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Rattlesnake Mesa Quadrangle Geologic Map
Rio Blanco County, Colorado

Authors' Notes

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Colorado Geological Survey
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View from LO7 Hill toward the northeast showing the Meeker Dome and the high Mesaverde escarpment in the background. The dome can be discerned by the disk-shaped treed area in center of photo. The low ridgeline between the high escarpment and the dome is the Meeker Sandstone cuesta that encircle the dome on the west, north, and east sides. The break in the cuesta and gap in the escarpment on the left side is the Curtis Creek valley that extends to Ninemile Gap. Highway 13, which follows Curtis Creek, can also be seen curving around the Meeker Sandstone bluff.

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FOREWORD

The purpose of Colorado Geological Survey's (CGS) *Rattlesnake Mesa Quadrangle Geologic Map, Rio Blanco County, Colorado* is to describe the geology of this 7.5-minute quadrangle located in the vicinity of the town of Meeker in northwestern Colorado. CGS staff geologist Jonathan L. White and field assistants James Hodge and Michael J. Zawaski completed the field work on this project at the end of the summer of 2010. Jon White, the principal mapper and author, created this report using field maps, photographs, structural measurements, and field notes generated by all the investigators. Signficant knowledge was also gained by a compilation of the available published geologic literature listed in the references. This map was improved from reviews by Larry Moyer (consulting petroleum geologist), David Noe (Colorado Geological Survey), as well as directly pertainable edits of the adjacent Meeker quadrangle by Rex Cole (Colorado Mesa University).

This mapping project was funded jointly by the U.S. Geological Survey (USGS) and the CGS. USGS funding comes from the STATEMAP component of the National Cooperative Geologic Mapping Program, award number G10AC00410, authorized by the National Geologic Mapping Act of 1997, reauthorized in 2009. CGS matching funding comes from the Colorado Department of Natural Resources Severance Tax Operational Funds, from severance taxes paid on the production of natural gas, oil, coal, and metals in Colorado.

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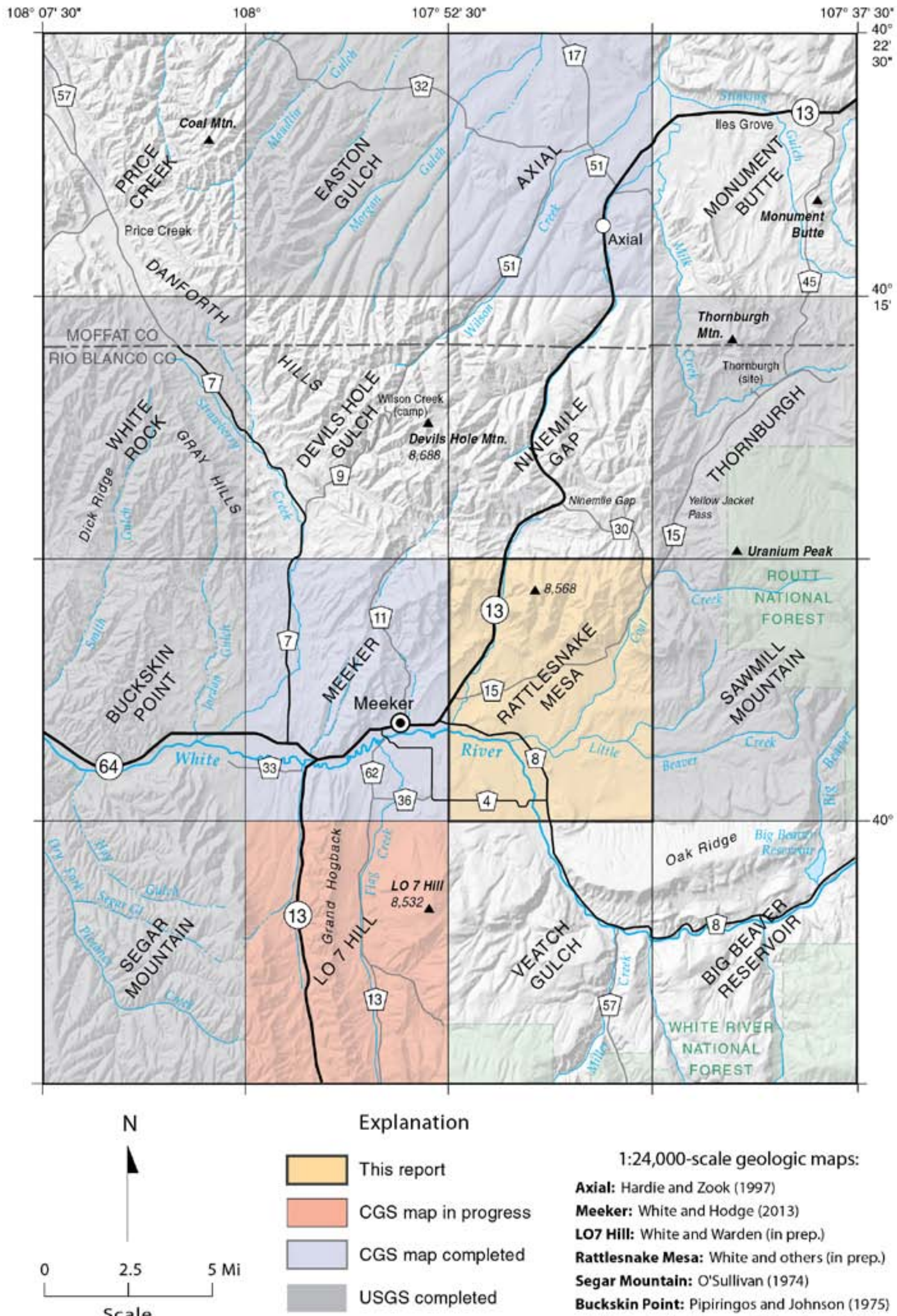
INTRODUCTION

The Rattlesnake Mesa 7.5-minute quadrangle is located in Rio Blanco County, Colorado, along the valley of the White River (**Figure 1**). The Town of Meeker lies to the west, just off the map along State Highway 13. Meeker is the county seat of Rio Blanco County.



Explanation

- This report
- CGS map in progress
- CGS map completed
- USGS completed

1:24,000-scale geologic maps:

Axial: Hardie and Zook (1997)
Meeker: White and Hodge (2013)
LO7 Hill: White and Warden (in prep.)
Rattlesnake Mesa: White and others (in prep.)
Segar Mountain: O'Sullivan (1974)
Buckskin Point: Pipiringos and Johnson (1975)
White Rock: Pipiringos and Rosenlund (1977)
Easton Gulch: Reheis (1981)
Sawmill Mountain: Reheis (1984a)
Thornburgh Mountain: Reheis (1984b)

Figure 1. Regional map with key of geologic quadrangle mapping near Rattlesnake Mesa

Figure 2 shows the major physiographic and structural features. The formal topographic names have been labeled. The most striking features in the quadrangle are the Meeker Dome, the Mesaverde escarpment and high ridges along the northern third of the quadrangle, and several secondary streams valley floors that debouche to the White River valley in the southern portion of the map in Agency Park. The highest elevation (8,568 feet) is on a ridge above the escarpment in the north-central portion of the quadrangle. The lowest elevation (6,270 feet) occurs on the floor of the White River valley where the river exits along the southwestern corner of the quadrangle.

The Colorado Geological Survey (CGS) mapped the geology of Rattlesnake Mesa quadrangle as part of the STATEMAP component of the National Cooperative Geologic Mapping Act (NCGMP), administered by the U.S. Geological Survey (USGS). Geologic maps produced by CGS through the program are intended as general-purpose maps that can be used for land-use planning, civil and geotechnical engineering, geologic-hazard assessment, mineral-resource development, and ground-water exploration.

The purpose of the CGS STATEMAP program is to produce 1:24,000-scale geologic maps with approximately equal focus on surficial units, bedrock units, and structural features. The intended benefits of this mapping approach for the Rattlesnake Mesa quadrangle include the following:

- The surficial units were not previously studied or mapped in any detail. The map adds appreciably to understanding the Quaternary geologic history of the area, especially dip-slope failures and landslide deposition, tributary valley-fill deposition, and alluvial deposition concurrent with the successive lowering of the White River base level. Many Quaternary unconsolidated deposits are considered soils in engineering terms. Many of these soils may have adverse swelling or settlement properties. The reader is encouraged to read the Authors' Notes for the adjacent Meeker quadrangle, which has a more in-depth discussion of the potential geologic hazards in the area (White and Hodge, 2013).

- The map shows the locations of alluvial deposits on the valley floors that may be suitable sources of sand and gravel, as well as potential for shallow ground-water aquifers.

- The Rattlesnake Mesa quadrangle bridges the available 1:24,000 geologic mapping of the north and east margins of Piceance Basin with coal-resource mapping to the east and northeast.

- The map shows the extent of the bedrock outcrops at a more detailed scale and with more accuracy than previous maps. More importantly, the individual formational members of the Mancos Shale and Mesaverde Group were subdivided and delineated on the map, including several member sandstones not shown in any previous maps.

- The map shows more detailed geologic structure with more bedding strike-and-dip notations and more faulting than previous maps.

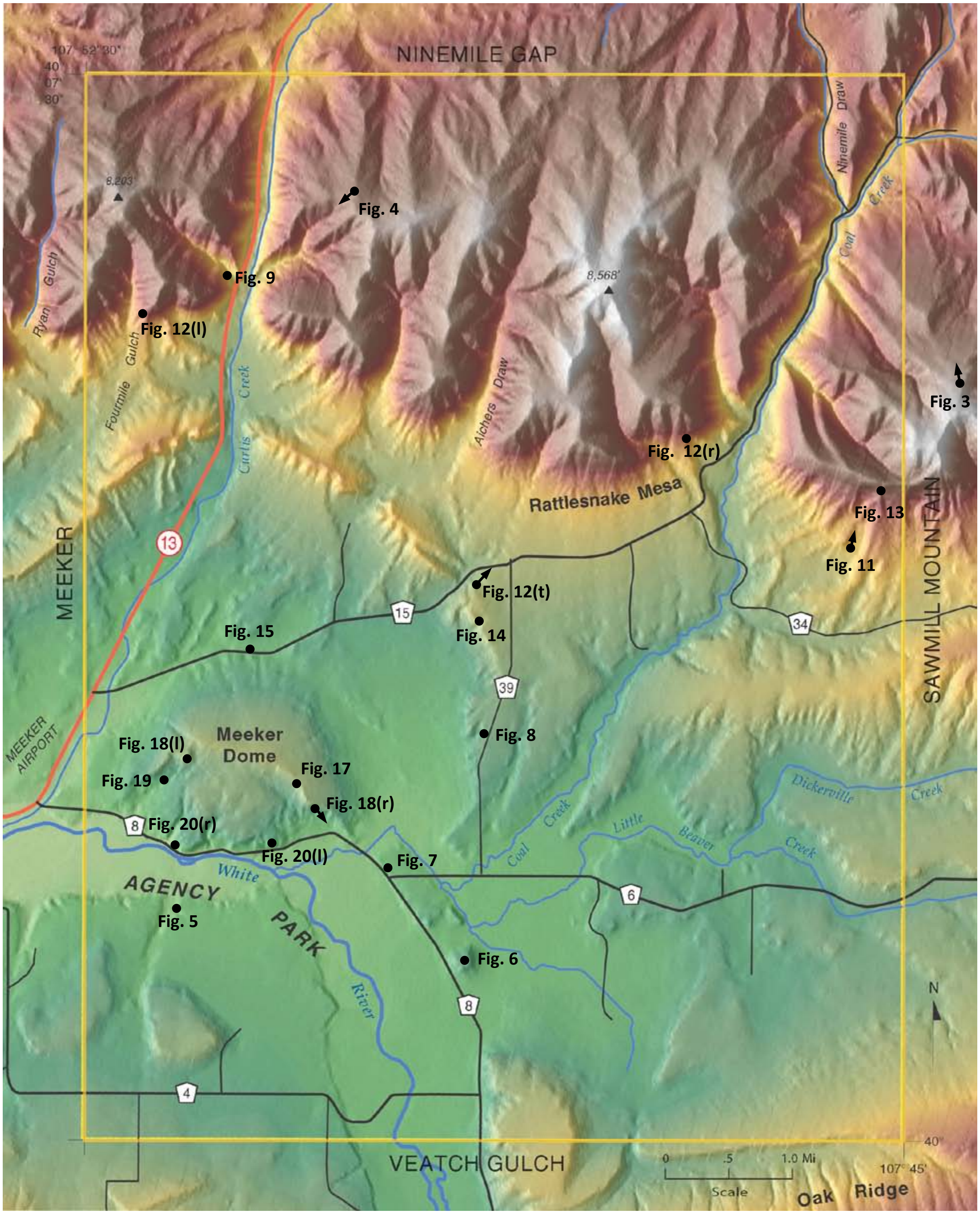


Figure 2. False-color shaded relief map of the Rattlesnake Mesa quadrangle showing major physiographic and topographic features. Figure numbers, if they are photographs, are shown by black dots. Vectors are included if photo is a panoramic view.

PREVIOUS MAPPING STUDIES

Figure 1 shows the status of 7.5-minute (1:24,000-scale) quadrangle geologic mapping in the area as of this writing. The Rattlesnake Mesa quadrangle is the second of three geologic maps done by CGS in the Meeker proximity. Previous mapping of the Rattlesnake Mesa quadrangle map area was conducted at a much more reconnaissance style for the regional, 1:250,000-scale, Craig 1x2^{o} geologic map (Tweto, 1976). Tweto (1976) relied on the earlier work by Hancock and Eby (1930), who produced a seminal geologic map and coal-resources report on the Meeker 15-minute (1:62,500 scale) quadrangle that includes the 7.5-minute Rattlesnake Mesa quadrangle. Murray (1962, 1966) completed his University of Colorado thesis and dissertation of the stratigraphy and structural geology of the Grand Hogback Monocline, including a 1:63,360-scale geologic map that contained the western half of the Rattlesnake Mesa map area. Madole (1989) mapped the surficial deposits of the area at a scale of 1:100,000.

MAPPING METHODOLOGY

The geologic interpretations shown on the Rattlesnake Mesa geologic map are based on the following sources: (1) CGS field investigations conducted from June to September, 2010; (2) published and unpublished geologic maps and reports; (3) interpretation of remote-sensing data; and (4) the National Resources Conservation Service (2009) Soil Survey Geographic (SSURGO) database for Rio Blanco County. The data used to map the geologic contacts include stereo pairs of black and white 1:20,000-scale Agricultural Stabilization and Conservation Service (ASCS) aerial photography flown in 1966, a 10-meter resolution digital elevation model (DEM), the USGS 1:24,000-scale topographic base map, and 1-meter resolution National Agricultural Imagery Program (NAIP) digital orthophotos taken in 2006 and 2009.

Bedrock geology and surficial deposits were mapped photogrammetrically in the field on stereo pairs of aerial photographs. Key geologic and photograph locations were recorded with a portable GPS receiver. Mapping from the aerial photos was scanned and digitized into an ESRI ArcMap GIS project file on a 1:24,000 topographic base map. Georeferenced 2009 NAIP orthophotography was also loaded into the GSI project to ensure the accurate map location of geologic features and contacts. Because of subtle errors found in the original 1:24,000-scale topographic map, the final geologic mapping was indexed to the more accurately georeferenced NAIP photography.

Portions of the Rattlesnake Mesa quadrangle can be well vegetated as a result of higher amounts of precipitation in the higher terrain, the shading of north-facing slopes, and the abundant irrigation on the many mesas and “parks” in the valley bottoms. Well exposed outcrops are present along the major escarpments but are more poorly exposed in the valley bottoms along the mesa edges where there is mostly easy-erodible shale. The mapping involved interpolation of geologic boundaries between known points. Many of the bedrock and surficial units have distinctive geomorphic signatures, lithologies, and fossil assemblages that assisted the authors in mapping the various strata.

PHYSIOGRAPHY AND GEOLOGIC SETTING

The Rattlesnake Mesa quadrangle lies near the junction of three physiographic provinces where the southern part of the Wyoming basin intersects the boundary of the Colorado Plateau and the Southern Rocky Mountains (Fenneman and Johnson, 1946). This physiographic intersection occurs where the south-to-north trending Grand Hogback Monocline ends and formational strikes bend 90° and transition to the asymmetrical east-to-west trending Sulphur Creek Syncline (White and Hodge, 2013). The west-east trending axis of the Sulphur Creek Syncline is mostly off map to the north, except for the northeast corner of the quadrangle where the axis curves southeastward and clips the corner of the map area (**Figure 3**) before continuing southeastward onto the adjacent Sawmill Mountain quadrangle (Reheis, 1984a). The Sulphur Creek Syncline marks the regional structural transition to the southwest flank of the Axial Fold Belt. This anticlinal trend from the Uinta Mountains to the White River Uplift is attributed to basement-involved thrust-fault-propagation fold structures that trend along the north and northeastern boundary of the Piceance Basin (Stone, 1991).

Figure 3. View northward of the asymmetrical Sulphur Creek Syncline. Strata here dip 12° on southwest limb and 65° across axis on northeast limb. The steep limb is illustrated by the prominent, light colored, Trout Creek Sandstone (Kit). Northeast corner of Rattlesnake Mesa quadrangle map area is shown by white dashed line. County Road 15 can be seen in Coal Creek valley below. Approximate trend of syncline axis is shown by thick black dashed line. [UTMX 266178, UTMY 4440856]

Bedrock exposed in the Rattlesnake Mesa quadrangle consists of Upper Cretaceous to Jurassic formations. From youngest to the oldest, they are the Williams Fork Formation, Iles Formation, Mancos Shale, Dakota Sandstone, and Morrison Formation. The shale units are nonresistant and form valleys and topographic basins. The tilted sandstone-bearing strata are more resistant to weathering. Accelerated base-level lowering of topography underlain by the soft and easily eroded Mancos Shale has formed the major escarpments, doming, and cuesta geomorphology seen in **Figure 2** that expresses the geologic structure across the landscape. The southern limb of the syncline in the northern third of the map area has northward dips that average about 22° (**Figure 4**) in the northwest but lessen to about 10° in the northeast map area near the syncline axis shown in **Figure 3**.

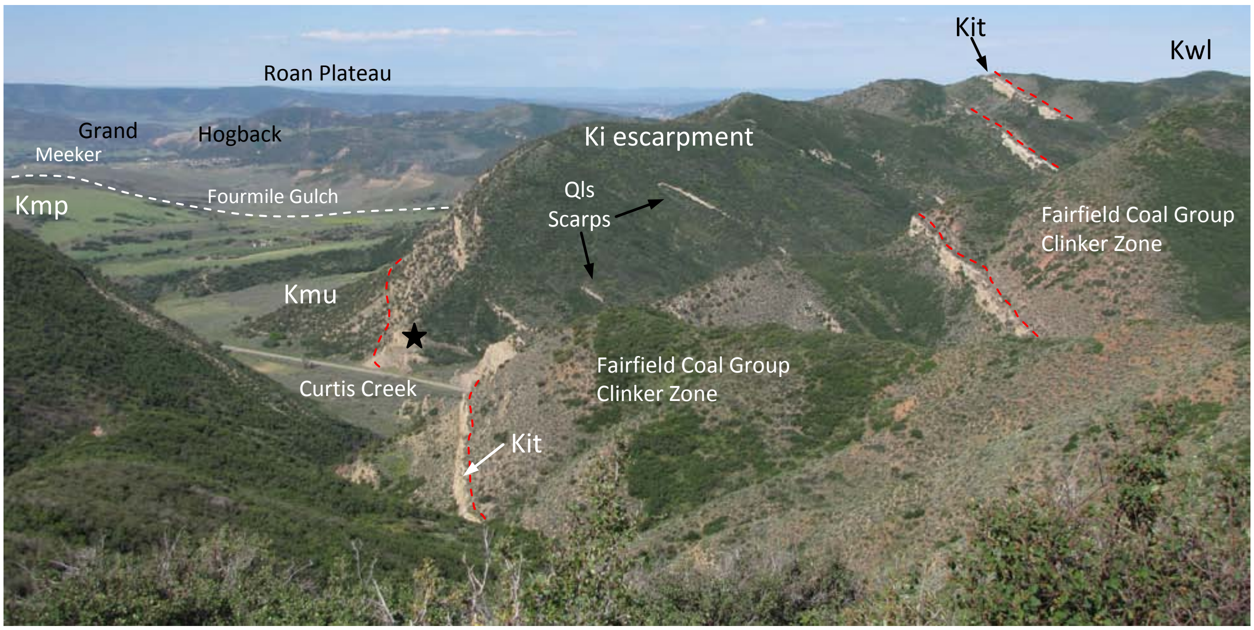


Figure 4. Southwest view down Curtis Creek valley and Fourmile Gulch towards the town of Meeker and Agency Park, east of the Grand Hogback. North-to-south western boundary of Rattlesnake Mesa quadrangle is shown by dashed white line. Note the east-to-west striking, 22°-25° dip of nearby strata (on the southern limb of the Sulphur Creek Syncline), which is perpendicular to the north-to-south strike trend of the Grand Hogback. Dashed red lines mark formational contacts, including the Iles Formation escarpment over the upper Mancos Shale (Kmu) and the prominent Trout Creek (Kit) Sandstone member. Note the red color in the Kwl slope within the Fairfield Coal Group Clinker Zone. Star is a thin coal seam shown in Figure 9. Roan Plateau is in the far background. [UTMX 258437, UTMY 4443764]

The White River, the region's major stream, flows from the south into the quadrangle, doglegs against the Meeker Dome uplift, and flows westward across the southwestern part of the quadrangle. Agency Park is a large topographic basin where the White River valley widens in the easily eroded Mancos Shale bedrock. The more resistant Frontier and Dakota Sandstone are exposed at the Meeker Dome on the north side of the River. The mesas in Agency park are strath terraces that recorded episodic Quaternary alluviation of glacio-fluvial gravel of the White River, as well as fluvial gravel deposition of tributary streams at their paleoconfluences. In addition to these broader mesas along the

White River, Quaternary erosion and base-level lowering of all streams has also formed smaller mesas and ridges along tributary valleys slopes, which are capped with earlier, rocky, more resistant, valley-fill deposits (See *Surficial Deposits* in *Description of Map Units* sections).

MEEKER DOME STRUCTURE

The most obvious structural feature in the Rattlesnake Mesa quadrangle is the Meeker Dome. This structural dome is about 2½ miles across with a structural relief of 2,000 vertical feet. This poorly understood structure rises from Agency Park where it is partially breached by White River downcutting. Dakota Sandstone and Morrison Formation strata are exposed at its core (**see frontispiece photo**). The major sandstone members of the Mancos Shale (Meeker and Frontier) form concentric cuestas that rise towards the dome's center on the west, north, and east sides (**Figure 2**).

The main east-west trending Meeker Dome anticline was mapped as steeply plunging in both directions from the dome's structural high. It apparently flattens and ends nearby within the Mancos Shale. Several small-displacement faults and folds on the dome accommodated this structural deformation. There is a paired syncline to the south. The syncline axis is buried beneath Agency Park where the southward dip of the dome structure transitions back to a dip northward; this is the same regional trend as on Oak Ridge, and on LO7 Hill to the south (White and Warden, in prep.). At the eastern terminus of the dome anticline near Coal Creek, this buried syncline curves northward, and shallowly plunges asymmetrically before terminating somewhere under the cover of Quaternary deposits on Rattlesnake Mesa. On the map, the Meeker sandstone outcrop doglegs from a north-northwest strike to more easterly. Measured strata inclination also flattens from 38° to about 10° across the axis. A second anticline axis runs due north from the dome apex before terminating in the Iles Formation along the Curtis Creek Canyon. At the Curtis Creek anticline, there is a corresponding dogleg in the map-view concentricity of the Meeker Sandstone ridgeline (**Figure 2**).

The literature record doesn't reveal what the basement structure of this site is. The following causes for the dome may be plausible: the dome is a deep-seated Laramide fault-block structure; or a compressional deep-thrust feature as the regional strike transitions from north-south to east-west; or lithostatic deformation from salt-diaperic flow; or a combination thereof.

Regarding salt neotectonics, Kirkham and Scott (2002) have documented salt neotectonics in terrain underlain by Pennsylvanian Eagle Valley Evaporite southwest, south, and east of the White River Uplift. In addition, active dissolution of evaporite bedrock and neotectonic deformation is occurring near Buford (White, 2012). Oil and gas wells on the Rattlesnake Mesa quadrangle (J Keller #1) reveal thick salt in the Pennsylvanian Eagle Valley Evaporite, which is called the Meeker Halite Basin on the Meeker-Buford side of the White River Uplift (Dodge and Bartleson, 1986). Very high saline concentrations were also noted in deep pressurized aquifers. Inadequate plugging of early oil exploration wells on, and in the vicinity of the Meeker Dome, resulted in pathways for movement of deep-reservoir, high-salinity waters into near-surface aquifers, causing upwelling and seepage at the ground surface (US Bureau of Reclamation, 1985). The Meeker well, flowing 3 cfs into the White River, was impounded and used by the Meeker townfolk for several years as a warm spring at the base of the Meeker Dome next to the highway. This well alone increased the salt load of the Colorado River by about 57,000 tons per year. This point-source salt loading of the Colorado River Basin at the Meeker Dome was identified and addressed by the U.S. Bureau of Reclamation (USBR) in their Colorado River Water Quality Improvement Program (CRWQIP). Seven wells shown below on the Rattlesnake Mesa geologic map plate were successfully replugged and sealed in the USBR program (US Bureau of Reclamation, 1985).

Well Name	Location
First National Bank if Meeker #1	NENW, Sec 17, T1N, R93W
First National Bank if Meeker #2	SWNW, Sec 17, T1N, R93W
Kritsas #1	SESE, Sec 8, T1N, R93W
Marland Well	SESE, Sec 20, T1N, R93W
Scott #1	NESW, Sec 20, T1N, R93W
KT Ranch #1	SESE, Sec 20, T1N, R93W
Meeker Well	NWNW, Sec 29, T1N, R93W

DESCRIPTION OF MAP UNITS

This section contains descriptions of surficial and bedrock units from the geologic map. The surficial units are organized by the dominant process of deposition (human-made, alluvial, and mass-wasting deposits) and by age, with the younger units preceding older units. Bedrock units are organized by increasing age. Geologic time divisions and nomenclature used in this report are shown in **Appendix A**.

SURFICIAL DEPOSITS

The surficial deposits in the Rattlesnake Mesa quadrangle are Quaternary (Holocene and Pleistocene) in age. They are widespread on the Rattlesnake Mesa quadrangle because of the erodible nature of the local bedrock, as well as topographic elevation differences that can foster rapid and extensive deposition of sediments in alluvial, colluvial, and mass-wasting environments. The deposits shown on the map are generally more than five feet thick but may be thinner locally. Certain contacts between surficial units may be gradational, and mapped units locally may include deposits of other types. Very few of these deposits have been absolutely age-dated. Relative age assignments (early, middle, late) for the Holocene and Pleistocene deposits are based primarily on relative age-dating techniques: degree of erosional modification of original surface morphology, height above modern stream levels, degree of dissection and slope degradation, and degree of soil development.

Surficial deposits are generally considered soils in engineering terms. Many of these "soils" can be considered geologic hazards that have adverse engineering properties. Collapsible (hydrocompactive) soils, swelling soils, erodible soils, and slope stability may be a concern depending on the type of soil material and the depositional environment. The reader is encouraged to review the Authors' Notes for the adjacent Meeker quadrangle, which has an in-depth discussion of the potential geologic hazards in the area (White and Hodge, 2013)

HUMAN-MADE DEPOSITS

Af **Artificial fill and disturbed land (latest Holocene)** – Generally unsorted gravel, sand, silt, clay, and rock or concrete debris emplaced as fill to construct highways, airport runways, and other human-made structures. Also includes stockpiled materials, excavations, and overburden spoils that are associated with aggregate mining at gravel pits, as well as overlot grading where the ground topography has been obscured.

ALLUVIAL DEPOSITS

Clay, silt, sand, gravel, cobbles, and boulders deposited in major and tributary stream channels and flood plains. Terrace alluvium and age-related tributary stream deposits were formed mostly during periods of wetter climate that coincided with Pleistocene-age glacial periods. These sediments are generally unconsolidated, although cemented zones were noted in some of the older units.

ALLUVIAL DEPOSITS OF THE WHITE RIVER

The White River flows northward to westward across the southwestern part of the Rattlesnake Mesa quadrangle. Its alluvium consists of gravel, cobbles, small boulders, sand, silt, and clay transported and deposited by flowing water. Alluvium deposited from confined-channel flow is the principal sediment underlying the modern flood plain. Clast sizes range from silt, sand, and some granule gravel in recent over-bank deposits while larger clasts predominate in the glacial-derived older and higher deposits on the adjacent mesas. In the three older, elevated and dissected, alluvial-terrace deposits of the White River, the depositional environment was higher energy and the glacio-fluvial sediments were deposited as an aggrading braidplain on the valley floor with common cut-and-fill channels. The dominant sediment is a clast-supported pebbly to cobbly gravel in a densely packed, coarse-sand matrix with scattered small (<2 feet diameter) boulders. Most of the terrace gravel deposits that cap the mesas are now mantled with variable thicknesses of more recent valley fill, including alluvial/alluvial fan deposits, sheetwash, and windblown loess. These subsequent deposits can be quite thick, over 50 feet in some areas. In certain areas of the map, the thickness of the overlying valley fill has covered and obscured the river terraces along the valley slopes.

Volcanic, crystalline, and lower-Paleozoic sedimentary rocks are exposed in the White River Uplift highlands. This distinct assemblage of lithologies dominates the composition of gravel and larger size fractions of all Quaternary deposits of the White River. Lithologic gravel-count composition average about 60% Tertiary basalt, 20% Cambrian Sawatch quartzite, 10% Precambrian igneous and metamorphic crystalline rock, and the remaining 10% other sedimentary rocks, including red clasts from the Maroon Formation. The gravel, cobble, and boulder clasts are generally spherical to subspherical, and well rounded to round. The older river alluvium deposits are relatively devoid of fine-grained silt and clay. Clast lithologies are hard and resistant to weathering. Differential erosion and downcutting of the surrounding weaker bedrock has caused topographic reversal so that mesas and terrace bluffs have formed in the greater White River valley. These older mesas have aggregate-mine value. There are several active and abandoned gravel pits in the White River alluvium. Exposures in gravel pits reveal imbrication of the clasts that show an east to west flow of water. Channel scour and fill features are also visible in quarry walls and lenses of clean well-sorted coarse-grained sand sometimes occur within the gravel.

Qaw$_1$ **Alluvium one of the White River (Holocene to late Pleistocene)** – Brown to dark brown sand, silt, and gravel of the modern, active flood plain of the White River. This unit includes the last Pleistocene glacio-fluvial gravel that occupies the current underfit White River valley floor, generally from bedrock valley wall to bedrock valley wall. The active river channel apparently has been actively migrating across this unit throughout much of the Holocene, so that the floodplain consists of abandoned oxbow meander channels and over-bank plains that have reworked the top of the Pleistocene sediment. In areas near smaller ephemeral tributary channels and ravines, this unit has been covered by alluvial fans that have been deposited out onto the valley floor. Many of the alluvial fans from ephemeral tributary streams have been truncated by this meandering. The channel bed load is predominantly cobbly gravel while the adjacent over-bank floodplain deposits and meander in-fills sediments are finer-grained silty to clayey sand. Maximum thickness is unknown, but wells for the Meeker municipal water supply remained in gravel at their total depth of 55 feet near where County Road 4 crosses the river.

Qaw2 **Alluvium two of the White River (late Pleistocene) –** These gray cobbly to pebbly gravel deposits exist as isolated strath terrace remnants 40-65 feet above the modern floodplain. Stage II+ calcite soil development (Machette, 1985) was observed in gravel pit exposures. This unit has a thickness of about 28 feet. Optically stimulated luminescence (OSL) dating for this unit on the Meeker Quadrangle yielded an age of 76.4±5.0 ka (White and Hodge, 2013). This unit is predominately unconsolidated but there are horizons of sufficient cementation to create conglomerate.

Qaw3 **Alluvium three of the White River (late to middle Pleistocene) –** Gray cobbly to pebbly gravel deposited in strath terraces 90 to 120 feet above the modern floodplain, except at the confluence with Little Bear Creek above the Meeker Dome. The present flood-plain constriction at the Meeker Dome is acting as a choke point and Qaw_2 deposits have apparently aggraded, widening the present floodplain. At that location, the Qaw_3 surface is only about 60 feet above base level. This unit is usually 15 to 20 feet thick along the bluff edges, but water well logs indicate thicknesses to 40 feet. The top of the unit contains terrace risers and undulations consistent with a braided stream morphology. The Qaw_3 terraces are the most extensively preserved on the Rattlesnake Mesa quadrangle. The large mesa across the river from the Meeker Dome in Agency Park is a Qaw_3 gravel terrace (**Figure 5**). Pit exposures reveal a Stage

Figure 5. Small gravel pit in Qaw_3 terrace in Agency Park. Close up on right shows typical White River gravel clasts and well developed Stage IV calcic soil development. [UTMX 255873, UTMY 4434658]

III+ calcic soil development (Machette, 1985). Based on the height above the modern floodplain and calcic soil development, this unit has been assigned a late to middle Pleistocene age. This unit is mantled by later old alluvial fans (Qfo) in the southwest corner of the map area.

Qaw_4 **Alluvium four of the White River (early middle Pleistocene) –** Gray cobbly to pebbly gravel deposited in strath terraces 325 to 350 feet above the modern floodplain. Gravel pit exposures reveal a stage IV developed calcic soil. The unit thickness was measured at 35 feet at its deepest. This unit caps high mesa remnants that rise above the valley floor and the Qaw_3 surface in Agency Park. Three of these mesas have, or are currently being mined for aggregate. On the adjacent Meeker quadrangle, another equivalent mesa at the same elevation was reported to contain the Lava Creek B (LCB) volcanic ash (Izett and Wilcox, 1982), giving this gravel an age of 640 ka. This unit is predominately unconsolidated but there are horizons of cementation of sufficient strength to create conglomerate.

ALLUVIAL DEPOSITS OF TRIBUTARY-STREAM AREAS

Alluvium of the tributary-stream areas consists of cobble, gravel, sand, silt, and clay transported and deposited by perennial tributary streams of the White River throughout the Rattlesnake Mesa quadrangle. The main perennial streams are Curtis Creek, Coal Creek, and Little Beaver Creek. Clast lithologies are generally sandstone rich, reflecting a predominately Cretaceous-formation provenance, through some later Mesozoic and upper Paleozoic source clasts also occur. Higher-order enumerated alluviums roughly correspond with the enumerated alluviums of the White River. Except for the base-level Qa_1 sediments, these alluviums are gravel rich but have a high silt and clay content in the sand matrix. Reflecting the natural breakage of sandstone beds, clast shape is typically prismoidal to subspherical and well rounded to rounded. With this common bladed shape, clast imbrications are easily seen that reflect a water-flow direction toward the confluence with the White River. These gravel-rich deposits form terraces and the terrace remnants can generally be traced down to erosional remnants of paleoconfluences where mixing and interlaying of alluvial units of the White River can occur (**Figure 6**).

Qa_1 **Alluvium one of tributary streams (Holocene)** — A dark brown to brown, weakly stratified, unconsolidated sediment composed of poorly to moderated sorted, silty to clayey sand with scattered pebbly to cobbly gravel lenses. Deposits of this unit were mapped at and near the base-level floodplains in tributary streams. The deposition of this unit caused the incision into valley fill and alluvial fan deposits, creating low but steep bluffs. Thickness is unknown, but likely varies, dependant on location along the tributary stream. There is likely a thickening of the deposit when the floodplain widens toward the confluence with the White River.

Qa_2 **Alluvium two of tributary streams (late Pleistocene) –** Tan to buff colored alluvium that ranges gradationally from cobbly gravel in very coarse silty sand to a finer-grained silty sand with only scattered gravel. This unit is poorly exposed at very discontinuous strath terrace remnants along all the major tributary valleys from 40 to 65 feet above the base-level. In most locations,

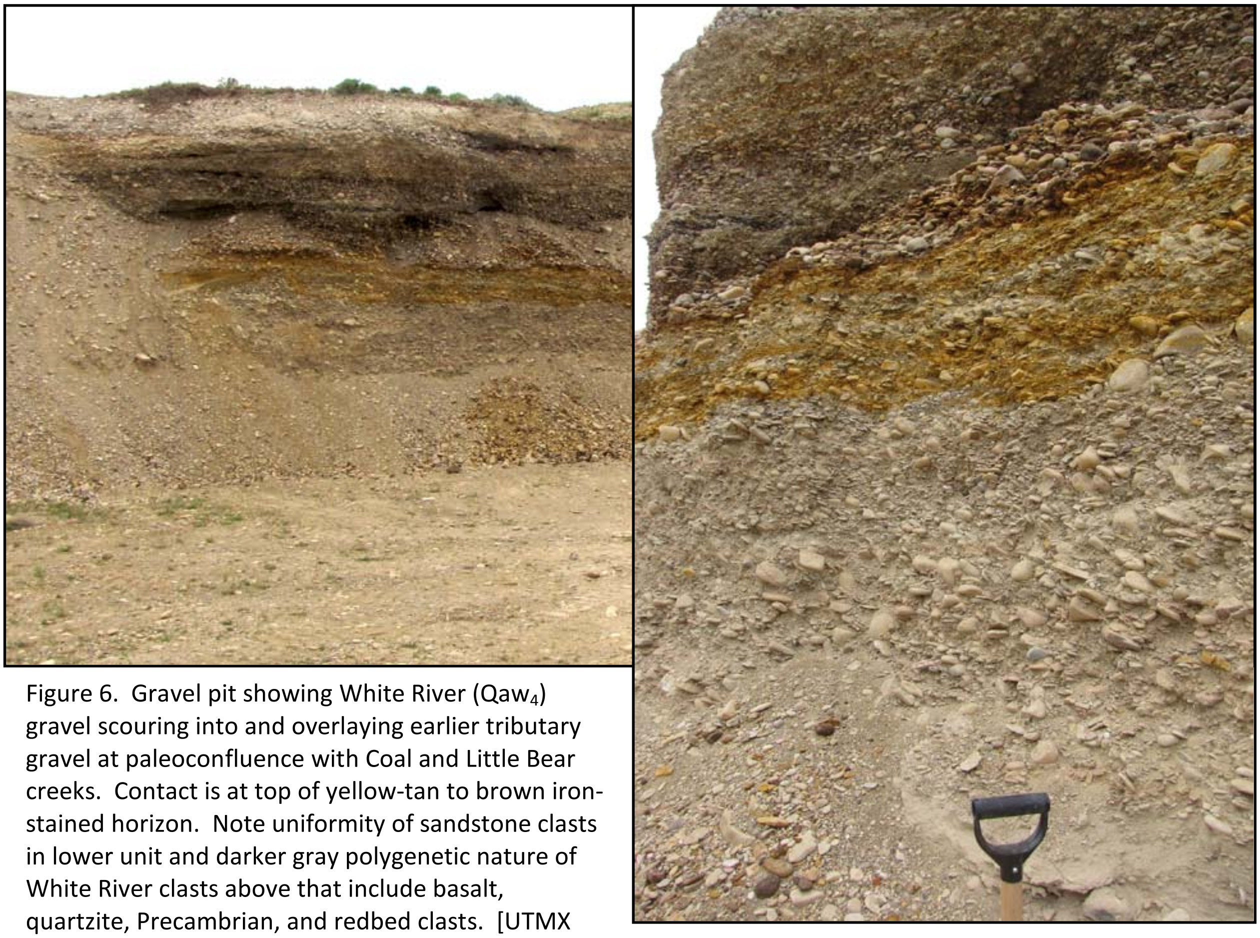


Figure 6. Gravel pit showing White River (Qaw_4) gravel scouring into and overlaying earlier tributary gravel at paleoconfluence with Coal and Little Bear creeks. Contact is at top of yellow-tan to brown iron-stained horizon. Note uniformity of sandstone clasts in lower unit and darker gray polygenetic nature of White River clasts above that include basalt, quartzite, Precambrian, and redbed clasts. [UTMX 259612, UTMY 4433852]

the exposure is just a subtle bump in the valley slopes where the slope surface is gravel and cobble rich. A larger mesa of this unit occurs near the confluence of Little Bear Creek and the White River where a quarry exists at the intersection of CR 6 and CR 8 (**Figure 7**). At that location unit thickness exceeded 27 feet. This unit contains a chalky-white Bk horizon (Stage II+ calcite soil development (Machette, 1985)).

Qa_3 **Alluvium three of tributary streams (late middle Pleistocene) –** Tan to brown, cobbly to pebbly gravel in very coarse silty sand. Where exposed a Stage III+ calcic soil is developed (Machette, 1985). The unit is up to 45 feet in thickness. This river terrace gravel is 90-110 feet above the creek base level. A sample of this unit (RM-891) was collected for age dating using optically stimulated luminescence, which yielded only a minimum age constraint - >113.4 ka (Steven Forman, University of Illinois at Chicago , written communication).

Qa_4 **Alluvium four of tributary streams (middle Pleistocene) –** Tan to buff-colored cobbly to bouldery gravel in very coarse silty sand. This unit is only exposed as a terrace remnant above Little Beaver Creek on the east boundary of the quadrangle. The terrace is 220 feet above the adjacent base-level floodplain of Little Beaver Creek.

Figure 7. Qa_2 gravel near confluence with the White River. This gravel did not intermix with the White River gravel as shown in figure 4. Sandstone clasts have only Coal Creek and Little Beaver Creek provenances. Note fine-grained silty to clayey sand layer near top. [UTMX 258654, UTMY 4435029]

Qa **Alluvial deposits, undifferentiated (Holocene) –** A dark brown to brown, weakly stratified, unconsolidated sediment composed of poorly to moderated sorted, silty to clayey sand with scattered pebbly gravel lenses. Unit is mapped in swale bottoms and the floors of third-order ephemeral streams.

MUDFLOW-DOMINATED ALLUVIUM AND ALLUVIAL-FAN DEPOSITS

The second most common surficial deposits that cover broad areas within the Rattlesnake Mesa quadrangle are associated with complex alluvial valley-fill and alluvial-fan systems along tributary streams and in broad basins. In these systems, channelized to laterally unconstrained mud-and-gravel debris flows have been the dominant depositional processes. Depending on the energy of deposition, these widespread Holocene to late Pleistocene deposits can range from fine-grained mudflow-dominated sandy to silty clay, to clast-supported pebbly to cobbly gravel more typical of riverine environments. These deposits are roughly stratified and channelized. The source material is derived from Cretaceous Mesaverde rocks and the Mancos Shale. Smaller fans have been deposited from the many gullies that have incised the high terrace mesas underlain by Mancos Shale. These latter deposits reflect erosion from the terrace gravels and the underlying shale, and so form a darker, more clayey deposit with dispersed reworked White River gravel from older alluvial deposits

Qaf **Alluvial and alluvial-fan deposits, undifferentiated valley fill (Holocene)** — Brown, tan to light-gray, poor to moderately sorted, unconsolidated, stratified clayey silt and sand with sporadic gravelly to cobbly lenses. This unit was deposited as an aggrading valley fill in larger tributary basins where the surrounding bedrock is relatively weak and prone to rapid erosion. This unit was separated from the Qa and Qf map units because it fills the entire valley or broad swale and doesn't have the morphological boundary from an alluvial fan slope to a flat alluvial floodplain. The stratification records episodic and dynamically differing energies of deposition as sediments aggraded the valley floor. This unit is best exposed in arroyo escarpments of Curtis Creek. Soil development reflects the aggrading nature of the deposit with multiple poorly developed Bt soil horizons. The highest arroyo escarpment in this unit was measured at 15 feet. Actual unit thickness may exceed 40 feet. These sediments may have collapsible-soil properties and may be prone to settlement when they become wet (hydrocompaction).

Qafo **Old alluvial and alluvial-fan deposits, undifferentiated valley fill (late to middle Pleistocene)** — Reddish tan, buff, brown, and tan-gray, poorly to moderately sorted, poorly consolidated, stratified silt, sand, gravel, cobbles and boulders deposited as coalescing valley fill in both alluvial fans and alluvial channel settings. Clasts are generally angular to subangular of local upslope bedrock sources. These older rocky deposits occur on higher mesas and dissected ridgelines. Near the Mesaverde (Iles) escarpment, Qafo deposits are typically much coarser and bouldery than the Qaf deposit, reflecting the climatic conditions of the Pleistocene glacial periods. The typical sediments deposited near steeper bedrock slopes range from unsorted clast-supported cobbles and boulders in a silty to pebbly sand matrix to sandy gravel interlayered with finer-grained clayey to silty sand. As slope gradients lessen, the primary deposit is a stream-deposited, moderately sorted, interlayered fine- to coarse-grained sand with sporadic sandy granule lenses. Channels of better sorted, imbricated, riverine gravels may occur in the deposit. These locations have been quarried for aggregate for local roads (**Figure 8**). Pit exposures reveal stage III+ calcic soil development (Machette, 1985). In some ridge-line locations, erosion has winnowed away the finer portions of the deposit leaving only the bouldery fraction exposed on the underlying bedrock surface. The individual layers and channels in the unit record episodic and dynamically differing alluvial and alluvial fan depositional events as sediments aggraded the tributary paleovalleys and terraces of the White River.

This unit is more resistant than the underlying Mancos Shale bedrock so topographic inversion occurs as base-level downcutting of streams continue. The highest and oldest Qafo surface forms Rattlesnake Mesa along CR 39. Near the mouth of the Coal Creek canyon it is 200 feet above the Coal Creek base level. Water well logs indicate thicknesses of approximately 35 feet. In the White River valley, the highest Qafo unit was deposited on the Qaw_4 terrace gravel about 270 feet above the White River. The description of this 12-foot thick, shale chip-rich deposit is detailed in the adjacent Meeker quadrangle author notes (White and Hodge, 2013).

Qf **Alluvial-fan deposits (Holocene)** — Tan to light-brown, poorly to unsorted, unconsolidated, roughly stratified, sandy silt with dispersed matrix-supported gravel that is gradational with much coarser sandy to cobble gravel with scattered small boulders. This unit was deposited in alluvial fans from the mouths of ephemeral steams that outlet from small tributary valleys. The deposits can have a fan-shaped morphology but generally have coalesced and aggraded the edges of the valley floors at low surface gradients. The sharply angular to subrounded clasts are from local sandstone sources eroded from high bedrock ridges and hillsides. Boulders can exceed five feet in diameter near the mouth of the larger ephemeral streams. Deposit may exceed 50 feet in thickness near the apexes of the larger fans. Sediments are deposited primarily as muddy debris flows, hyperconcentrated flows, and earth flows. These sediments can be hydrocompactive.

Figure 8. Pit exposure of riverine gravel in Qafo deposit. Late middle Pleistocene age is relatively determined by development of Stage III^+ calcic Bk soil horizon and elevation above base-level streams in area. Clasts are sandstones of local sources. [UTMX 259915, UTMY 4436767]

Qfo **Old alluvial-fan deposits (late to middle Pleistocene)** — Tan to orange tan to dark reddish brown, poorly to unsorted, unconsolidated, sandy to clayey silt with dispersed gravel that can range to a much coarser clayey to sandy, bouldery gravel. A broad apron of this unit occurs in the southwest corner of the quadrangle that fans northward to cover portions of the Qaw3 terrace mesa in Agency Park. This unit is poorly exposed, but the top was observed in graded fields of the NRCS-affiliated Upper Colorado Environmental Plant Center on CR 4 [UTMX 256750, UTMY 4431820]. At that location, chalky soil zones were noted and angular to subangular rock clasts were exposed at the surface coated by a discontinuous rind of $CaCO_3$, which indicates that a calcic Bk soil horizon is present. Rapid mud deposition is indicated by the unsorted nature of the deposits, with angular clasts generally dispersed and supported within a finer-grained matrix. Based on available water well logs, the unit can reach 40 feet. This deposit may be mantled by a thin discontinuous veneer of loess. Deposit may be prone to hydrocompaction.

ALLUVIAL/COLLUVIAL AND MASS-WASTING DEPOSITS

These deposits were transported downslope primarily by gravity and not within or under another medium, such as water or ice, except where noted in mixed alluvial and colluvial deposits. These deposits are formed in combinations of the following depositional systems: 1) downward transport of slope regolith by creep and sheetflooding into colluvial wedges at the base of slopes, 2) rockfall forming talus, 3) shear-plane landsliding along defined zones of weaknesses in the underlying bedrock or in unconsolidated sediments, and 4) clay-rich earthflows where the entire sliding mass was very wet and has partially fluidized and flowed down the slope. More detailed information on the geologic hazards inherent in these types of deposits can be found in the Authors' Notes of the adjacent Meeker quadrangle (White and Hodge, 2013).

Qc **Colluvial deposits (Holocene)** — Heterogeneous tan to tan-gray deposits consisting of unsorted and unstratified to poorly stratified clay, silt, and sand with dispersed matrix-supported angular gravel to boulder-sized rock fragments. Colluvium is generally very rocky where it mantles the base of steep or cliffy valley sides and ridgelines. Unit may include areas of accelerated creep. Unit thickness is variable, from five feet to over 20 feet at the base of slopes, and may include areas much thinner or where weathered bedrock is at or near surface.

Qco **Old colluvial deposits (late Pleistocene)** — Heterogeneous tan, reddish tan, tan-gray deposits consisting of clast-supported, angular, bouldery-pebbly gravel-sized rock fragments in an unsorted sandy clay matrix. These older colluvial deposits typically occur as remnants of an old erosional surface that covered the Mancos Shale slope below the Iles Formation escarpment. These very rocky deposits contain sandstone clasts and are more resistant to weathering than the underlying Mancos Shale. Where they exist, this unit has formed relict faceted slopes that are commonly covered with vegetation compared to the nearby bare Mancos Shale slopes. **Figure 11** shows old colluvium on a landslide scarp edge. Some Qco units may include small landslide deposits where the diagnostic landslide morphology has been obscured by subsequent erosion.

Qac **Alluvial and colluvial deposits, undifferentiated (Holocene)** —Tan to tan-gray unconsolidated silt, clay, and sand with lesser amounts of dispersed, matrix-supported gravel and larger rocks, up to small boulder in size. Unit is poorly sorted, very weakly stratified, and clasts are angular and of local up-slope origin, reflecting the in-situ weathering of soft bedrock slopes and formation of residuum and regolith. These deposits are derived by sheetwash processes and smaller mudflows where fine-grained sediments accumulate at the base of steeper slopes. Stratification, when present, is poorly defined and likely reflects short-term climatic changes when down-slope movement and deposition of sediment accelerated. These deposits are found on flatter slopes at the base of steeper slopes, including valley fills and along upland mesa edges. Soil development is weak. Deposit may be prone to hydrocompaction.

Qaco **Old alluvial and colluvial deposits, undifferentiated (late Pleistocene)** —Reddish tan to tan, unconsolidated silt, clay, and sand with lesser amounts of dispersed, matrix-supported gravel with scattered larger rocks up to small boulder in size. Deposit is poorly sorted, very weakly stratified, and the angular clasts are of local upslope origin. These flatter slopes are older surface remnants of the late Pleistocene valley sides that are now dissected and isolated by erosion and base-level lowering. This unit may also include reworked windblown dust (loess). Exposures are poor, but chalky-white exposure along slope breaks and ridgeline saddles reveal a well-developed calcic Bk horizon. That soil development and the reddish hue of the surface soils assign this deposit a late Pleistocene age. Thickness is highly variable and likely does not exceed 10 feet. The sediments in this unit may also have collapsible-soil properties (hydrocompaction).

Qls **Landslide deposits (Holocene to late Pleistocene)** — Landslide deposits in the Rattlesnake Mesa quadrangle are found in two types of terrains: 1) Along dip slopes of tilted interbedded formations within the Mesaverde Group, primarily in weak mudstone intervals of the lower Williams Fork Formation Hogback, though there is also a circumstance where a landslide formed on the Dakota/Morrison dip slope at the Meeker Dome, and 2) the steeper escarpments of Mancos Shale. This map makes no age distinction of the mapped landslides.

Large failures of the Mancos Shale below the Iles Formation escarpment includes the slippage of steep colluvium from the slope. At the crescent-shaped scarp, amphitheatre-type landforms are created that contain the best exposures of upper Mancos sandstone members. In some locations, the landslide mobilized as earthflows that filled the valley below. The earthflow toe from the scarp shown in **Figure 11** was traced 4,700 feet down the valley. These deposits are generally composed of unsorted, nonstratified, and chaotically mixed angular rock fragments in a gray silty clay matrix.

The landslide deposits within the tilted Mesaverde Group bedrock formations are quite different. The lower Williams Fork Formation is composed of sandstone beds interbedded with thicker beds of low shear-strength shale, mudstone, and coal seams. If these interbedded strata are moderately tilted, dip-slope failures may occur when weak or soft beds, or bedding planes shear and slip. These tilted bedding planes may be even further weakened by pre-existing bedding-plane faults that were created by differential flexural slip along bedding to accommodate the original Laramide strain deformation as the strata was uplifted and tilted, much like bending a deck of cards and watching the individual cards slide against each other. Such flexural slips, or any bedding plane shear zones in weak-lithology strata for that matter, are extremely difficult to see in outcrop. However, such an occurrence identified in a coal seam in the Highway 13 rock cut (**Figures 4 and 9**) is attributed to flexural shear (Vince Matthews, Colorado Geological Survey, written communication).

Removal of formational material that buttresses the slope (by erosion and downcutting) will eventually "daylight" the strata bedding (i.e., potential shear planes), and formational material above can then slide down the now exposed bedding dip slope. The disturbed and sliding bedrock is usually transformed into a mass of chaotic, unsorted, unconsolidated rubble. This landslide rubble of broken rock can include very large sandstone blocks, tens of feet across. In

Figure 9. Crenulations in coal cleats believed to be formed by strain deformation from left-lateral flexural slip (slip direction shown by red arrow) along shear parting (black dotted line) in Ki coal bed that occurred when the formation was originally uplifted. Such a compressional fabric would not have resulted from right-lateral, downward movements along dip. However, this shear parting is now a zone of weakness for any subsequent dip-slip landslides that would move to the right, which have occurred nearby. Coal seam location is shown by small star in Figure 4. [UTMX 256827, UTMY 4442731]

some location, there was suitable water content in the landslide debris for it to mobilize as an earthflow. Examples occur along State Highway 13 and swales in the lower Williams Fork dip slopes. Landslides are less prone to occur where the Fairfield Coal Group Clinker Zone occurs. This fused and baked clinker zone is stronger than the original formational strata and less susceptible to shear and slope failure.

EOLIAN DEPOSITS

Eolian deposits are fine-grained sediments (dust and very fine-grained sand) that are transported and deposited by wind. They are a homogenous deposit that mantle relatively flat-lying ground surfaces. Eolian deposits were only mapped where there was a suitable thickness that exceeded five feet. Many old alluvial and colluvial deposits on flatter terrain may also be covered by thin discontinuous veneers of eolian deposits, much of which has been reworked as Qac and Qaco sheetwash that usually contain small regolithic chips of sandstone.

Qlo **Loess deposits (late Pleistocene)** — Reddish tan silt and minor very fine grained sand deposited by wind. This homogenous deposit is located on broad flattened hills and mesas in the vicinity of the Meeker Airport. This unit has a reddish hue and contains a chalky white, moderately developed Bk soil horizon. Loess deposits may by hydrocompactive.

BEDROCK UNITS

From the youngest to the oldest, the bedrock exposed in the Rattlesnake Mesa quadrangle consists of the Upper Cretaceous lower unit of the Williams Fork Formation; the Upper Cretaceous Iles Formation including the regionally persistent Trout Creek Sandstone Member; the Upper Cretaceous Mancos Shale members including the upper Mancos Shale that envelopes the Loyd, Duffy Mountain, and Morapos sandstones, the Prairie Canyon and the Meeker sandstone lentil, Smoky Hill, Frontier, and Mowry; the Lower Cretaceous Dakota Sandstone; and the Jurassic Morrison Formation. All these units have been mapped showing member units that could be identified in the field. We also separated units based on facies changes. The Frontier Member of the Mancos Shale has been subdivided into a sandstone facies and a shale facies. **Figure 10** contains a stratigraphic column of formations mapped on the Rattlesnake Mesa quadrangle.

WILLIAMS FORK FORMATION (UPPER CRETACEOUS)

The Iles and the Williams Fork Formations are, together, considered part of the Mesaverde Group of Upper Cretaceous rocks. The Williams Fork Formation was deposited in terrestrial coastal plain and near-shore estuary environments. Only the lower unit of the Williams Fork Formation occurs within the boundary of the Rattlesnake Mesa Quadrangle.

Kwl **Williams Fork Formation, lower unit** — Interbedded buff to tan sandstone, gray siltstone, dark gray mudstone, red clinker, brown carbonaceous shale, and coal. This unit rests conformably on

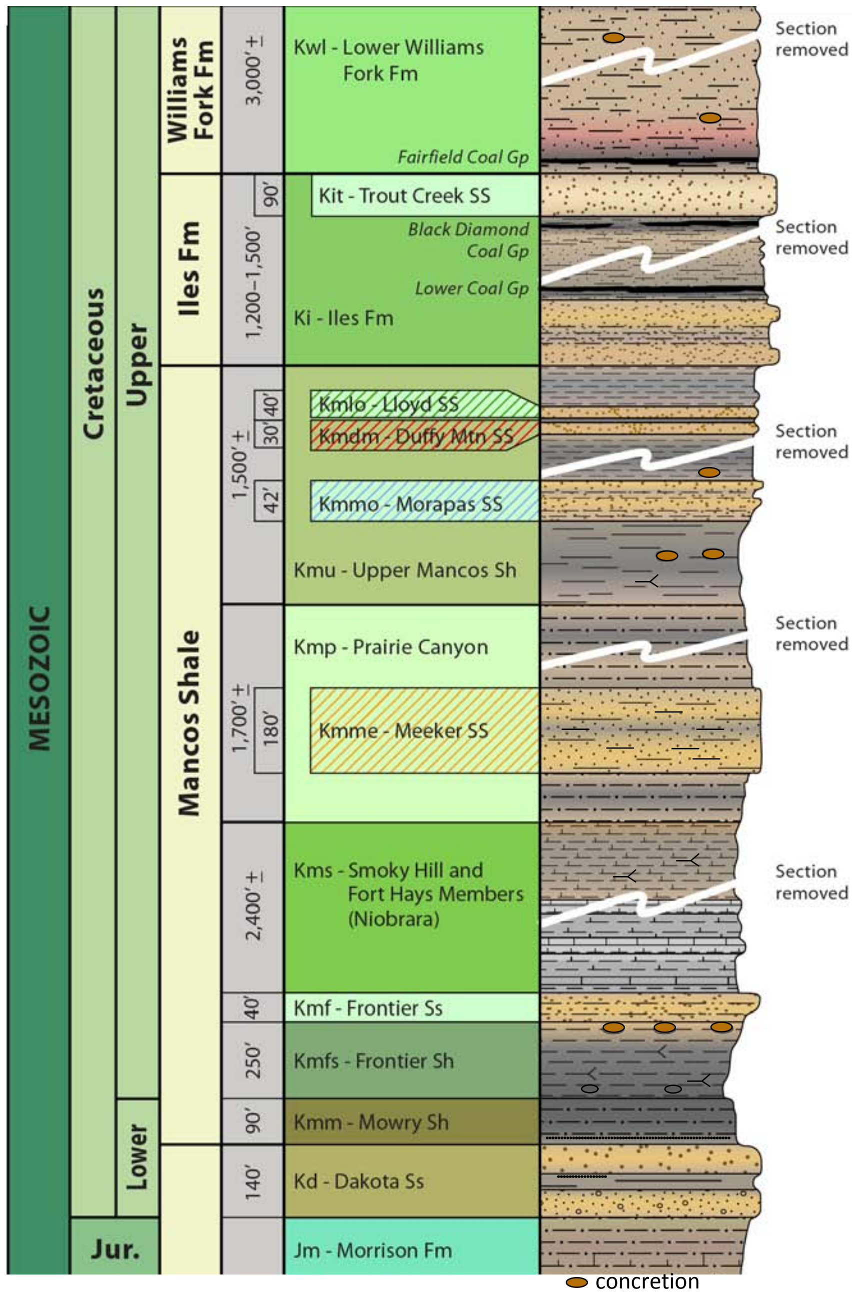


Figure 10. Stratigraphic/geologic column of formations present in the Rattlesnake Mesa quadrangle with approximate thicknesses. Not to scale.

the Trout Creek Sandstone. There are two coal groups within the lower Williams Fork Formation; the upper Goff Group and the more significant basal Fairfield Group. More data about the coal resources of this area are found in Hancock and Eby (1930), Collins (1976), and Brownfield and others (2000). Within and above the Fairfield Coal Group there is an extensive zone of red clinker that is shown on the map plate as the "Fairfield Coal Group Clinker Zone." This baked and fused rock zone, related to the burning of coal beds, is more resistant to erosion and supports the highest ridges of the Mesaverde escarpment (**Figure 4**). Above the clinker zone, the lower unit becomes increasingly finer-grained mudstone with fewer and thinner sandstone beds. This interval is prone to instability so dip-slope landslides are very common where Kwl strata is exposed.

There are coal mines that worked the Fairfield coal seams on Rattlesnake Mesa quadrangle. The largest was the Rienau Mine that has been reclaimed along State Highway 13. Smaller workings and prospects are also located up Coal Creek valley and Ninemile Draw where the Fairfield Coal Group is accessible to CR 15 near the axis of the Sulphur Creek Syncline. More information about the historic mines and their production in the Meeker area can be found in the CGS historic coal mine publication by Carroll and Bauer (2002).

ILES FORMATION (UPPER CRETACEOUS)

The Iles Formation represents a major depositional cycle where sediments changed from shallow-marine lithofacies to progradational shoreface and coastal-plain lithofacies, and then back to a marine depositional setting (Warner, 1964; Boyles and others, 1981). This cycle reflects a major regression and transgression episode of the Cretaceous Western Interior Seaway in the project area. Terrestrial coastal-plain sediments, sourced from the Sevier orogenic belt to the west and northwest, were conformably deposited onto the Mancos Shale as the Cretaceous seashore regressed eastward. Estuarine and swamp conditions occurred where coal could form. Marine interbedded shale and sand below the Trout Creek Sandstone Member marks the end of this cycle as the Cretaceous seaway, through a combination of eustatic sea level rising and subsidence of the Cretaceous coastal plain, again transgressed westward over this package of terrestrial sediments. The base of the Iles Formation was selected at the first sandstones seen of a basal progradational shoreface sandstone sequence that occurs on the Mancos Shale. The top of the Iles Formation is the distinctive and easily traced Trout Creek Sandstone member. The thick sandstone units of the Iles Formation mark the eastern edge of the Grand Hogback ridgeline above Meeker and form the major escarpment above Rattlesnake Mesa. Rockfall hazardous areas exist at the base of the Iles escarpment. Thickness of the Iles Formation is approximately 1,200 feet.

Ki **Iles Formation** — Interbedded sandstone, mudstone, clay shale, carbonaceous shale, and coal. The base of the Iles is composed of prominent ridge-forming sandstones; three to four progradational shoreface sequences composed of thin bedded sandstone interbedded with mudstone and ripple-marked sandstone that transition to thicker beds of hummocky to trough crossbedded sandstone; thinly bedded mudstone and carbonaceous shale; and minor coal. The first major sandstone has been referred to as the Rimrock. The coal zone is referred to as the "Lower Coal Group" by Hancock and Eby (1930). Tidal channel deposits were noted in the major sandstones that contained abundant marine mollusk fossils, mudstone rip-up clasts, and petrified wood and plant fragments. The upper section of the Iles is finer grained, which reflects a cyclic coastal swamp, tidal-influenced estuarine, and lower-energy fluvial environments. Sandstone beds are thinner, becoming interlaminated with mudstone. Some thicker sandstone beds have soft-sediment deformation. Several thin coal beds exist in this unit, referred to as the "Black Diamond Coal Group" by Hancock and Eby (1930). Sporadic red clinker zones also occur in the upper section of the Iles related to these coal beds. A shaly section of the Iles Formation, related to a major late Cretaceous marine transgression, occurs near the top where it is overlain by the Trout Creek Sandstone Member.

Kit **Trout Creek Sandstone Member** — Very light gray to gray-white, fine to medium grained, moderately well sorted, cross-stratified sandstone.   The sandstone is predominantly noncalcarous and somewhat friable with common orange-tan staining. In outcrop, the unit has a general rounded, massive-bedded appearance, compared to the more angular, blocky outcrops of the lower Iles Formation sandstone beds. The Trout Creek Sandstone is a prominent gray-white ledge former that is very conspicuous and easily traceable above the Iles Formation escarpment above Rattlesnake Mesa (**Figure 4**) and steeply dipping along the northeast limb of the Sulphur Creek Syncline (**Figure 3**). Maximum thickness measured was 90 feet.

MANCOS SHALE (UPPER CRETACEOUS)

The Mancos Shale was deposited during the marine transgression of the Cretaceous North American Western Interior seaway with subunits deposited in various deep shelf, shelf-bar, and near shore environments (Warner, 1964; Boyles and others, 1981). Surface exposures of the Mancos Shale were generally poor on the Rattlesnake Mesa quadrangle because the shale is easily eroded and there is widespread cover of regolith or Quaternary deposits. Exposures improve on the slope directly below the Iles Formation escarpment and around the Meeker Dome where sandstone members, resistance to weathering, have formed hogbacks and subdued ridgelines where they are exposed. For most shale members, there are diagnostic lithologic changes where unit boundaries are located. However, there was some estimation of contacts between the varied members where exposures were poor, the contact is gradational, or the contact was covered by surficial deposits. Mancos Shale contains expansive clay minerals; clayey soils derived from it should be considered susceptible to swelling-soil hazards. The Mancos Shale may also have salinity and selenium concentration levels that may be a concern for irrigation water that discharge from, or seep out of, the member units. See the geologic hazard discussion in the Authors' Notes for the adjacent Meeker quadrangle (White and Hodge, 2013) for additional information.

Kmu **Mancos Shale, upper unit** — Gray to dark-gray, platey to sub-blocky, non-calcareous shale with minor sandstone and orange-tan limey concretions. This unit is undifferentiated shale that exists between the base of the Iles Formation and the top of the sandy Prairie Canyon Member. It contains named marine sandstone members in the upper part of the Mancos Shale: the Loyd, Duffy Mountain, and Morapos. There are other unnamed tan noncalcarous marine sandstone within this unit that are poorly exposed or occur as sporadic lenses and it is unsure how they correlate regionally. Fossil marine shell fragments were found in certain beds, as were oscillating ripple marks and animal-burrow ichnofossils. A very dark-gray claystone interval, characterized by large limonite-stained calcareous concretions and high percentages of swelling clay minerals, occurs between the Prairie Canyon Member and Morapos Sandstone. This unit, a valley former and very poorly exposed, appears to share lithologic similarity with the Sharon Springs Member in the same stratigraphic interval in west-central Colorado (Noe and others, in prep). The thickness of this unit from the base of the first Iles sandstone to the approximate top of the Prairie Canyon Member is 1,500 feet, including the upper Mancos sandstone members.

Kmuu **Upper unit unnamed sandstone member** — Cross-laminated, tabular bedded, very-fine grained sandstone 20-30 feet below the contact with the Iles Formation. Unit may be the Tow Creek Sandstone equivalent (**Figure 11**).

Kmlo **Loyd Sandstone Member** — Green-gray to olive-tan with orange-tan staining, non to moderately calcareous, fine to medium, moderately sorted, sandstone and minor mudstone. Unit weathers tan-gray to orange-brown in outcrop. The sandstone generally exhibits no

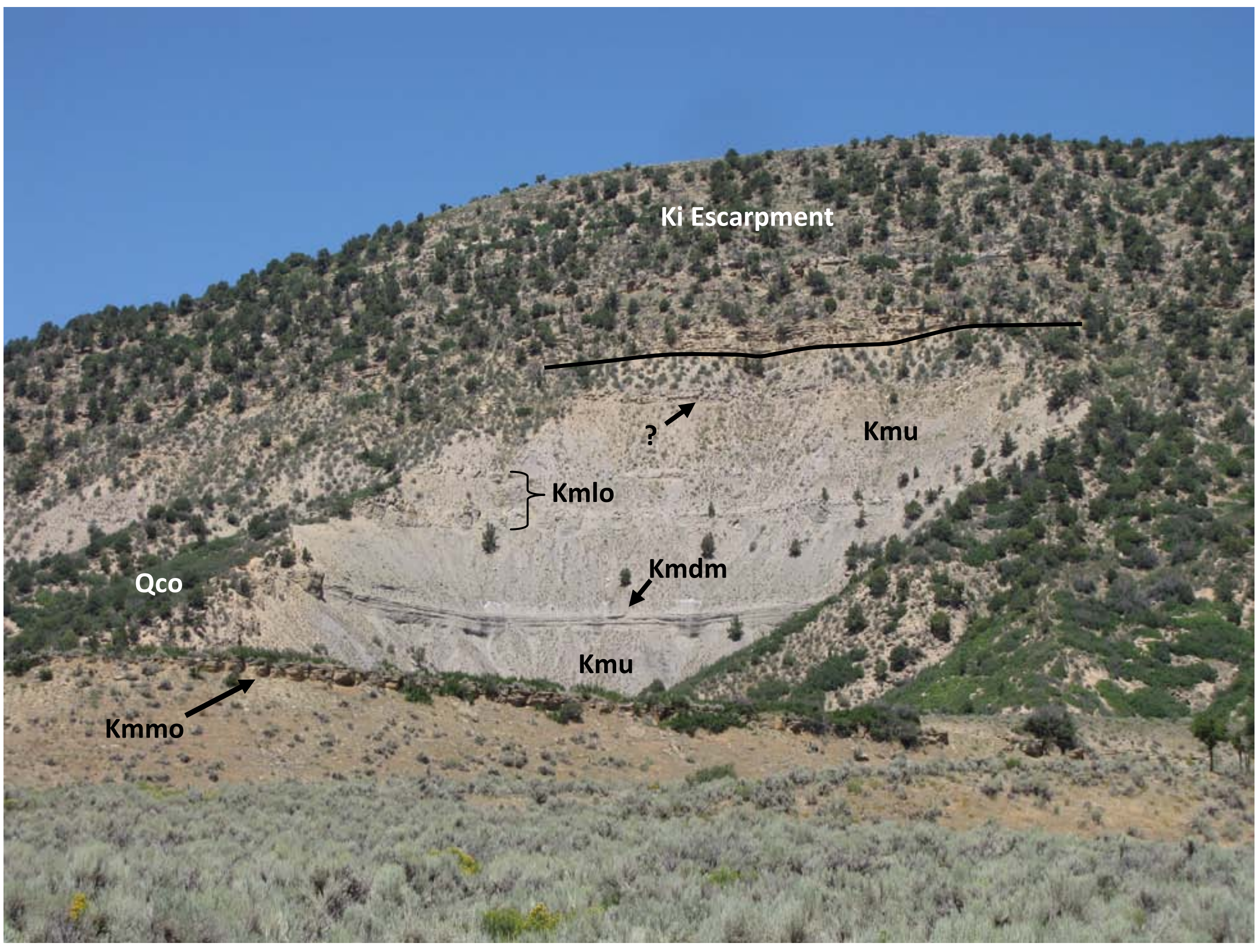


Figure 11. Landslide scarp exposing individual sandstones in Upper Mancos Shale. The contact with the Iles Formation is shown by heavy black line. Top queried sandstone is shown on the map as Kmuu and may be the Tow Creek member. Loyd sandstone (Kmlo) develops two lumpy ledges in outcrop. The more tabular bedded Duffy Mountain (Kmdm) is the lowest sandstone on the scarp. Ridgeline of Morapos Sandstone (Kmmo) is below. Facet of old colluvium (Qco) mantles the left slope on the side of the landslide scarp. [UTMX 264765, UTMY 4439021]

distinct bedding and closely approximates the description in Dyni and Cullins (1965) and Kiteley's work (in Boyles and others, 1981). It is typically less indurated, and very fossiliferous with marine fossils dispersed in the sand matrix and clumped in brown calcareous nodules. Several articulated inoceramid bivalves collected on the adjacent Meeker quadrangle were identified belonging to the *Cataceramus subcompressus* Western Seaway Inoceramid Interval Zone of the Middle Campanian Series (White and Hodge, 2013). *Baculities sp.* fragments were also found. Unique to this Mancos member sandstone is its weathering profile. Where exposed in outcrop, the sandstone intervals weather to either a rounded lump-like mass or a nodular/spheroidal appearance. In many areas the sandstone is buried by thin unmapped colluviums, regolith, and slope-wash sediments. However, below the Iles escarpment there are a number of areas where the Loyd forms a prominent sandstone bench . From east to west, outcrops of the Loyd Sandstone show a change in stratigraphy where it transitions from one sandstone bench to two lumpy sandstone benches separated by a sandy mudstone interval. **Figure 12** shows examples of outcrops of the Loyd Sandstone. This unit is mapped only by a line trace where reliable exposures could be determined. Unit thickness is about 40 feet on the west edge of the map area. With the muddy interval separating two sandstone ledges to the east, the thickness increases to about 80 feet.

Kmdm **Duffy Mountain Sandstone Member** — gray to tan-gray, very fine to medium grained, very slightly to moderately calcareous, moderately well-sorted, marine sandstone. Weathers tan in outcrop. Coarsening upwards, the unit is muddy at the base with interlaminated to thinly bedded mudstone and very fine grained sandstone. Upwards the sandstone beds thicken and grain sized becomes medium (**Figure 13**). There are thin very calcareous beds. The entire upwards-coarsening sequence is about 65 feet thick, including the lower muddy sequence. The more developed top sandstone is about 25 feet thick. This unit is poorly exposed and only crops out in landslide scarps and ditch excavations on the east side of the map area.

Kmmo **Morapos Sandstone Member** — tan to buff to tan-gray, slightly calcareous marine sandstone that occurs as a upwards-coarsening sequence. Near Meeker and the western side of the map area, there are two upwards-coarsening sequences (White and Hodge, 2013) This coarsening sequence begins in the Upper Mancos Shale. The shale transitions to bioturbated silty to sandy mudstone interlaminated with poorly- to moderately-sorted, very-fine-grained, sandstone and sandy mudstone. Upwards, the sandstone beds become more numerous and thicken, becoming well-sorted, medium-grained, sandstone that exhibits both hummocky cross-stratification and tabular to trough cross-bedding. Mud rip-up clasts are common in the coarser sandstone intervals. The Morapos outcrop shown in **Figure 11** shows only the top upwards-coarsening sequence. The Morapos Sandstone is wholly enclosed within the upper Mancos Shale unit and geographically restricted. It has been interpreted to have been deposited in a marine shelf-bar environment. Unit thickness is about 40 feet.

Figure 12. Loyd Sandstone. Top photo shows the Loyd outcrop (black arrows) as a prominent bench in the Upper Mancos Shale. Dashed line above is the Kmu/Ki contact [UTMX 259717, UTMY 4438550]. Lower left photo was taken at western boundary of map area [UTMX 255680, UTMY 4442343]. Lower right photo [UTMX 262667, UTMY 4440563] was taken about 5 miles east and reveals the Loyd to have a middle shaly interval. Note lumpy nature of outcrop.

Figure 13. Duffy Mountain Sandstone outcropping at right side of landslide scarp shown in figure 11. [UTMX 265071, UTMY 4439715]

Kmp **Prairie Canyon Member** — Dark gray to tan-gray, noncalcareous, platey, bioturbated, sandy to silty shale interlaminated with buff to tan-gray, very fine- to fine-grained, non to moderately calcareous, sandstone. There are occasional thin bentonite beds. The sandstone is usually interlaminated, but in some strata it thickens to discontinuous lenses up to 1.5 inches thick. Starved ripples form lenticular "pinch-and-swell" changes in bed thicknesses. Marine mollusk fossil fragments are rare. Invertebrate animal-burrow and surface track ichnofossils are very common in the sandstone beds. The main field identifier of the Prairie Canyon Member is very fine-grained sandstone chips in ground exposures. Sandstone chips do not occur in the underlying Smoky Hill Member or the overlying undifferentiated Upper Mancos Shale. Where the sandstone beds thicken, there is generally an increase in topographic relief (low hills). At those locations, small (<6 inch diameter) slabs of thin (<1 inch thick) sandstone typically litter the slopes. The Meeker Sandstone Member is wholly enclosed, stratigraphically, within the Prairie Canyon Member. Top and basal contacts of the Prairie Canyon were obscured on the Rattlesnake Mesa quadrangle and were estimated based on cessation of sandstone chips in slope float and increase in calcareousness of the underlying Smoky Hill shale. The unit is equivalent to the sandy Mancos "B" interval (Kellogg, 1977) at the Douglas Arch region near Utah, the Prairie Canyon Member (Cole and others, 1997) in the Book Cliffs, and the Cortez Member (Leckie and others, 1997) in southwestern Colorado. The thickness of this unit is approximately 1,400 feet, including the Meeker Sandstone lentil.

Kmme **Meeker Sandstone Member** — tan to tan-gray, rarely red stained, non to slightly calcareous, very fine to medium grained, wavy to cross-stratified marine sandstone and interlaminated bioturbated gray mudstone. Individual sandstone bed thicknesses range from laminations to up to a foot. The Meeker Sandstone contains up to four upward-coarsening sandstone sequences (**Figure 14**), separated by interlaminated sandy-silty shale intervals. The sandstone sequences contain thicker, coarser-sand beds with common shale partings, becoming medium grained with tabular, trough, and hummocky cross bedding. Some beds are cross laminated. Marine mollusk fossil shell fragments were seen, and marine animal-burrow ichnofossils are abundant. The individual sandstone sequences become increasingly obscured toward the eastern boundary of the map area. The Meeker Sandstone is a geographically restricted shelf-bar sand facies that lies entirely within the Prairie Canyon Member. Its top and bottom boundaries are gradational. The type section of the Meeker Sandstone (Dyni and Cullins, 1965) lies within the Rattlesnake Mesa quadrangle where State Highway 13 cuts through the ridgeline. At that location, the Meeker sandstone was reported as 180 feet thick.

Kms **Smoky Hill (Niobrara) Member** — Light gray to very dark gray, calcareous shale, marlstone, and shaly to chalky limestone. The upper contact with the overlying Prairie Canyon Member is marked by a cessation of interlaminated very fine-grained sandstone and silty mudstone and a transition to calcareous, homogeneous, fissile to platy, shale with common *Inoceramus sp.* fragments; the larger fragments of which are typically encrusted with *Pseudoperna congesta* oysters. These large *Inoceramus sp.* fragments are petroliferous and a strong oil odor is noted

Figure 14. Meeker sandstone ridgeline. The four major sandstone intervals are shown by arrows. Background is the Iles Formation escarpment. [UTMX 259919, UTMY 4438190]

when they are freshly broken. There can be stratigraphic intervals with high percentages of swelling-clay minerals. Thin, iron-stained, waxy-textured, cream-colored bentonite beds also occur. In the middle and lower intervals, the shale becomes increasingly limy and occasionally chalky. Where limy, the shale exposures become increasingly blocky and weather with a subspheroidal appearance. Discontinuous slabs of secondary very-coarsely crystalline calcite occur along fracture planes, up to two inches in thickness. Limestone beds occur in the limy shale that have a speckled appearance from ostracod microfossils. Limestone beds are also fossiliferous with marine Inoceramids (**Figure 15**). The last prominent limestone bed near the base of the unit is considered to be the equivalent to the Fort Hays Limestone along the Front Range of Colorado. Below this prominent limestone is a thin basal interval of dark gray to gray-black shale that is equivalent to the Carlile Shale along the Front Range.

In most surface exposures, the shale is highly fractured with common crystalline gypsum (selenite) fracture filling. Where secondary gypsum is heavy, the shale has a limonite tan-brown staining.

The Smoky Hill and the basal Fort Hays member is named the Niobrara Formation along the Front Range. The depositional environment of this unit is considered the deeper shelf of the Cretaceous North American Western Interior seaway. The limy to chalky intervals are of interest to oil and gas exploration using horizontal well-completion techniques. For this reason, most oil and gas wells in the Meeker area refer to the interval with the limestone beds as the Niobrara Formation in their stratigraphic picks. The thickness of this unit is approximately 2,300 feet.

Figure 15. Marine Inoceramus fossils in limestone of the Smoky Hill Member, exposed in a road cut on County Road 15. [UTMX 256903, UTMY 4437986]

Kmf **Frontier Member, sandstone facies** — Buff to tan to gray sandstone and minor olive-tan gray, marine-mollusk calcarenitic sandstone, interbedded with dark gray to gray-black noncalcareous fissile shale. There are three intervals in the sandstone. The unit contact with the overlying Smoky Hill Member is marked by the first occurrence of thin beds of fossil-hash sandy calcarenite and very calcareous gray fossiliferous sandstone interbedded with dark gray to gray black shale. The fossil "hash" in the calcarenite is composed of broken and intact marine pelecypod and gastropod shells that range in size from coarse sand to shells six inches in long diameter (**Figure 16**). *Prionocyclus sp.*, *Lopha lugubris*, *Inocermius sp.*, were seen, indicating a biostratigraphic equivalent to the Juana Lopez Member of southwest and west-central Colorado Mancos Shale (Scott and others, 2001). Lithology and fossil content of the upper thin calcarenite beds are also similar to the Juana Lopez member calcarenite described in the Uncompahgre and Gunnison valleys (White and others, 2008, Noe and others, in prep.).

With stratigraphic depth in the middle interval, the calcarenite and calcarenitic sandstone transitions to thicker beds of tan to tan-gray, well sorted, fine to medium grained, non to moderately calcareous, marine sandstone (**Figure 17**). The sandstone beds are interbedded with thinner beds of dark gray to gray-black, noncalcareous, fissile shale; some of which are just wavy interlaminated partings. The sandstone may be cross-stratified, contains oscillation ripple

Figure 16. Fossil samples found in thinly bedded calcarenitic sandstone of the upper interval of the Frontier Member sandstone facies.

marks, and locally abundant horizontal and vertical marine invertebrate tracks and burrow ichnofossils. Abundant small black grains or pellets give the sandstone a salt-and-pepper appearance under the microscope. Sole mark sedimentary structures are also common, mostly groove casts on the underside of individual sandstone beds. The cleaner better-sorted sandstone beds contain much fewer marine fossils, but intact "bottle cap" *lopha lugubris* shells were noted. The third interval sandstone becomes thinner bedded, increasing gray, and finer-grained to muddy siltstone with increasing thicknesses of interbedded dark gray to gray-black shale. A prominent horizon of large tan-brown limey concretions occur at the contact of the sandstone and the underlying shale facies (**Figure 17, inset photo**). These concretions, up to five feet in long diameter, exhibit radial cone-in-cone structures. The Frontier sandstone is found in the Rattlesnake Mesa quadrangle as dip slope exposures that rim the Meeker Dome and along the Frontier hogback in the southeast corner as strata incline towards Oak Ridge.

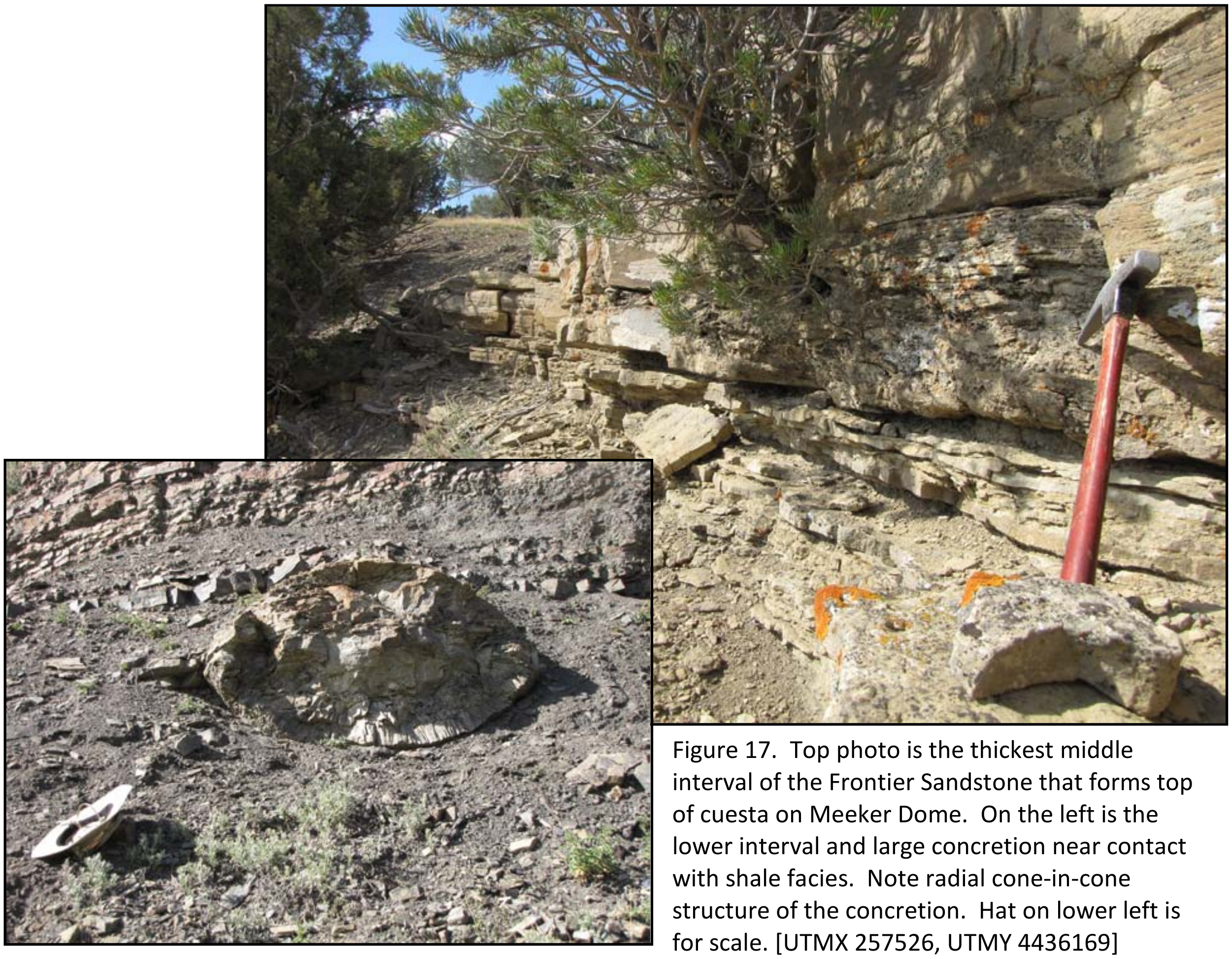


Figure 17. Top photo is the thickest middle interval of the Frontier Sandstone that forms top of cuesta on Meeker Dome. On the left is the lower interval and large concretion near contact with shale facies. Note radial cone-in-cone structure of the concretion. Hat on lower left is for scale. [UTMX 257526, UTMY 4436169]

Kmfs **Frontier Member, shale facies** — Gray-black to very dark gray, soft, noncalcareous, finely fissile shale. Throughout the unit, thick bentonite beds show as gray-white bands that are visible at a distance because the shale slopes is not, or is only poorly, vegetated. This thick shale is poorly indurated, and the fine fissile fabric quickly crumbles so its outcrops form smoothed rounded slopes (**Figure 18**). Infrequent thin beds of hard siliceous shale are near the base of the unit. Small (4-7 inch) brown-black disk-shaped chert concretions litter the slopes in the basal part of the soft shale. The contact with the underlying Mowry was picked either at the first thick blocky siliceous shale bed, if exposed, or where the smooth shaly slope transitioned to small gravel to cobble sized Mowry blocks littering the slope.

Kmm **Mowry Shale Member** — Dark gray to brown-gray, hard, siliceous shale interlaminated with light-gray coarse siltstone to very-fine-grained sandstone. Thinly bedded and hard, a tight joint spacing causes the Mowry to break into small orthogonal blocks and cubes. In outcrop certain intervals of the shale can weather with a silvery sheen. The blocky fragments weather to tan to brown and commonly litter the slope where this unit outcrops on the surface. Fish scales are commonly seen along bedding planes. Thinly interbedded in the hard blocky beds are iron-

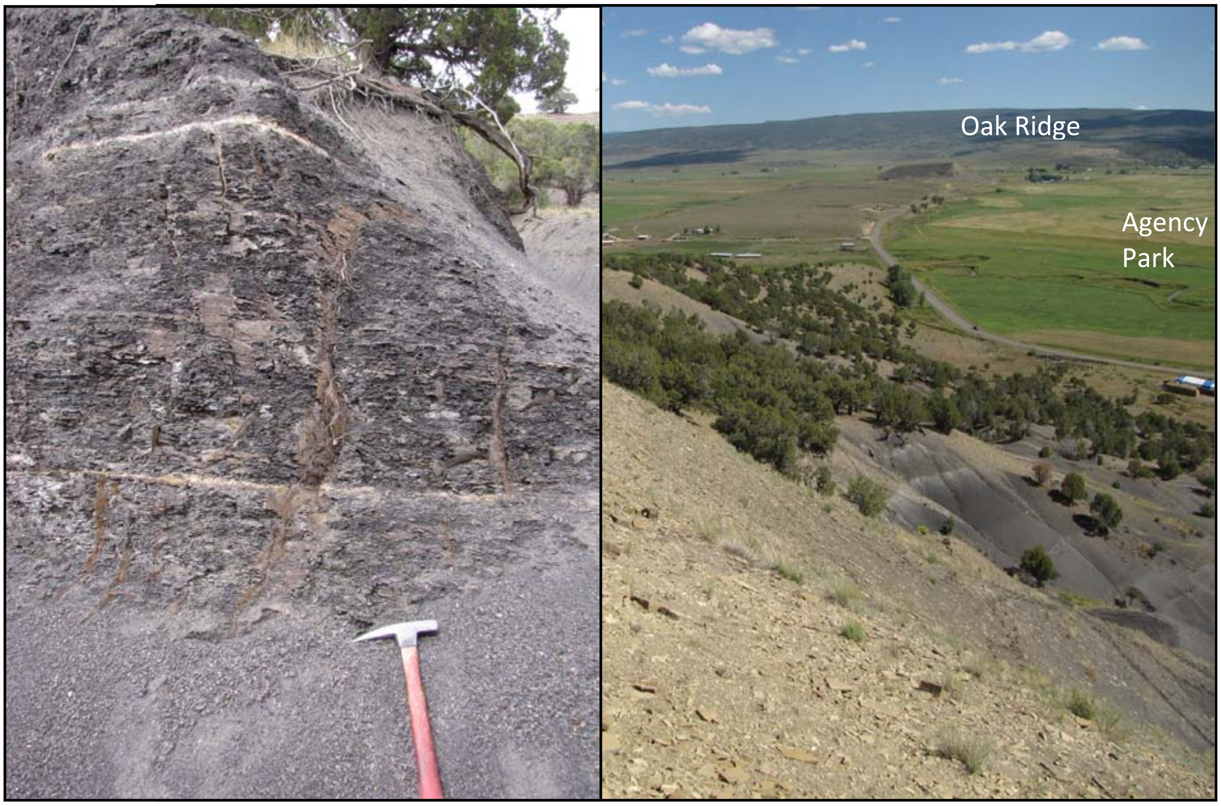


Figure 18. Right photo shows exposure of Frontier shale facies below Frontier Member sandstone on east limb of Meeker Dome [UTMX 257823, UTMY 4435872]. Note thick bentonite bands in the gray-black shale. Left photo is a gully exposure showing the fine fissile fabric of this easily eroded shale, as well as thin bentonite seams and brown-stained joints [UTMX 256208, UTMY 4436633].

stained bentonite and soft, finely fissile shale. The light-gray interlaminated silt and very-fine-grained sand give the Mowry a banded appearance in hand samples. These light-colored bands can be crosslaminated, or distorted, pinched, even swirled, by both soft-sediment deformation and bioturbation (**Figure 19**). The Mowry top was picked where the blocky siliceous shale predominated in outcrop.

DAKOTA SANDSTONE (LOWER CRETACEOUS)

The Dakota Sandstone was mapped as a single formation in the Rattlesnake Mesa quadrangle. This rock package consists of an upper sandstone unit, a middle shaly unit, and a lower sandstone unit. In the literature, many authors have given group status to the Dakota, and have described and named an underlying Cedar Mountain/Burro Canyon Formation.

Kd **Dakota Sandstone** — Buff to gray-white to orange-tan sandstone with a middle section of dark gray to dark green-gray shale that contains thinner interbedded sandstone beds. The sandstone is fine to medium grained with coarse-grained gritty beds that have chert-pebble conglomeritic lenses. The sandstone is very thick to thinly bedded and commonly cross-bedded and cross-laminated. The sandstone is commonly iron stained, giving the rock a reddish-brown, pink, or

Figure 19. Typical exposures of Mowry Shale. Note the blocky nature of the outcrop. Also the silvery sheen in top photo in gully side exposure. White dashed line show location of thin bentonite beds. Image at lower left shows dipslope exposure on gully floor. Note the tight jointing. Image at top left is typical slope exposure of Mowry, littered with rock fragments. [UTMX 255884, UTMY 4436426]

yellow-tan hue. The sandstone is siliceous, and can be quartzitic and very hard in outcrop. However, poorly-cemented friable zones occur, generally in the lower unit. There are black carbonaceous laminations in the sandstone. Formation top was picked where a 2-foot-thick, buff-colored fine- to medium-grained sandstone bed occurs within increasingly sandy, brown-gray, laminated siltstone of the Mowry Shale. The upper sandstone is over 25 feet thick, thickly bedded and cross bedded. The shale intervals and lower sandstones are poorly exposed. The Burro Canyon/Cedar Mountain equivalent was not mapped separately but the top is revealed by a 15-foot bright green-gray shale interval near the base of the unit that is exposed along County Highway 8. The contact with the underlying Morrison Shale is placed where the outcrop was primarily red to variegated-colored mudstone and thinly bedded sandstone.

In the map area, the Dakota Sandstone is exposed only in the Meeker Dome uplift. The best exposures are where it rises from the river's edge and forms bluffs above Highway 8 (**Figure 20**). Outcrops shows common evidence of deformation related to the uplift. The rock is highly fractured and jointed. There are also abundant shear zones (some with little or no vertical displacement) with slickensides and deformation banding.

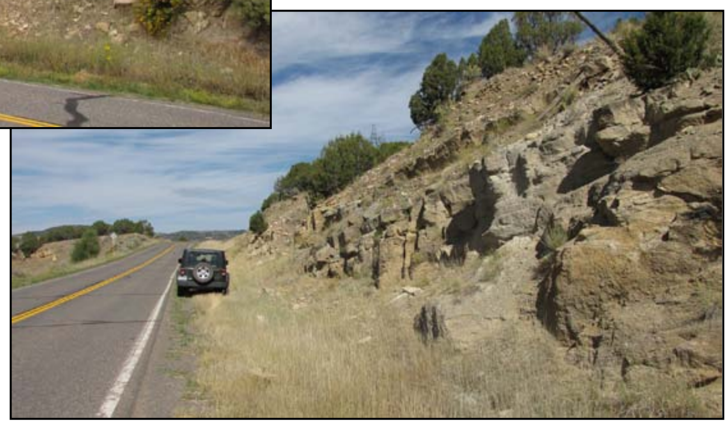


Figure 20. Exposures of Dakota Sandstone along County Road 8 on the north bank of the White River at the Meeker Dome. Thickest beds at road level in top left photo [UTMX 257252, UTMY 4435435]. Right image shows dipping beds of conglomeritic sandstone [UTMX 255610, UTMY 4435579]. Top right is a close up of typical chert-pebble conglomerate.

MORRISON FORMATION (UPPER JURASSIC)

Most of the Morrison Formation is subsurface in the Rattlesnake Mesa quadrangle map area. Only the upper 30-50 feet of the formation is poorly exposed along Highway 8 within the core of the Meeker Dome uplift.

Jm **Morrison Formation** — Interbedded green-gray, and light reddish-gray mudstone, hard green siliceous shale, and thin sandstone and limestone beds.

OLDER BEDROCK UNITS SHOWN ON GEOLOGIC CROSS SECTION

Cross Section A-A' runs from near the southwest corner of the quadrangle to the northeast corner. There is a small angle in the line so that it can extend through the center of the Meeker Dome and through the axis of the Sulphur Creek Syncline. The section line is shown on **Plate 1**. The cross section is shown on **Plate 2**. Additional, older bedrock units are included as subsurface units on the cross section. They do not crop out within the Rattlesnake Mesa quadrangle. Reported thickness values reflected in the section are from: measured sections to the south in the LO7 Hill quadrangle (White and

Warden, in prep.), measured sections southeast along Oak Ridge (Trask, 1956), and formation tops of quadrangle oil and gas well logs available on-line from the Colorado Oil and Gas Conservation Commission.

JꞦ **Undivided formations of the Lower Jurassic and Triassic** — Includes the eolian Entrada and Glen Canyon sandstones, and the red beds of the Chinle and Moenkopi/State Bridge formations.

PIPm **Maroon Formation (Permian/Pennsylvanian)** — Includes the Maroon Formation red beds and the overlying Weber Sandstone (Schoolhouse Tongue).

IPme **Undivided formations of the Pennsylvanian** — Includes the gray-colored Morgan/Minturn Formation, Eagle Valley Evaporite, and Belden Shale units.

MD **Undivided formations of the Mississippian and Devonian** — Includes the Mississippian Leadville Limestone and undivided Devonian rocks.

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APPENDIX A

DIVISION OF GEOLOGIC TIME ADOPTED BY THE COLORADO GEOLOGICAL SURVEY