in an important scenic recreational area.

Stone

The quadrangle, as its name implies, contains agate and other decorative and ornamental stone. In spite of the quadrangle name, most of the "agate" is jasper. Jasper is yellow, red, or brown, impure, slightly translucent chalcedony (cryptocrystalline quartz), whereas agate is either banded or irregularly clouded, variously colored chalcedony. The jasper is found scattered in the Tidwell and Brushy Basin Members of the Morrison Formation and in the Cedar Mountain Formation where it is associated with thin limestone beds or nodule zones. Some of the material found in the Agate quadrangle is suitable for polishing.

Rocks from two other formations have been used as decorative and landscaping stones. The Dakota has sandstone in various hues of yellow and orange. The Kayenta Formation contains brownish-red to orangish-red, thin, platy sandstone that has been used as flagstone.

WATER RESOURCES

The Agate quadrangle is located in a middle-latitude desert at the foot of the Book Cliffs and annual precipitation ranges between 6 and 8 inches (15-20 cm) (Lines and others, 1984, p. 13). Elevations rise both to the northwest toward the Book Cliffs and to the southeast toward the Uncompahgre Plateau where annual precipitation averages 16 to 20 inches (41-51 cm) in the highest areas (Waddell and others, 1981).

The quadrangle is crossed by the Colorado River, three small perennial streams, and many ephemeral streams. The perennial streams, Westwater Creek, Cottonwood Wash, and the Little Dolores River, are utilized for limited irrigation upstream of the quadrangle. Westwater Creek and the Little Dolores have a small year-round flow; Cottonwood Wash would also flow year-round if not for irrigation withdrawal.

Concentration of dissolved solids in surface water in the quadrangle ranges from 0.13 to more than 0.26 ounces per gallon (1,000-2,000 mg/l) in Cottonwood Wash and Westwater Creek, and from less than 0.07 to more than 0.13 ounces per gallon (500-2,000 mg/l) in the Colorado River (Lines and others, 1984, p. 34). Water in streams that cross the Mancos Shale generally carry large amounts of sulfate.

Many of the rocks and unconsolidated deposits in the Agate quadrangle contain water. Generally, units consisting of coarser materials, the Dakota Sandstone, Moab Member of the Entrada Sandstone, and the Kayenta Formation have better porosity and permeability. Aquifers in unconsolidated deposits are present only in the area near the mouth of Westwater Creek. Yields from properly constructed wells are expected to be between 1 and 10 gallons (3.8-38 l) per minute (Price and Arnow, 1974, plate 1F). Some of the oil and gas wells yield water (table 1).

Springs are rare in the quadrangle and only one is indicated on the topographic map. This intermittent spring in the SE¼NW¼SE¼ section 26, T. 20 S., R. 24 E. issues from the base of the Dakota Sandstone during wet years. A few other springs issue in the channels of Cottonwood Wash, Westwater Creek, the Little Dolores River, and the Colorado River.

Several catchment basins have been constructed across washes in the area to catch sporadic rain and snow melt for cattle, sheep, and wildlife. Around 1900, a rock-faced dam was built across Cottonwood Wash, but it is now breached (NW¼, section NW, T. 20 S., R. 24 E). Small ditches, now abandoned, were dug north of the Agate townsite to catch runoff, presumably for the railroad and homesteads.

GEOLOGIC HAZARDS

Geologic hazards in the Agate quadrangle are expansive rock and soil, flash flooding, rockfalls, landslides, and blowing dust and sand. Damage to roads is the greatest concern since the quadrangle is sparsely inhabited, but it is crossed by major transportation lines. Clay- and evaporite-bearing rock and soils that expand and contract as they absorb and lose moisture, and that deform when loaded, cause problems for railroad and highway construction and maintenance. The Chinle, Morrison, Cedar Mountain, Dakota, and Mancos formations all contain problem clays (Mulvey, 1992). Large troughs and swells in older roads constructed across the Mancos Shale attest to this

Table 3.

Results of tests run by the Utah Department of Transportation on gravel and fill materials in the Agate quadrangle area (Utah Department of Highways, not dated, about 1967). The section 20 site is located just north of the quadrangle but is believed to be representative of pediment deposits in the northern part of the Agate quadrangle. B.G.= base gravels (for use beneath pavement), S.G.= surface gravels (for use in pavement), NP= nonplastic. The thicknesses are in feet.

LOCATION					MATERIAL					TEST DATA-REPRESENTATIVE SAMPLE																	
													SIEVE ANALYSIS														
													BEFORE CRUSHING		PERCENT PASSING AFTER CRUSHING TO 1" MAX. SIZE										IMMERSION COMPRESSION AVG. P.S.I. LIME		
TOWNSHIP	RANGE	40 ACRE TRACT	QUARTER SECTION	SECTION	USE OF MATERIAL	TYPE OF DEPOSIT	PRESENT ESTIMATED QUANTITY (CU. YDS.)	THICKNESS OF MATERIAL	DEPTH OF OVERBURDEN	DATE SAMPLED *	TYPE OF SAMPLE	DEPTH OF SAMPLE	>3"	>1"	1"	1/2"	No. 4	No.* 10	No.* 40	No.* 200	LIQUID LIMIT	PLASTICITY INDEX	SWELL	A. A. S. H. O. CLASSIFICATION	wo/	w/	ABRASION 500 REV.
20S	24E	SW	NE	11	Borrow, Select Base	Stream Channel	13,000	4	0	1956					100		86.9	72.8	38.7	4.3	18.3	NP		A-1-b			
19S	25E	NW	SE	20	B.G., S.G.	Pediment	290,000	14	0-3	1967	CUT BANK	0-9	0	10.8	100	76.9	52.5	44.6*	31.0*	17.0	17.5	NP	.002	A-1-b	120	264	31.4

problem. Even Interstate 70, with a thick fill base, has been distorted by expansive foundation materials.

Westwater Creek, Cottonwood Creek, and the Little Dolores River all drain large basins and experience flash floods after heavy rainstorms. Westwater Creek is as much as 10 feet (3 m) deep for a few hours after large storms, whereas typically it is only a few inches deep.

Rockfalls are common on steep slopes beneath resistant sandstone ledges. Secondary roads and the railroad are most vulnerable.

Landslides, mapped in sections 3 and 10, T. 20 S., R. 25 E. and section 24, T. 20 S., R. 24 E., involve bentonitic intervals of the Brushy Basin Member of the Morrison Formation and the Cedar Mountain Formation. No evidence of historic landslide activity was noted in the quadrangle.

Eolian deposits are very common and attest to frequent summer dust and sand storms. Active and semiactive dunes are common in the central to southern part of the quadrangle. Road construction or other activity that destroys vegetation may cause the dunes to reactivate, creating road maintenance problems.

The quadrangle is in the central part of the Colorado Plateau, a region of small- to moderate-magnitude earthquakes with a low to moderate recurrence interval (Wong and Humphrey, 1989). Earthquakes greater than magnitude 4 (large enough to be felt) are rare in the region, and the quadrangle is far from any known Quaternary faults (Arabasz and others, 1979; Hecker, 1993). The quadrangle is in Uniform Building Code zone one, indicating low potential for earthquake damage. There are three zones in Utah; zone one has the lowest potential for damage (International Conference of Building Officials, 1991).

SCENIC AND RECREATION RESOURCES

The Agate quadrangle is in the "redrocks" country of eastern Utah and receives much recreational use. Vistas in the southern part are generally excellent and are mostly undisturbed by human development. Primary attractions are the intricately eroded sandstone formations and the deep, rugged gorge of Westwater Canyon of the Colorado River (figure 3). Easy access from nearby Interstate 70 adds to the recreational use of the area.

Westwater Canyon, the upper part of which is within the quadrangle, is popular and heavily used for white-water rafting and kayaking. The primary launch site is located just a few hundred feet east of the quadrangle boundary, and the two major launch-site access roads, one paved and the other graded, cross the quadrangle.

Bicycling and 4-wheel-vehicle exploring are also popular in the quadrangle. The Kokopelli Trail, maintained by the Bureau of Land Management and by bicycle organizations, passes diagonally from northeast to southwest across the quadrangle.

ACKNOWLEDGMENTS

This study has benefitted from numerous discussions with Robert Young, Rex Cole, and Adolph Yonkee. Brent Gage of the U.S. Bureau of Mines provided information on the U.S. helium reserve. Fitz Davis served as project manager. Fitz Davis, Jon King, Bill Mulvey, Doug Sprinkel, Dave Tabet, and Bob Young reviewed the map and manuscript and provided many helpful suggestions.

REFERENCES

Arabasz, W.J., Smith, R.B., and Richin, W.D., editors, 1979, Earthquake studies in Utah 1850 to 1978: University of Utah Seismograph Stations, 552 p.

Biggar, N.E., 1987, Quaternary studies in the Paradox basin, southeastern Utah: Prepared for Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio, Technical Paper BMI/ONWI-622, 247 p.

Birkeland, P.W., Machette, M.N., and Haller, K.M., 1991, Soils as a tool for applied Quaternary geology: Utah Geological Survey Miscellaneous Publication 91-3, 63 p.

Case, J.E., 1966, Geophysical anomalies over Precambrian rocks, northwestern Uncompahgre Plateau, Utah and Colorado: American Association of Petroleum Geologists Bulletin, v. 50, no. 7, p. 1423-1443.

Case, J.E., 1991, Geologic map of the northwestern part of the Uncompahgre uplift, Grand County, Utah and Mesa County, Colorado, with emphasis on Proterozoic rocks: U.S. Geological Survey Miscellaneous Investigations Map I-2088, scale 1:24,000.

Cashion, W.B., 1973, Geologic and structure map of the Grand Junction quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Investigations Map I-736, scale 1:250,000.

Cater, F.W., 1970, Geology of the salt anticline region in southwestern Colorado: U.S. Geological Survey Professional Paper 637, 80 p.

Chatman, M.L., 1987, Mineral resources of the Black Ridge Canyons (CO-070-113), Black Ridge Canyons West (CO-070-113A and UT-060-116, 117), and Westwater Canyon (UT-060-118) wilderness study areas, Mesa County, Colorado, and Grand County, Utah: U.S. Bureau of Mines Open-File Report MLA-87, 53 p.

Cole, R.D., and Young, R.G., 1991, Facies characterization and architecture of a muddy shelf-sandstone complex: "Mancos B" interval of Upper Cretaceous Mancos Shale, northwest Colorado, northeast Utah, *in* Miall, A.D., and Tyler, Noel, editors, The three-dimensional facies architecture of terrigenous clastic sediments and its implications for hydrocarbon discovery and recovery: Society of Economic Paleontologists and Mineralogists, Concepts in Sedimentology and Paleontology v. 3, p. 277-287.

Cole, R.D., Young, R.G., and Willis, G.C., in preparation, The Prairie Canyon Member, a new unit of the Upper Cretaceous Mancos Shale, west-central Colorado and east-central Utah: Utah Geological Survey Special Study.

Craig, L.C., and Shawe, D.R., 1975, Jurassic rocks of east-central Utah, *in* Canyonlands Country: Four Corners Geological Society Guidebook, 8th Field Conference, p. 157-165.

Dane, C.H., 1935, Geology of the Salt Valley anticline and adjacent areas, Grand County, Utah: U. S. Geological Survey Bulletin 863, 184 p.

Dickerson, R.P., Case, J.E., and Barton, H.N., 1988, Mineral resources of the Black Ridge Canyons wilderness study area, Mesa County, Colorado, and Grand County, Utah, and Westwater Canyon wilderness study area, Grand County, Utah: U.S. Geological Survey Bulletin 1736, Chapter C, 24 p.

Doelling, H.H., 1969, Mineral resources, San Juan County, Utah and adjacent areas: Part II-Uranium and other metals in sedimentary host rocks: Utah Geological and Mineralogical Survey Special Studies 24, 64 p.

Doelling, H.H., 1993, Interim geologic map of the Moab 30′x60′ quadrangle, Grand County, Utah: Utah Geological Survey Open-File Report 287, 16 p., scale 1:100,000.

Doelling, H.H., and Graham, R.L., 1972, Eastern and northern Utah coal fields: Vernal, Henry Mountains, Sego, LaSal-San Juan, Tabby Mountain, Coalville, Henrys Fork, Goose Creek, and Lost Creek: Utah Geological and Mineralogical Survey Monograph 2, 409 p.

Doelling, H.H., Yonkee, W.A., and Hand, J.S., 1994, Geologic map of the Gold Bar Canyon quadrangle, Grand County, Utah: Utah Geological Survey Map 155, 26 p., scale 1:24,000.

Dubiel, R.F., 1994, Triassic deposystems, paleogeography, and paleoclimate of the western interior, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, USA: Society for Sedimentary Geology, Rocky Mountain Section, p. 133-168.

Ellis, M.S., and Hopeck, J.T., 1985, Geologic map showing coal beds in the Dakota Sandstone, Harley Dome quadrangle and parts of the Bitter Creek Well, Westwater 4 SE, and Westwater 4 SW quadrangles, Colorado and Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1800, scale 1:50,000.

Fisher, D.J., Erdmann, C.E., and Reeside, J.B., Jr., 1960, Cretaceous and Tertiary formations of the Book Cliffs, Carbon, Emery, and Grand Counties, Utah and Garfield and Mesa Counties, Colorado: U.S. Geological Survey Professional Paper 332, 80 p.

Fouch, T.D., Lawton, T.F., Nichols, D.J., Cashion, W.B., and Cobban, W.A., 1983, Patterns and timing of synorogenic sedimentation in Upper Cretaceous rocks of central and northeast Utah, *in* Reynolds, M.W. and Dolly, E.D., editors, Mesozoic paleogeography of the west-central United States: Rocky Mountain Section of the Society of Economic Paleontologists and Mineralogists, p. 305-336.

Frahme, C.W., and Vaughn, E.B., 1983, Paleozoic geology and seismic stratigraphy of the northern Uncompahgre front, Grand County, Utah, *in* Lowell, J.D., editor, Rocky Mountain foreland basins and uplifts: Rocky Mountain Association of Geologists, p. 201-211.

Gable, D.J., and Hatton, Tom, 1983, Maps of vertical crustal movements in the conterminous U.S. over the last 10 million years: U.S. Geological Survey Miscellaneous Investigations Map I-1315, scales 1:5,000,000, 1:10,000,000.

Gries, Robbie, 1983, North-south compression of Rocky Mountain foreland structures, *in* Lowell, J.D., editor, Rocky Mountain foreland basins and uplifts: Rocky Mountain Association of Geologists, p. 9-32.

Gualtieri, J.L., 1988, Geologic map of the Westwater 30′ by 60′ quadrangle, Grand and Uintah Counties, Utah and Garfield and Mesa Counties, Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-1765, scale 1:100,000.

Hecker, Suzanne, 1993, Quaternary tectonics of Utah with emphasis on earthquake-hazard characterization: Utah Geological Survey Bulletin 127, 157 p., scale 1:500,000.

Hedge, C.E., Peterman, Z.E., Case, J.E., and Obradovich, J.D., 1968, Precambrian geochronology of the northwestern Uncompahgre Plateau, Utah and Colorado: U.S. Geological Survey Professional Paper 600-C, p. 1-96.

Heyman, O.G., 1983, Distribution and structural geometry of faults and folds along the northwestern Uncompahgre uplift, western Colorado and eastern Utah, *in* Averett, W.R., editor, Northern Paradox basin - Uncompahgre uplift: Grand Junction Geological Society Guidebook, p. 45-57.

Heyman, O.G., Huntoon, P.W., and White-Heyman, M.A., 1986, Laramide deformation of the Uncompahgre Plateau-geometry and mechanisms, *in* D.S. Stone, editor, New interpretations of northwest

Colorado geology: Rocky Mountain Association of Geologists, p. 65-76.

Hintze, L.F., 1988 (as revised, 1993), Geologic history of Utah: Brigham Young University Geology Studies, Special Publication 7, 202 p.

Hunt, C.B., 1956, Cenozoic geology of the Colorado Plateau: U.S. Geological Survey Professional Paper 279, 99 p.

International Conference of Building Officials, 1991, Uniform Building Code: Whittier, California, International Conference of Building Officials, 1,050 p.

Izett, G.A., and Wilcox, R.E., 1982, Map showing localities and inferred distributions of the Huckleberry Ridge, Mesa Falls, and Lava Creek B ash beds (Pearlette family ash beds) of Pliocene and Pleistocene age in the western United States and southern Canada: U.S. Geological Survey Miscellaneous Investigations Series Map I-1325, scale 1:4,000,000.

Jackson, A.L., 1983, Humates and their development at Harley Dome, Utah, *in* W.R. Averett, editor, Northern Paradox basin-Uncompahgre uplift: Grand Junction Geological Society, p. 17-19.

Jamison, W.R., and Stearns, D.W., 1982, Tectonic deformation of Wingate Sandstone, Colorado National Monument: American Association of Petroleum Geologists Bulletin, v. 66, no. 12, p. 2584-2608.

Johnson, R.C., 1985, Early Cenozoic history of the Uinta and Piceance Creek basins, Colorado and Utah, with special reference to the development of Lake Uinta, *in* Flores, R.M., and Kaplan, S.S., editors, Cenozoic paleogeography of the west-central United States, Rocky Mountain Paleogeography Symposium 3: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, p. 247-276.

—1989, Detailed cross sections correlating Upper Cretaceous and Lower Tertiary rocks between the Uinta basin of eastern Utah and western Colorado and the Piceance basin of western Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-1974, 2 sheets.

Johnson, R.C., and Finn, T.M., 1986, Cretaceous through Holocene history of the Douglas Creek Arch, Colorado and Utah, *in* D.S. Stone, editor, New interpretations of northwest Colorado geology: Rocky Mountain Association of Geologists, p. 77-95.

Kauffman, E.G., 1977, Illustrated guide to biostratigraphically important Cretaceous macrofossils, western interior basin, U.S.A., *in* Kauffman, E.G., editor, Field guide: Cretaceous facies, faunas, and paleoenvironments across the western interior basin: Rocky Mountain Association of Geologists, v. 14, nos. 3 and 4, p. 225-274.

Kauffman, E.G., Sageman, B.B., Gustason, E.R., and Elder, W.P., 1987, Field trip guidebook: High-resolution event stratigraphy, Greenhorn cyclothem (Cretaceous) western interior basin of Colorado and Utah: Geological Society of America, Rocky Mountain Section Regional Meeting, Boulder, Colorado, May, 1987, 198 p.

Keebler, W.E., 1956, Cottonwood-Harley Dome area, Grand County, Utah, *in* Peterson, J.A., editor, Geology and economic deposits of east central Utah: Intermountain Association of Petroleum Geologists Seventh Annual Field Conference Guidebook, p. 190-194.

Kirkland, J.I., 1992, Dinosaurs define a two-fold Lower Cretaceous zonation of the Cedar Mountain Formation, central Utah: Geological Society of America Rocky Mountain Section Abstracts with Programs, v. 24, no. 6, p. 22.

Kowallis, B.J., Christiansen, E.H., and Deino, A.L., 1991, Age of the Brushy Basin Member of the Morrison Formation, Colorado Plateau, western USA: Cretaceous Research, v. 12, p. 483-493.

Kowallis, B.J., and Heaton, J.S., 1987, Fission-track dating of bentonites and bentonitic mudstones from the Morrison Formation in central Utah: Geology, v. 15, p. 1138-1142.

Lawton, T.F., 1986, Fluvial systems of the Upper Cretaceous Mesaverde Group and Paleocene North Horn Formation, central Utah; a record of transition from thin-skinned to thick-skinned deformation in the foreland region, *in* Peterson, J.A., editor, Paleotectonics and sedimentation in the Rocky Mountain region, United States: American Association of Petroleum Geologists Memoir 41, p. 423-442.

Lines, G.C., and others, 1984, Hydrology of area 56, northern Great Plains and Rocky Mountain coal provinces, Utah: U.S. Geological Survey Water-Resources Investigations Open-File Report 83-38, 69 p.

Lohman, S.W., 1965, Geology and artesian water supply Grand Junction area, Colorado: U.S. Geological Survey Professional Paper 451, 149 p.

Luttrell, P.R., 1987, Basin analysis of the Kayenta Formation (Lower Jurassic), central portion Colorado Plateau: Flagstaff, Northern Arizona University, M.S. thesis, 217 p.

Machette, M.N., 1985, Calcic soils of the southwestern United States: Geological Society of America Special Paper 203, p. 1-21.

Mack, G.H., and Rasmussen, K.A., 1984, Alluvial-fan sedimentation of the Cutler Formation (Permo-Pennsylvanian) near Gateway, Colorado: Geological Society of America Bulletin, v. 95, p. 109-116.

Molenaar, C.M., and Cobban, W.A., 1991, Middle Cretaceous stratigraphy on the south and east sides of the Uinta basin, northeastern Utah and northwestern Colorado: U.S. Geological Survey Bulletin 1787-P, 34 p.

Mulvey, W.E., 1992, Soil and rock causing engineering geologic problems in Utah: Utah Geological Survey Special Study 80, 23 p., scale 1:500,000.

Munger, R.D., 1965, Subsurface exploration mapping, southern Uinta basin, Castlegate and Dakota-Cedar Mountain Formations: The Mountain Geologist, v. 2, no. 3, p. 141-166.

O'Sullivan, R.B., 1970, The upper part of the Upper Triassic Chinle Formation and related rocks, southeastern Utah and adjacent areas: U.S. Geological Survey Professional Paper 644-E, 22 p.

—1981, Stratigraphic sections of Middle Jurassic Entrada Sandstone and related rocks from Salt Valley to Dewey Bridge in east-central Utah: U.S. Geological Survey Oil and Gas Investigations Chart OC-113.

—1984, The base of the Upper Jurassic Morrison Formation in east-central Utah: U.S. Geological Survey Bulletin 1561, 17 p.

O'Sullivan, R.B., and Pipiringos, G.N., 1983, Stratigraphic sections of Middle Jurassic Entrada Sandstone and related rocks from Dewey Bridge, Utah, to Bridgeport, Colorado: U.S. Geological Survey Oil and Gas Investigations Chart OC-122.

Palmer, A.R., 1983, Decade of North American geology 1983 geologic time scale: Geology, v. 11, no. 9, p. 503-504.

Peale, A.C., 1878, Geological report on the Grand River district [Colorado]: U.S. Geological and Geographical Survey Territorial 10th Annual Report, p. 170-185.

Peterson, Fred, 1988, A synthesis of the Jurassic system in the southern Rocky Mountain region, *in* Sloss, L.L., editor, Sedimentary cover - North American craton, U.S.: Geological Society of America, The Geology of North America Series, v. D-2, p. 65-76.

Peterson, Fred, and Pipiringos, G.H., 1979, Stratigraphic relations of the Navajo Sandstone to Middle Jurassic formations, southern Utah and northern Arizona: U.S. Geological Survey Professional Paper 1035-B, p. B1-B43.

Peterson, Fred, and Ryder, R.T., 1975, Cretaceous rocks in the Henry Mountains region, Utah, and their relation to neighboring regions, *in* Fassett, J.E., editor, Canyonland Country: Four Corners Geological Society Guidebook, eighth field conference, p. 167-190.

Peterson, Fred, Ryder, R.T., and Law, B. E., 1980, Stratigraphy, sedimentology, and regional relationships of the Cretaceous System in the Henry Mountains region, *in* Picard, M.D., editor, Henry Mountains Symposium: Utah Geological Association Publication 8, p. 151-170.

Pipiringos, G.N., and O'Sullivan, R.B., 1975, Chert pebble unconformity at the top of the Navajo Sandstone in southeastern Utah, *in* Fassett, J.E., editor, Canyonland Country: Four Corners Geological Society Guidebook 8th Field Conference, p. 149-156.

Pipiringos G.N., and O'Sullivan, R.B., 1978, Principal unconformities in Triassic and Jurassic rocks, western interior United States--a preliminary survey: U.S. Geological Survey Professional Paper 1035-A, 29 p.

Poole, F.G., and Stewart, J.H., 1964, Chinle Formation and Glen Canyon Sandstone in northeastern Utah and northwestern Colorado, *in* Geological Survey Research 1964: U.S. Geological Survey Professional Paper 501-D, D30-D39.

Price, Don, and Arnow, Ted, 1974, Summary appraisals of the nation's ground-water resources--upper Colorado region: U.S. Geological Survey Professional Paper 813-C, 40 p.

Quigley, W.D., 1961, Seiber Nose oil field, *in* Preston, Don, editor, A symposium of the oil and gas fields of Utah: Intermountain Association of Petroleum Geologists Guidebook, not paginated.

Richardson, G.B., 1909, Reconnaissance of Book Cliffs coal field between Grand River, Colorado, and Sunnyside, Utah: U.S. Geological Survey Bulletin 371, 54 p.

Ryer, T.A., and McPhillips, Maureen, 1983, Early Late Cretaceous paleogeography of east-central Utah, *in* Reynolds, M.W., and Dolly, E.D., editors, Mesozoic paleogeography of west-central United States: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, Mesozoic Paleogeography Symposium, p. 253-272.

Simpson, G.C., 1926, The age of the Morrison Formation: American Journal of Science, 5th Series, v. 12, p. 198-216.

Sinnock, Scott, 1981, Pleistocene drainage changes in Uncompahgre Plateau-Grand Valley region of western Colorado, including formation and abandonment of Unaweep Canyon: a hypothesis, *in* Epis, R.C., and Callender, J.F., editors, Western Slope Colorado: New Mexico Geological Society Thirty-second Field Conference, p. 113-120.

Stewart, J.H., Poole, F.G., and Wilson, R.F., 1972, Stratigraphy and origin of the Chinle Formation and related Upper Triassic strata in the Colorado Plateau region: U.S. Geological Survey Professional Paper 690, 336 p.

Stokes, W.L., 1944, Morrison and related deposits in and adjacent to the Colorado Plateau: Geological Society of America Bulletin, v. 55, p. 951-992.

—1952, Lower Cretaceous in Colorado Plateau: American Association of Petroleum Geologists Bulletin, v. 36, p. 1766-1776.

Stowe, Carlton, 1972, Oil and gas production in Utah to 1970: Utah Geological and Mineralogical Survey Bulletin 94, 179 p.

Trimble, L.M., and Doelling, H.H., 1978, Geology and uranium-vanadium deposits of the San Rafael Swell mining area, Emery County, Utah: Utah Geological and Mineral Survey Bulletin 113, 122 p.

Tschudy, R.H., Tschudy, B.D., and Craig, L.C., 1984, Palynological evaluation of Cedar Mountain and Burro Canyon Formations, Colorado Plateau: U.S. Geological Survey Professional Paper 1281, 24 p.

Tweto, Ogden, 1987, Rock units of the Precambrian in Colorado: U.S. Geological Survey Professional Paper 1321-A, 54 p., scale 1:1,000,000.

Utah Geological and Mineralogical Survey, 1966, Gold placers in Utah, a compilation: Utah Geological and Mineralogical Survey Circular 47, 29 p.

Utah Geological and Mineral Survey, 1983, Energy resources map of Utah: Utah Geological and Mineral Survey Map 68, scale 1:500,000.

Utah State Department of Highways, (not dated, about 1967), Materials inventory-Grand County: Utah State Department of Highways, Materials and Research Division, Materials Inventory Section, 15 p.

Van Wagoner, J.C., Mitchum, R.M., Campion, K.M., and Rahmanian, V.D., 1990, Siliciclastic sequence stratigraphy in well logs, cores, and outcrops: American Association of Petroleum Geologists Methods in Exploration Series, no. 7, 55 p.

Waddell, K.M., Contratto, P.K., Sumsion, C.T., and Butler, J.R., 1981, Hydrologic reconnaissance of the Wasatch Plateau-Book Cliffs coal-fields area, Utah: U.S. Geological Survey Water-Supply Paper 2068, 45 p., 7 plates, scale 1:125,000.

White, M.A., and Jacobsen, M.I., 1983, Structures associated with the southwest margin of the ancestral Uncompahgre uplift: Grand Junction Geological Society Field Trip Guidebook, p. 33-40.

Whitney, J.W., 1981, Surficial geologic map of the Grand Junction 1°x2° quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Investigations Map I-1289, 1:250,000.

Williams, P.L., 1964, Geology, structure, and uranium deposits of the Moab quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-360, 1:250,000.

Willis, G.C., 1992, Lava Creek "B" volcanic ash in pediment mantle deposits, Colorado Plateau, east-central Utah--implications for Colorado River downcutting and pedogenic carbonate accumulation rates: Rocky Mountain Section Geological Society of America Abstracts with Programs, v. 24, no. 6, p. 68.

—1994, Geologic map of the Harley Dome quadrangle, Grand County, Utah: Utah Geological Survey Map 157, 18 p., scale 1:24,000.

Willis, G.C., and Kowallis, B.J., 1988, Newly recognized Cedar Mountain Formation in Salina Canyon, Sevier County, Utah: Brigham Young University Geology Studies, v. 35, p. 57-61.

Wong, I.G., and Humphrey, J.R., 1989, Contemporary seismicity, faulting, and the state of stress in the Colorado Plateau: Geological Society of America Bulletin, v. 101, p. 1127-1146.

Wright, J.C., Shawe, D.R., and Lohman, S.W., 1962, Definition of members of Jurassic Entrada Sandstone in east-central Utah and west-central Colorado: American Association of Petroleum Geologists Bulletin, v. 46, no. 11, p. 2057-2070.

Yingling, V.L., 1987, Timing of initiation of the Sevier orogeny: Morrison and Cedar Mountain Formations and Dakota Sandstone, east-central Utah: Laramie, University of Wyoming, M.S. thesis, 169 p.

Young, R.G., 1955, Sedimentary facies and intertonguing in the Upper Cretaceous of the Book Cliffs, Utah, Colorado: Geological Society of American Bulletin, v. 66, p. 177-202.

—1960, Dakota Group of Colorado Plateau: American Association of Petroleum Geologists Bulletin, v. 44, p. 156-194.

—1966, Stratigraphy of coal-bearing rocks of Book Cliffs, Utah-Colorado: Utah Geological and Mineral Survey Bulletin 80, p. 7-22.

—1973, Depositional environments of basal Cretaceous rocks of the Colorado Plateau, *in* Fassett, J.E., editor, Cretaceous and Tertiary rocks of the southern Colorado Plateau: Four Corners Geological Society Memoir, p. 10-27.

—1983, Petroleum in northeastern Grand County, Utah, *in* Averett, W.R., editor, Northern Paradox basin-Uncompahgre uplift: Grand Junction Geological Society, p. 1-7.

APPENDIX A

Measured Section 1

Ferron Sandstone Member and Tununk Shale Member of Mancos Shale

Near junction of two roads to Westwater boat launch area; south center of section 33, T. 19 S., R. 25 E., Agate quadrangle; measured September 30, 1992 by G.C. Willis; continues from top of measured section 2.

Unit	Thickness (feet)	
Top of Ferron Sandstone Member of Mancos Shale (top is eroded, but probably not much of unit is missing based on sighting across wash) (strike and dip at end N. 20° W., 3° W.)		
22	10	Coarsening upward sequence from sandy mudstone to brown sandstone; locally contains bivalve fossils
21	10	Mudstone to very fine sandstone; coarsens upward to mostly thin sandstone; sandstone is orangish-brown, platy; plates are thicker than in sandstone units below
20	7	Dark-gray to black shale with sparse, thin, chippy sandstone; forms nonresistant dip slope; coarsens upward
19	26	Dark-gray papery shale and papery sandstone; thinly laminated; generally barren of plant fossils but has carbonaceous to coaly plant hash on bedding; rare bivalve and ammonoid fossils; yields abundant platy to chippy sandstone float; holds up lower of the two cuestas that define the Ferron throughout the area; coarsens upward
18	10	Sandstone and interbedded mudstone; sandstone is platy; thin-bedded to laminated; grayish-orange; sparse burrows; this unit is source of most float on slope below; grows more brush than other units; forms a lower cuesta in a few areas where unit 19 is eroded back
17	26	Dark-brownish-gray to brownish-black shale with minor sandstone; forms smooth slope but has rare calcareous sandstone concretions; has a browner look from a distance than lower units
16	17	Pale-gray sandy mudstone with thinly laminated chippy sandstone
15	16	Medium- to dark-gray shale and mudstone; has distinctive dark-brown calcareous sandstone concretions near top; concretions are cored with calcite spar, and range from 1 to 3 feet in diameter
14	2	Lag deposits of medium- to coarse-grained sandstone; pale-gray to brownish-gray; rare fish teeth; mottled and bioturbated; laminated to blocky bedding
Total thickness - 124 feet (small part at top eroded)		
Base of Ferron Sandstone Member		
Top of Tununk Shale Member		
13	12	Light- to medium-gray mudstone and shale; poorly exposed; no preserved sedimentary structures
12	6	Dark-gray to black shale like unit 10
11	14	Light-gray sandy mudstone and shale capped by a prominent 1- to 2-foot-thick, laminated, very fine-grained, laterally persistent sandstone with hummocky bedding (this hummocky sandstone is persistent throughout the quadrangle and can be confused with the coarser grained lag deposits at the base of the Ferron Sandstone Member [unit 14] from a distance); contains possible black chert and glauconite
10	7	Shale, dark-brownish-gray to black; this is the darkest unit yet described in the section; forms a prominent band throughout the area
9	7	Light-gray mudstone; low slope former; slightly sandy measured dip of 1° toward NW (precise strike can't be determined)
8	6	Sandstone concretions and mudstone; forms unique marker bed throughout the area (is most conspicuous part of Coon Spring Bed); most concretions are 1 to 4 feet thick and 3 to 6 feet wide; forms resistant rounded ledges; fine- to very fine-grained; glauconitic; moderate-brown to light-grayish-brown; mottled; cemented with iron carbonate; commonly have sparite core (these concretions are primarily sandstone whereas those in unit 6 are calcareous ironstone or mudstone and are distinctly finer grained)

7	15	Light-gray mudstone with a few calcareous concretions
6	10	Light-grayish-brown weathering mudstone; sandy on surface; has abundant calcareous concretions 1 to 4 feet thick with splintery calcite near base and large sandy limestone concretions near top; interbedded with minor, resistant, laminated, hummocky, very fine-grained sandstone; concretions are locally fossiliferous; some are poorly developed septarian nodules and are cored by coarse sparite that is tan to black
5	9	Medium- to dark-brownish-gray mudstone with abundant chippy sandstone float (float is probably from overlying units)
4	30	Broad bench, mostly covered, weathered mudstone float
3	15	Poorly exposed mudstone with abundant oyster fossils in float
2	20	Covered slope

Total thickness Tununk Shale Member - 151 feet

Base of Tununk Shale Member

1	--	Sandstone, pale-yellowish-gray, medium-grained.

Measured Section 2

Dakota Sandstone

Near junction of two roads to Westwater Canyon boat launch area; SE¼SE¼ section 33, T. 19 S., R. 25 E.; end near benchmark 4649 in section 33; measured June 19, 1992 by G.C. Willis.

Top of Dakota Sandstone (strike and dip near end is N. 40° W., 5° NW)

Unit	**Thickness (feet)**	
13	3	Sandstone; very fine- to fine-grained; thin, platy, slope or thin ledge former
12	7	Sandy carbonaceous shale; forms broad dip slope on more resistant unit 11
11	6	Sandstone; resistant capping ledge, the upper surface of which forms a broad dip slope; pale-yellowish-brown to dark-brown; locally strong desert varnish coating
10	16	Sandstone and carbonaceous shale; sandstone is platy, well-sorted, and fine-grained; ledgy slope former
9	20	Carbonaceous shale with thin sandstone beds; slope former
8	4	Coaly carbonaceous shale and coal; very pale-gray, 6-inch-thick volcanic ash at base and 10-inch-thick ash at top with many plant fossils
7	16	Carbonaceous shale
6	2	Coaly carbonaceous shale
5	8	Carbonaceous shale
4	4	Sandstone; very pale-yellowish-brown; very fine-grained; very thin-bedded; platy; bleached with uneven limonitic alteration
3	4	Coaly carbonaceous shale; poorly exposed slope former
2	2	Sandstone; light- to medium-brown; medium-grained; subangular to angular grains; well-sorted; porous; very resistant; forms overhanging ledge
1	30	Sandstone; bleached, very pale-yellow, white, pink, or reddish-gray; upper fine- to lower medium-grained; pebbly conglomerate in stringers; cross-bedded; moderately resistant; top is erosional surface with 1 to 4 feet of relief; base not exposed due to road fill but laterally it is channeled 10 to 15 feet into the greenish-gray mudstone of the Cedar Mountain Formation

Base of Dakota Sandstone

Total Dakota 122 feet

Top of Cedar Mountain Formation

-	--	Greenish gray mudstone

APPENDIX B.

Description of larger humate prospect pits in the Dakota Sandstone.

Section A (SW¼SW¼SW¼ section 3, T. 20 S., R. 25 E.)	
Ash (near surface and highly weathered	1 ft 6 in
Carbonaceous and gray shale	1 ft 6 in
Ash zone	6 in
Gray shale	8 in
Carbonaceous mudstone	4 in
Gray shale	1 ft 6 in
Coal or lignite alternating with high ash coal	2 ft 6 in
Carbonaceous shale	6 in
White claystone and brown siltstone	1 ft 1 in
Total	8 ft 7 in

Section B (SW¼SW¼SW¼ section 3, T. 20 S., R. 25 E.)	
Gray shale (top)	
Carbonaceous shale	1 ft 6 in
Gray shale with thin stringers of carbonaceous shale	4 ft 5 in
Impure coal	2 ft 6 in
Claystone split	3 in
Coal, blocky and lignitic	1 ft 6 in
Claystone (base of pit)	
Total	10 ft 2 in

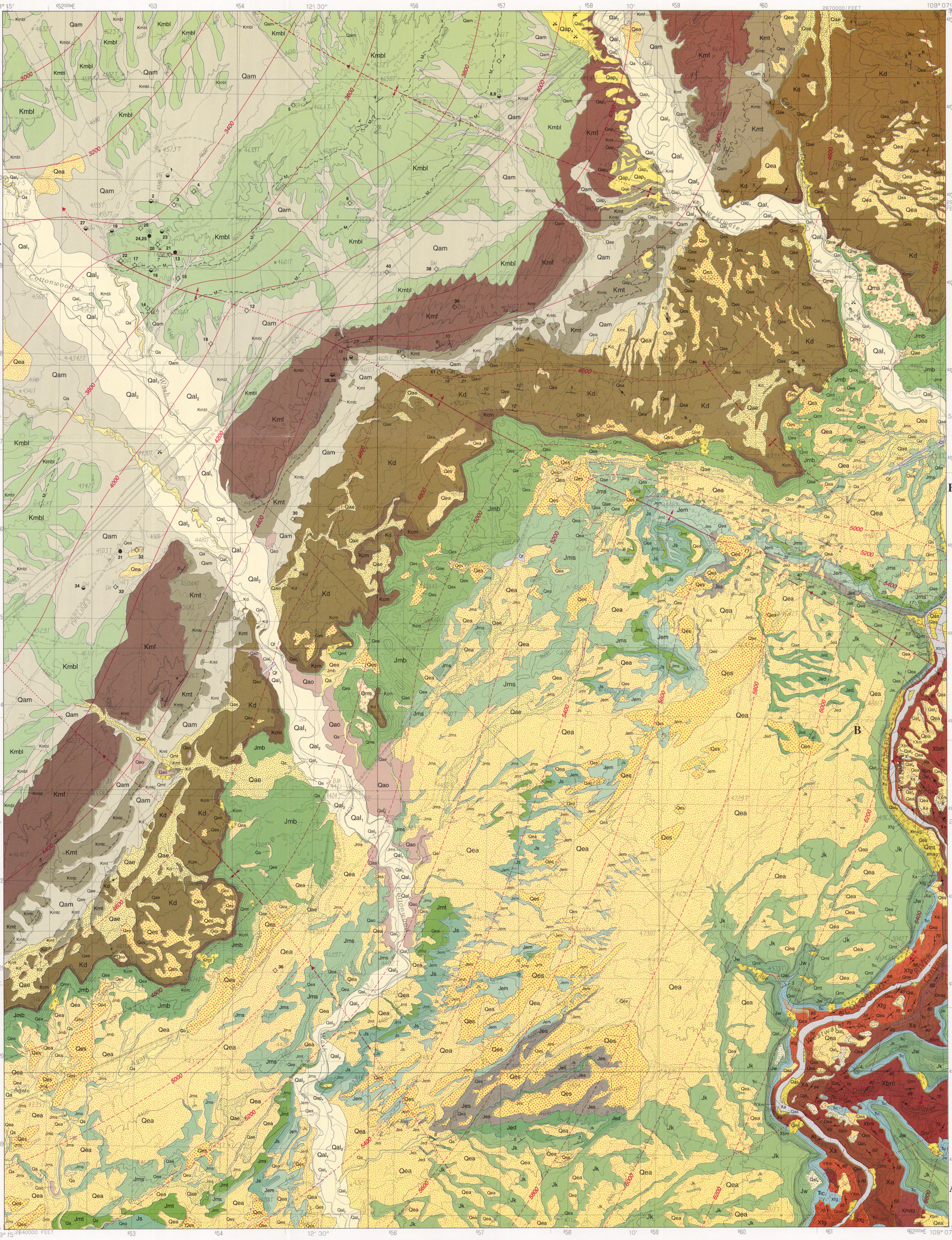
Section C (SW¼SW¼SW¼ section 3, T. 20 S., R. 25 E., lower pit)	
Soft sandstone (top)	
Gray shale	15 ft
Highly weathered carbonaceous shale or coal	6 in
Gray shale	11 in
Coal	2 ft
Carbonaceous sandstone	5 ft
Gray shale alternating with carbonaceous mudstone	2 ft 3 in
Coal	7 in
Gray shale (base)	3 in
Total	11 ft 10 in

Section D (NW¼SE¼SE¼ section 27, T. 19 S., R. 25 E.)	
Sandstone ledge, medium-grained	
Gray sandy shale	15 ft
Ash	6 in
Coal	11 in
Carbonaceous shale	2 ft
Interbedded carbonaceous shale and thin coal stringers	5 ft
Ash, sandstone, and claystone	2 ft 3 in
Carbonaceous shale	7 in
Gray shale sandstone	3 in
Coaly carbonaceous shale	1 ft 1 in
Coal with thin shaly coal splits	2 ft
Gypsiferous bone and clay split	4 in
Coal	1 ft 6 in
Shaly coal and claystone (base)	
Total	31 ft 5 in

ISBN 1-55791-570-9

Agate geology

UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES



Base from U.S. Geological Survey,
Agate 7.5′ Provisional Quadrangle, 1985

Quadrangle mapped by authors, 1992-93

SCALE 1:24 000

MILES
FEET
KILOMETERS
METERS

CONTOUR INTERVAL 40 FEET
SUPPLEMENTAL CONTOUR INTERVAL 20 FEET

12°39′ E
225 MILS
1996 MAGNETIC NORTH
DECLINATION AT CENTER OF MAP

UTAH
QUADRANGLE LOCATION

1 Antone Canyon
2 Harley Dome
3 Bitter Creek Well
4 Danish Flat
5 Westwater
6 Cisco
7 Big Triangle
8 Marble Canyon

ADJOINING 7.5′ QUADRANGLE NAMES

GEOLOGIC MAP OF THE AGATE QUADRANGLE, GRAND COUNTY, UTAH

by

Grant C. Willis, Hellmut H. Doelling, and Michael L. Ross

1996

DESCRIPTION OF MAP UNITS

QUATERNARY (number subscripts indicate relative age--1 are the youngest (active) and 8 are the oldest mapped Quaternary deposits)

Deposits from human activity

Qf — Fill: Mapped railroad base and dam embankments. Most fill for highways, railroads, and small dams on ephemeral streams was not mapped separately.

Alluvial deposits

Qas — Sand and gravel deposits of the Colorado River: Moderately to well-sorted sand and gravel in the active river channel; inundated and reworked by spring floods; little or no vegetative cover; 0 to 20 feet (0-6 m) thick.

Qa — Alluvial deposits: Poorly to moderately sorted clay- to boulder-size deposits in washes and ephemeral stream channels; materials are from local sources and have undergone limited transport; unit includes other types of deposits too small to map separately; similar to Qae and Qam except confined to better-defined drainages and has a smaller mud and eolian component; 0 to 20 feet (0-6 m) thick.

Qao — Older alluvial deposits: Poorly to moderately sorted, clay- to boulder-size material deposited by streams and sheet wash; form erosional remnants due to later downcutting and dissection; protrude from beneath overlying eolian deposits; 0 to 40 feet (0-12 m) thick.

Qal_1 — Younger alluvial stream deposits: Moderately sorted boulders, cobbles, sand, silt, and clay along washes of perennial streams; contain materials transported from outside of local area; form benches up to 10 feet (3 m) above active drainages; better sorted than Qa deposits; gradational with other Quaternary surficial deposits; range from 0 to about 20 feet (0-6 m) thick.

Qal_2 — Older alluvial stream deposits: Moderately sorted boulders, cobbles, sand, silt, and clay along washes of perennial streams; deposits have been incised 10 to 30 feet (3-9 m) by downcutting of washes; contain materials transported from outside of local area; locally, materials are being deposited on these surfaces from small side washes and adjacent slopes; gradational with other Quaternary surficial deposits; range from 0 to about 30 feet (0-9 m) thick.

Qap_{3-4} — Pediment- and terrace-mantle deposits: Poorly to moderately sorted boulders, cobbles, sand, silt, and clay; form a thin veneer on pediment and terrace surfaces; numbers indicate relative age and height above modern drainages-- Qap_3 ranges from 30 to 50 feet (9-15 m) above adjacent drainages-- Qap_4 from 60 to 100 feet (18-30 m); 0 to 40 feet (0-12 m) thick.

Qat_{2-8} — Terrace gravels deposited by the Colorado River: Moderately to moderately well-sorted cobble- to boulder-size gravel and sand deposited by the Colorado River; isolated on terraces and ledges by continued downcutting of the river; clasts are exotic to quadrangle and come from many miles upstream; range up to 460 feet (140 m) above current river level; numbers indicate relative age and height above modern drainages (see correlation chart, lower right); Qat_3 and Qat_5 are not recognized in quadrangle; 0 to 40 feet (0-12 m) thick.

Eolian deposits

Qes — Eolian deposits: Well- to very well-sorted sand, silt, and minor loess; probably derived from local sandstone units; may include a large component of residuum; blanket benches and broad surfaces where protected from erosion; have a distinctive pale-reddish-orange color imparted by source materials (Jurassic and Triassic "red rock" formations); range from 0 to 80 feet (0-24 m) thick.

Mass-movement deposits

Qms — Landslide deposits: Very poorly sorted boulder- to clay-size material on slopes; hummocky upper surface; contains boulders up to 20 feet (6 m) in diameter; derived from Morrison and Cedar Mountain Formations; locally include talus and colluvial deposits; 0 to 50 feet (0-15 m) thick.

Qmt — Talus deposits: Very poorly sorted, angular boulders and lesser smaller-size materials on, and at base of, steep slopes; derived from resistant overlying units; small deposits are not mapped separately; 0 to 30 feet (0-9 m) thick.

Mixed-environment deposits

Qam — Alluvial mud and sheet-wash deposits: Moderately well-sorted silt, clay, and some sand; locally with minor coarse clastic or eolian deposits; mostly sand near outcrops of Dakota Sandstone; cover broad surfaces with poorly developed drainages; derived primarily from the Mancos Shale and the middle part of the Dakota Sandstone; gradational with units Qal_1, Qal_2, Qae, and Qea; range from 0 to 20 feet (0-6 m) thick.

Qac — Mixed alluvial and colluvial deposits: Poorly to moderately sorted, clay- to boulder-sized material deposited in channels near steep slopes; many smaller deposits are not mapped separately; locally contain abundant eolian materials; gradational with other Quaternary surficial deposits; 0 to 20 feet (0-6 m) thick.

Qae — Mixed alluvial and eolian deposits: Moderately to well-sorted clay- to boulder-sized material; dominated by alluvial processes; present in areas with minor to moderate erosion where eolian deposits have had time to accumulate; eolian component varies from locally absent to moderate; intermediate between, and gradational with, Qa and Qea; similar to Qam but there is more sand and less clay and silt; 0 to 30 feet (0-9 m) thick.

Qea — Eolian and alluvial deposits: Moderately well- to very well-sorted sand, silt, loess, and local gravel; eolian component generally more abundant than alluvial component; have a distinctive reddish-orange color imparted by eolian source materials (Jurassic and Triassic "red rock" formations); present on older surfaces in areas of limited alluvial influence; gradational with other surficial deposits; range from 0 to 40 feet (0-12 m) thick.

unconformity

CRETACEOUS

Kmbl — Lower part of the Bluegate Shale Member of the Mancos Shale: Medium- to dark-gray, brownish-gray, or black mudstone, siltstone, and shale; weathers to pale gray; contains 0.5 to 2 inch (1-5 cm) thick layers of white to light-gray bentonite and a few thin, very fine-grained sandstone beds; rare bivalves, ammonites, gastropods, and fish scales; trace fossils are locally common; bedding is poorly developed and is generally lenticular; heavily weathered at surface; preserved part of unit is about 1,500 to 1,600 feet (450-480 m) thick; upper part not preserved in quadrangle; includes two thin sandstone marker beds, M_1 and M_2.

Kmf — Ferron Sandstone Member of the Mancos Shale: Medium- to dark-gray, interlayered mudstone and siltstone, and pale- to medium-grayish-brown, medium- to very fine-grained sandstone; locally, base is a coarse sandstone up to 5 feet (1.5 m) thick with scattered grit and rare pebbles up to 0.5 inch (1 cm) in diameter and with rare fish teeth; sandstone forms coarsening upward sequences that are generally 1 to 5 inches (1-12.5 cm) thick; bivalves, trace fossils, and calcite-cored concretions are locally present; has ripple laminations, sole marks, and horizontal to lenticular bedding; gradational upper contact; forms a low cuesta; unit is about 100 to 125 feet (30-38 m) thick.

Kmt — Tununk Shale Member of the Mancos Shale: Medium- to dark-gray, brownish-gray, or black mudstone, siltstone, and shale; weathers to pale gray; contains several 0.5 to 2 inch (1-5 cm) thick layers of white to light-gray bentonite and a few dense, thin, very fine-grained sandstone beds; has pods of dark-gray aragonite up to 3 inches (7.5 cm) thick; fossils and trace fossils are locally common; oyster shells are locally abundant near the base of the unit; bedding is poorly developed and is generally lenticular; 150 to 190 feet (45-57 m) thick.

Kmtc — Coon Spring Sandstone Bed of the Tununk Shale Member: Medium- to dark-brownish-gray, silty shale and mudstone with interbedded yellowish-brown to pale-gray, thin, platy, very fine-grained sandstone, mudstone, and calcareous sandstone concretions; locally fossiliferous; sandstone forms very thin beds up to about 3 inches (7.5 cm) thick; large rounded sandstone concretions are up to about 6 feet (2 m) in diameter; calcareous sandstone concretions are up to 3 feet (1 m) in diameter and are sparitic to fibrous; generally forms mound or swell littered with resistant concretions about 100 feet (30 m) above base of Tununk; the sandstone or calcareous sandstone concretions are commonly the only well exposed part of the unit; gradational upper and lower contacts; unit is 35 to 45 feet (11-14 m) thick; mapped as a marker bed because lower and upper contacts are poorly exposed.

Kd — Dakota Sandstone: Pale-yellowish-orange, yellowish-gray, or gray, fine- to coarse-grained, quartz sandstone and conglomeratic sandstone and medium- to dark-gray carbonaceous shale and mudstone. Lower part is medium- to thick-bedded and generally cross-bedded sandstone and conglomerate, conglomerate is lenticular and discontinuous, clasts in the conglomerate are generally less than 1 inch (2.5 cm) in diameter, dense ironstone concretions are abundant. Middle part is medium- to dark-gray carbonaceous shale, mudstone, thin coal, and lenticular fine- to medium-grained, thin- to thick-bedded, cross-bedded, channel sandstone deposits; has volcanic ash layers with some plant fossils, coal ranges from 0.5 to 2 feet (0.15-.6 m) thick. Upper part is fine- to medium-grained sandstone that contains scattered quartzite cobbles up to about 2 inches (5 cm) in diameter; upper contact is a sharp, irregular surface; forms a resistant cliff throughout quadrangle. Unit is 90 to 120 feet (27-36 m) thick.

unconformity

Kcm — Cedar Mountain Formation: Pale-greenish-gray, thin- to medium-bedded sandstone and mudstone; locally has large lenticular channel deposits of medium to coarse sandstone; 60 to 100 feet (18-30 m) thick.

JURASSIC

Jmb — Brushy Basin Member of Morrison Formation: Variegated, red, maroon, light-green, gray, and white shale and mudstone interbedded with varying amounts of argillaceous sandstone, conglomeratic grit, thin lenses of dense gray limestone, and nodular limestone; forms steep slope; 380 to 420 feet (116-128 m) thick.

Jms — Salt Wash Member of Morrison Formation: Interbedded sandstone and mudstone; sandstone is light to yellow gray, medium to coarse grained, cross-bedded in lenticular beds as much as 20 feet (6 m) thick, and resistant; mudstone is generally red with less common green horizons, and forms slopes; about 200 to 250 feet (61-76 m) thick.

Jmt — Tidwell Member of Morrison Formation: Lavender and brown mudstone containing nodular, gray, hard limestone horizons and local large concretions of white chalcedony and quartz; slope forming; 20 to 45 feet (6-14 m) thick.

J-5 unconformity

Js — Summerville Formation: Gray, tan, and brown sandstone; mostly fine grained, thin bedded, and ledge forming in upper part; reddish, slope-forming, fine-grained silty sandstone and claystone in lower part; 40 to 55 feet (12-17 m) thick.

Je — Entrada Sandstone: shown on cross section only.

Jem — Moab Member of Entrada Sandstone: White sandstone, fine- to medium-grained, well-rounded grains; generally in massive resistant beds, tops of beds weather into polygonally fractured blocks; 70 to 80 feet (21-24 m) thick.

J-3 unconformity? (eolian cross-beds in Slick Rock Member are truncated at contact with Moab Member)

Jes — Slick Rock Member of Entrada Sandstone: Light-brown or buff, light-reddish-brown or salmon-colored, pinkish-orange sandstone; chiefly very fine- to fine-grained, rounded to well-rounded, moderately well-sorted subarkosic arenite; occasional medium- to coarse-grained quartz sand along cross-bed laminae; calcareous, poorly cemented; horizontal bedding and large-scale eolian cross-bedding; forms bare, smooth cliffs and steep rounded hills; about 140 to 150 feet (43-46 m) thick.

Jed — Dewey Bridge Member of Entrada Sandstone: Pale-reddish-brown to light-brown, moderate-reddish-brown, silty sandstone interbedded with very pale-orange, grayish-orange, pale-yellowish-orange sandstone; colors commonly mottled; black specks of residual oil are common in yellowish-orange sandstone; sandstone is generally very fine- to fine-grained, subrounded to rounded, moderately sorted subarkosic arenite, calcareous, and poorly cemented; silty sandstone is generally very fine to medium grained, subangular to rounded, moderately sorted, calcareous, and moderately indurated; within beds are indistinct areas of disturbed thin to thick laminae; basal contact is sharp erosional truncation surface on which detrital chert granules, pebbles, and cobbles are widespread; sparse stringers of coarse-grained quartz and chert in basal sandstone; forms irregular rounded ledges and rubbly slope; about 25 to 35 feet (8-11 m) thick.

J-2 unconformity

Jk — Kayenta Formation: Grayish-red-purple, pale-red-purple, pale-reddish-brown sandstone, intraformational conglomerate, and siltstone interbedded with bluish-white to very light-gray sandstone; wedge-shaped to tabular sandstone packages of very fine- to medium-grained, subrounded, moderately to well-sorted feldspathic to lithic arenite; thinly laminated to thick bedded; small- to large-scale cross-bedding; intraformational conglomerate contains rip-up clasts of siltstone and mudstone; poorly sorted; small-scale trough cross-bedding; calcareous, well-indurated; thick to massive bedding; forms step-like ledgy cliffs and slopes; gradational and irregular contact with underlying Wingate Sandstone; about 200 feet (60 m) thick.

Jw — Wingate Sandstone: Grayish-orange-pink and light-brown quartz sandstone; very fine to fine grained; grains are rounded, well sorted, and frosted; calcareous; well cemented; horizontal bedding to large-scale eolian cross-bedding; interbedded ripple-laminated sandstone and thinly laminated siltstone at base; forms massive cliff or step-like massive ledges; commonly coated with a veneer of dark-rusty-red to black desert varnish; about 300 feet (90 m) thick.

J-0 unconformity

TRIASSIC

ℛc — Chinle Formation: Reddish-brown, grayish-red, pale-brown, and pale-red siltstone, sandstone, mudstone, limestone, and pebble conglomerate and sparse pale-green limestone and mudstone; predominantly siltstone and fine-grained sandstone; siltstone is calcareous, indurated, structureless to horizontally laminated, and has a few vertical burrows in upper part; sandstone is fine grained, moderately sorted, calcareous, well cemented, and is locally ripple laminated to trough cross-bedded; at some locations at the top of the formation there is a lens 5 to 10 feet (1.5-3 m) thick of thick-bedded, fine- to medium-grained, moderately sorted, quartzose sandstone; at the base of the formation pebble conglomerate forms discontinuous gravel lenses containing abundant angular to subrounded metamorphic and granitic rock clasts; about 70 to 110 feet (21-33 m) thick.

ℛ-3 unconformity

EARLY TO MIDDLE PROTEROZOIC Note: Dike-like and irregular bodies of granitic pegmatite, aplite, and lamprophyre cross-cut all gneissic units; bodies are generally linear, small, and discontinuous; pegmatites may be late phases of quartz monzonite intrusion southeast of map area. They are too small and scattered to map separately.

YXu — Undivided metamorphic and igneous rock: Shown in cross section only.

YXm — Altered mafic and ultramafic rock: Non-foliated, strongly metasomatized rock with generally equigranular, fine-grained texture that overprints medium- to coarse-grained amphibole and plagioclase, mostly altered to chlorite, clay minerals, and serpentine, carbonate, and hematite; forms small, dark-greenish-black to dark-brownish-black, pipe-like bodies; weathers to debris-covered black knobs.

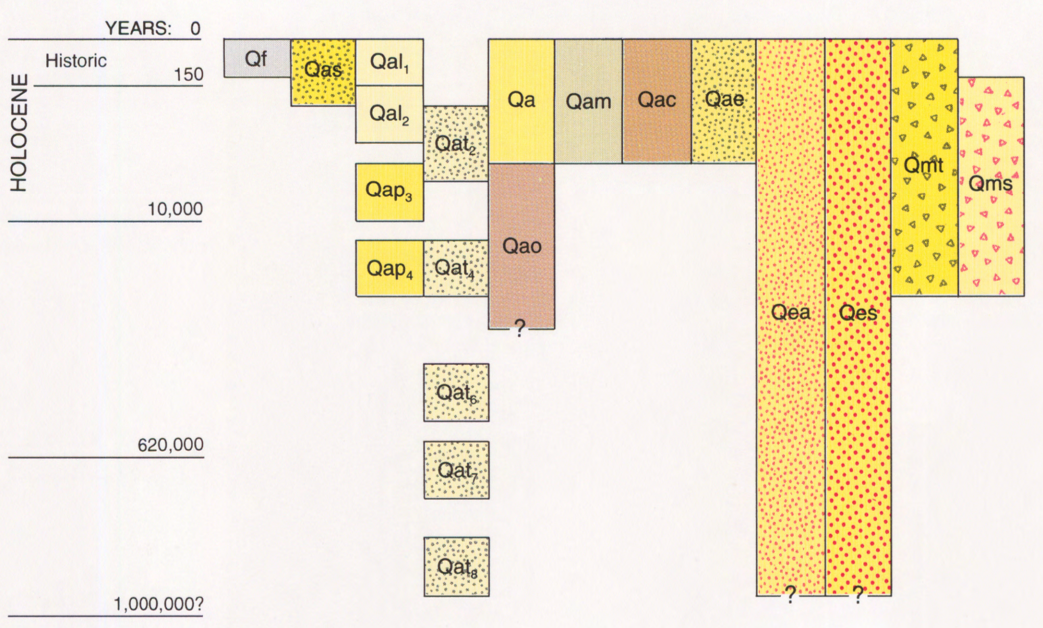
Xbm — Biotite-microcline gneiss: Fine- to medium-grained gneiss composed of quartz, K-feldspar, plagioclase, biotite, and rare sillimanite; well foliated; thinly layered; highly deformed; locally migmatitic; forms light- and dark-banded, bouldery outcrops; interlayered with amphibolite (Xa) bodies at Westwater Canyon; thought to be meta-sedimentary.

Xmag — Microcline augen gneiss: Distinctive pinkish-gray to "salt and pepper" colored gneiss composed of large (up to 1 inch; 2.5 cm) subhedral "birds-eye" structures that are either augen of microcline or recrystallization aggregates in a fine- to medium-grained groundmass of plagioclase, quartz, biotite, and minor muscovite; forms foliated sill-like masses; thought to be meta-igneous.

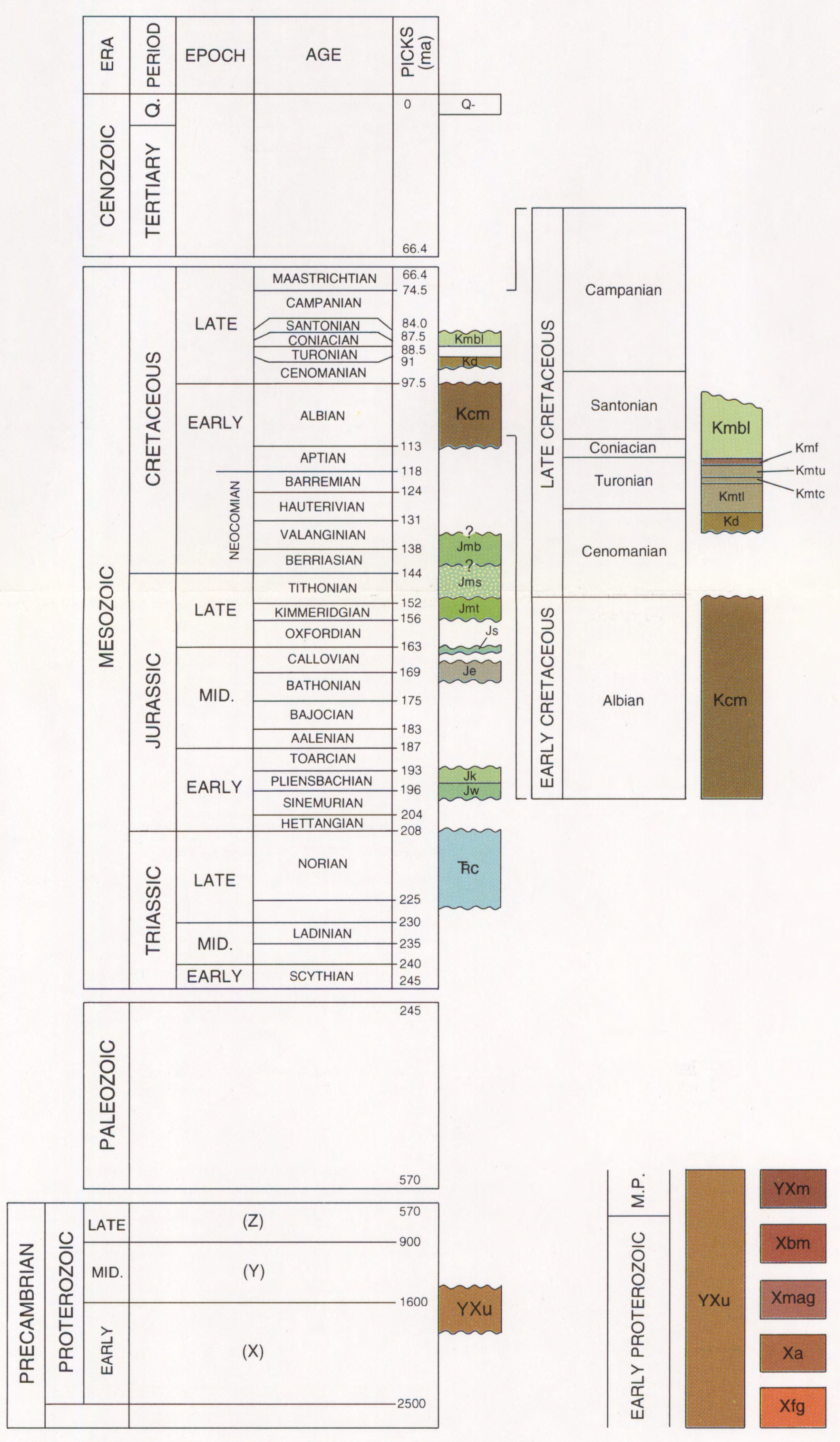
Xa — Amphibole gneiss and amphibolite: Characterized by fine- to medium-grained amphibole, quartz, plagioclase, K-feldspar, trace amounts of garnet and apatite; forms dark-gray to black sill-like masses or layers in and adjacent to the feldspathic gneiss (Xfg); most of the unit is structurally above the feldspathic gneiss and below the biotite-microcline gneiss (Xbm); thought to be meta-igneous (basaltic sills and flows).

Xfg — Feldspathic gneiss: Medium- to coarse-grained, homogeneous quartz-feldspar gneiss that contains abundant biotite and minor amphibole, apatite, sphene, garnet, and opaque minerals; well foliated, prominent mineral lineations are pervasive; forms light-pinkish-gray to black bouldery outcrops; thought to be meta-igneous (flows, ignimbrite sheets or sills).

CORRELATION OF SURFICIAL DEPOSITS

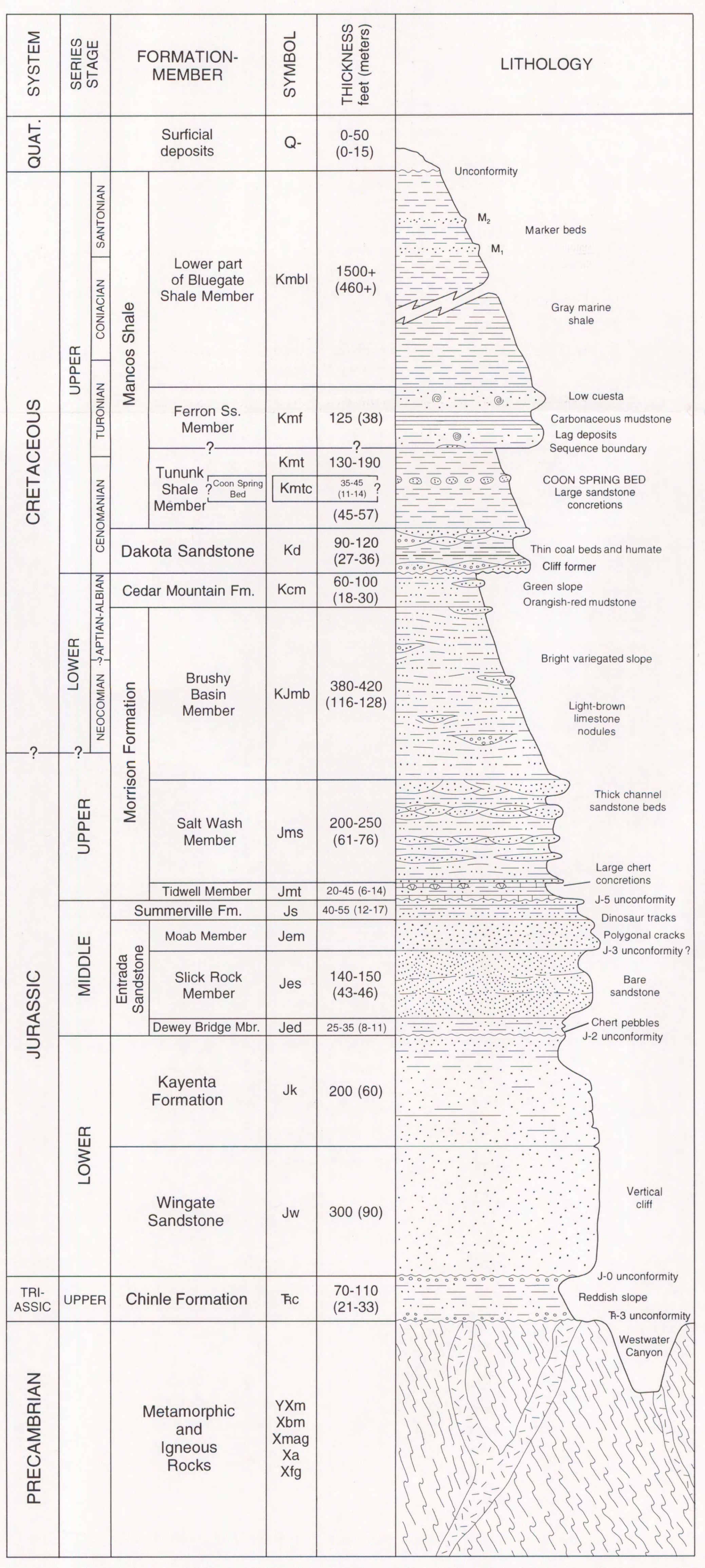


CORRELATION OF BEDROCK UNITS

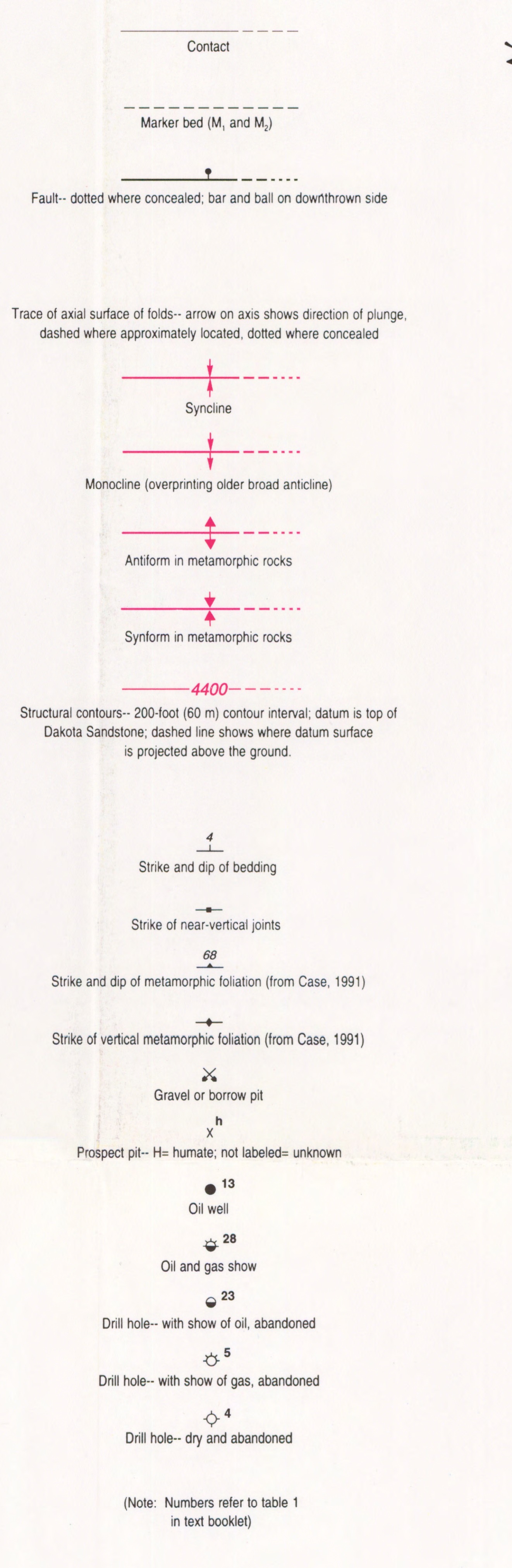


Scale modified from Palmer, 1983.

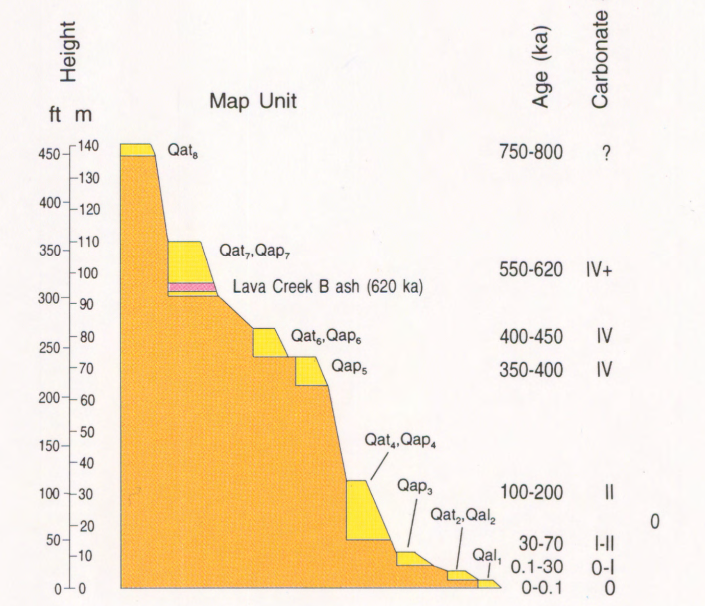
LITHOLOGIC COLUMN



MAP SYMBOLS



CORRELATION OF PEDIMENT AND TERRACE DEPOSITS



Pediment- and terrace-mantle deposits form erosional remnants up to 460 feet (140 m) above adjacent active drainages. Height above drainages, amount of pedogenic carbonate development, and comparison with nearby deposits of known age is used to estimate age and correlation of these deposits (Willis, 1992 and 1994). See discussion in the text. Mapped deposits without number subscripts generally have a wider age range.