OPEN-FILE REPORT 13-02

LO7 Hill Quadrangle Geologic Map, Rio Blanco County, Colorado

Authors' Notes

John W. Hickenlooper, Governor
State of Colorado

COLORADO
DEPARTMENT OF NATURAL RESOURCES

Mike King, Executive Director
Department of Natural Resources

Vincent Matthews
State Geologist and Director
Colorado Geological Survey

by
Jonathan L. White and Geoffrey Warden

Colorado Geological Survey
Department of Natural Resources
Denver, Colorado
2013

LO7 Hill Quadrangle Geologic Map, Rio Blanco County, Colorado

by
Jonathan L. White and Geoffrey Warden
Colorado Geological Survey, Denver, Colorado

This mapping project was funded jointly by the Colorado Geological Survey and the U.S. Geological Survey through the National Cooperative Geologic Mapping Program under STATEMAP Agreement No. G11AC20250

FOREWORD

The purpose of Colorado Geological Survey's (CGS) *LO7 Hill Quadrangle Geologic Map, Rio Blanco County, Colorado* is to describe the geology of this 7.5-minute quadrangle located south of the town of Meeker in northwestern Colorado. CGS staff geologist Jonathan L. White and field assistant Geoff Warden completed the field work on this project at the end of the summer of 2011. Jon White, the principal mapper and author, created this report using field maps, photographs, structural measurements, and field notes generated by all the investigators. Significant knowledge was also gained by a compilation of the available published geologic literature listed in the references.

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 G11AC20250, 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.

Vince Matthews
State Geologist and Director
Colorado Geological Survey

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

INTRODUCTION

The LO7 Hill 7.5-minute quadrangle is located in Rio Blanco County, Colorado along the Grand Hogback south of the White River Valley (**Figure 1**). The Town of Meeker lies 2½ miles to the north, inside (east of) the Grand Hogback on State Highway 13. Meeker is the county seat of Rio Blanco County.

Figure 2 shows the major physiographic and topographic features. The formal topographic names have also been labeled. The most striking features in the LO7 Hill quadrangle are the uplands along the southwest margin, the Grand Hogback in the center, and highlands in east that includes LO7 Hill. South- to north- flowing Sheep Creek and Flag Creek are the major drainage basins. The highest elevation is 8,831 feet, in the White River National Forest above Hay Flat Trail in the southeast corner of the quadrangle. The lowest elevation (6,203 feet) occurs on the floor of an unnamed, ephemeral creek channel in the northwest corner of the quadrangle that flows to the White River Valley.

Geologic mapping of the LO7 Hill quadrangle was undertaken by the Colorado Geological Survey (CGS) as part of the STATEMAP program. STATEMAP is a component of the National Cooperative Geologic Mapping Act, 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 and mineral fuel-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 LO7 Hill quadrangle include the following:

- The surficial units were not previously studied or mapped in any detail. This 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 review the author's 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 LO7 Hill quadrangle bridges the available 1:24,000 geologic mapping of the northern edge of the Piceance Basin to the northwest with the mapping of the eastern margin of the Basin along the Grand Hogback to the south (See **Figure 1** for references)

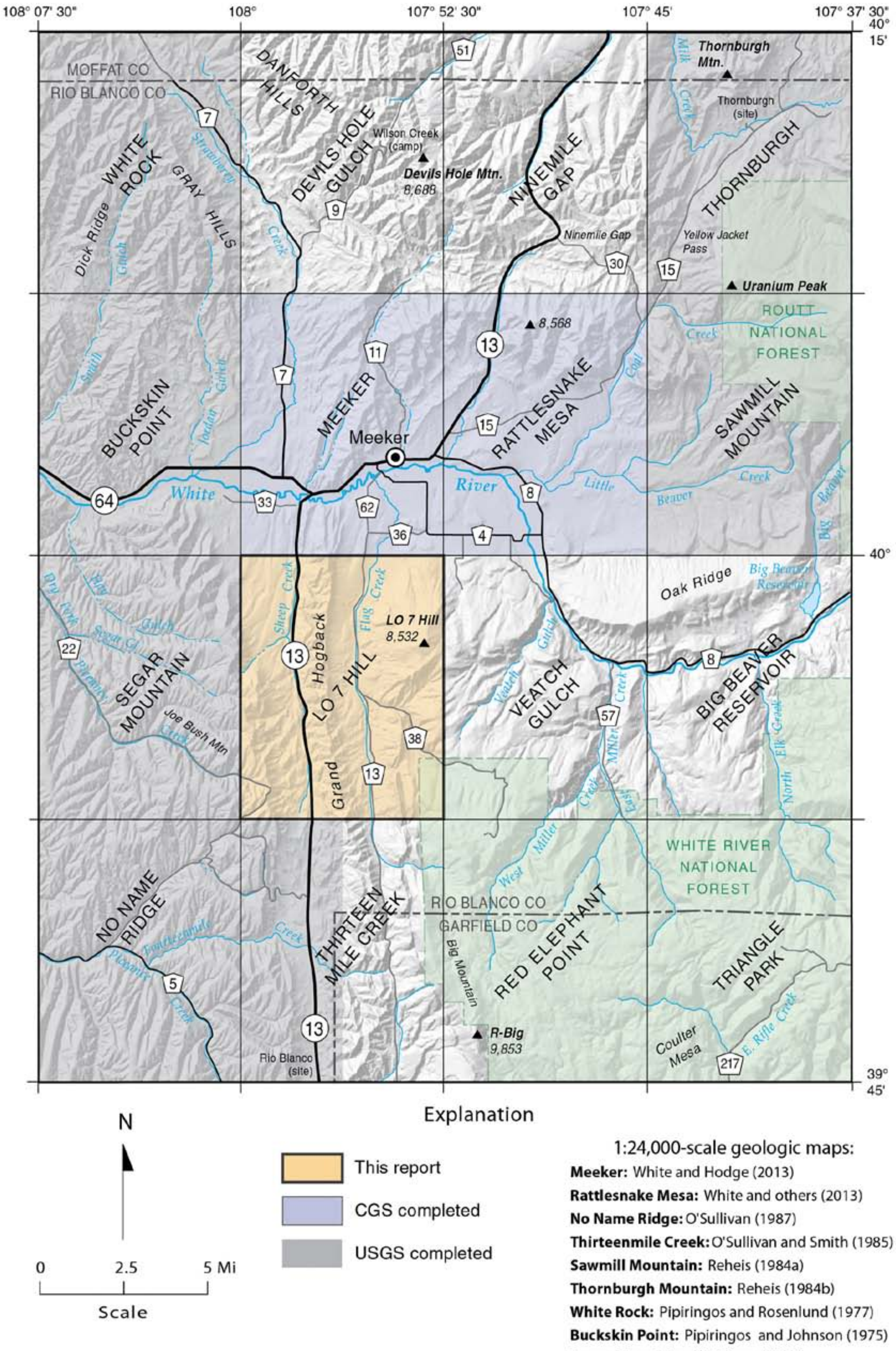


Figure 1. Regional map with key of geologic mapping near LO7 Hill.

- This map shows the extent of the bedrock outcrops at a more detailed scale and with more accuracy than previous maps. The formational members of the Mancos Shale have also been subdivided and individually mapped.
- The map shows more bedding strike-and-dip readings and more geologic structure than previous maps.

PREVIOUS MAPPING STUDIES

Figure 1 shows the status of 7.5-minute (1:24,000-scale) quadrangle geologic mapping in the area by the U.S. Geological Survey and the CGS. The LO7 Hill quadrangle is the third of three geologic maps recently done by CGS in the proximity of the town of Meeker. The LO7 Hill quadrangle map area is also included in a regional geologic map of the Leadville 1x2-degree sheet (Tweto and others, 1978) at a scale of 1:250,000. Tweto and others (1978) relied heavily on the earlier work by Murray (1962, 1966), who completed his University of Colorado thesis and dissertation of the stratigraphy and structural geology of the Grand Hogback Monocline. Murray (1966) included a black and white, 1:63,360-scale geologic map that contains the LO7 Hill map area.

MAPPING METHODOLOGY

The geologic interpretations shown on the LO7 Hill 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 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 stereo and orthophotos taken in 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 GIS 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 2009 NAIP photography.

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.

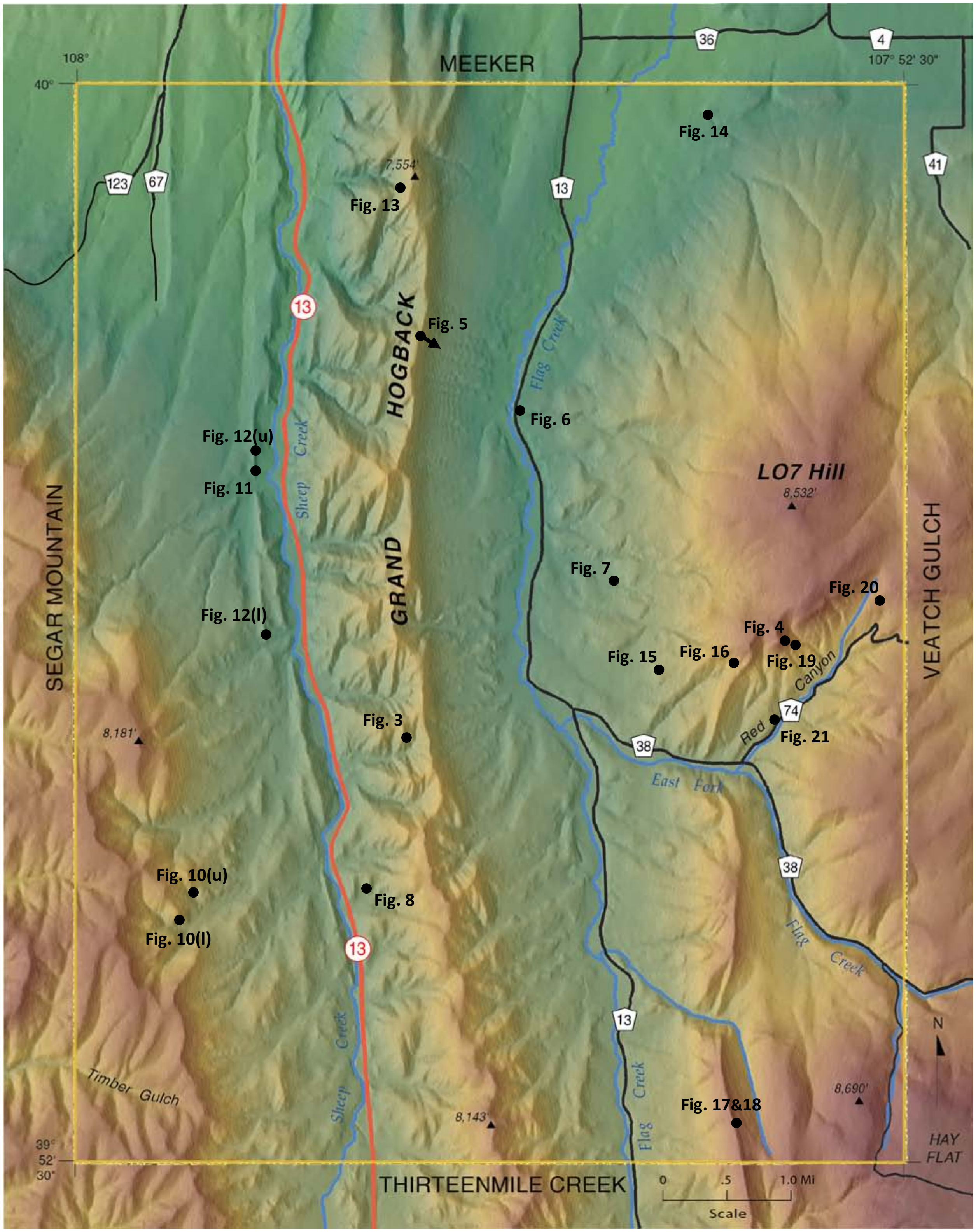


Figure 2. False-color shaded relief map of the LO7 Hill Quadrangle showing major physiographic and topographic features. Figure numbers, if they are photographs, are shown by black dots. Vectors are included if photo is a panoramic view.

PHYSIOGRAPHY AND GEOLOGIC SETTING

The LO7 Hill quadrangle lies along the northern extent of the Grand Hogback, which is the boundary between the Colorado Plateau and the Southern Rocky Mountains (Fenneman and Johnson, 1946). Locally, the Grand Hogback marks the structural transition from the early Cenozoic Piceance Creek syntectonic depositional basin to the adjacent, Laramide, White River Uplift.

Figure 2 illustrates the physiographic features and their underlying geologic structure. Shale and mudstone units are nonresistant and form the green-colored valleys and topographic basins where Flag and Sheep Creeks have preferentially eroded. The sandstone-bearing strata are more resistant, and form the yellow to brown-colored escarpments, hogbacks, ridges, and plateaus that easily express the geologic structure across the landscape. From west to east the geologic units get older. The high dissected plateau on the west is underlain by the gently-dipping Eocene Green River Formation. This unit forms a broad escarpment above the mudstone-predominant Wasatch Formation on the west valley side of Sheep Creek. The Grand Hogback in the center of the quadrangle is formed from near vertical to overturned Upper Cretaceous Mesaverde strata. The Flag Creek valley behind is underlain by steeply dipping Mancos Shale. Topographic highs on the east and southeast portions of the quadrangle map area reflect structural highs of the White River Uplift where more resistant, Middle to Lower Mesozoic and Upper Paleozoic rocks are folded upwards and exposed. The north-plunging LO7 Hill anticline is capped by the Dakota Sandstone and Morrison Formation. The sharp ridgeline that curves southwest and south from below LO7 Hill (between Flag Creek and its East Fork) was formed from the resistant, steeply dipping, Jurassic Entrada and Glen Canyon sandstone. Triassic to Pennsylvanian redbeds are exposed behind the sharp ridgeline, most prominently along Red Canyon.

The Quaternary geology story is one of punctuated incision and base-level lowing of stream levels, landsliding of oversteepened slopes, and periodic alluviation by terrace gravels and valley-fill deposits. These sequences are tied to Pleistocene glacial epochs. The physiographic results are the formation of small mesas, fans, and ridges along Sheep Creek and Flag Creek valley slopes, which are capped with earlier, rocky, more resistant, valley-fill and river-terrace deposits (See *Surficial Deposits* in *Description of Map Units* sections).

STRUCTURAL GEOLOGY

The major structural elements of the LO7 Hill quadrangle are the Grand Hogback monoclinal fold off of the White River Uplift and the plunging, asymmetrical LO7 Hill anticline. In the map area formational strike quickly wraps from due north to an easterly orientation that, off map, trends towards Veatch Gulch and across the White River valley to Oak Ridge. Minor folds, minor-displacement normal faults, shear/breccia zones, deformation banding, and tensional en-echelon fracturing occurred to accommodate this 90 degree change in formational strike.

Several normal faults, roughly perpendicular to the trend of the Grand Hogback monocline also occur. They are most noticeable where they offset the Ohio Creek Conglomerate ridgeline or the Trout

Creek Sandstone (**Figure 3**). Murray (1966) attributes most of these normal faults as primarily a consequence of tensional stresses perpendicular to the trend of the monocline.

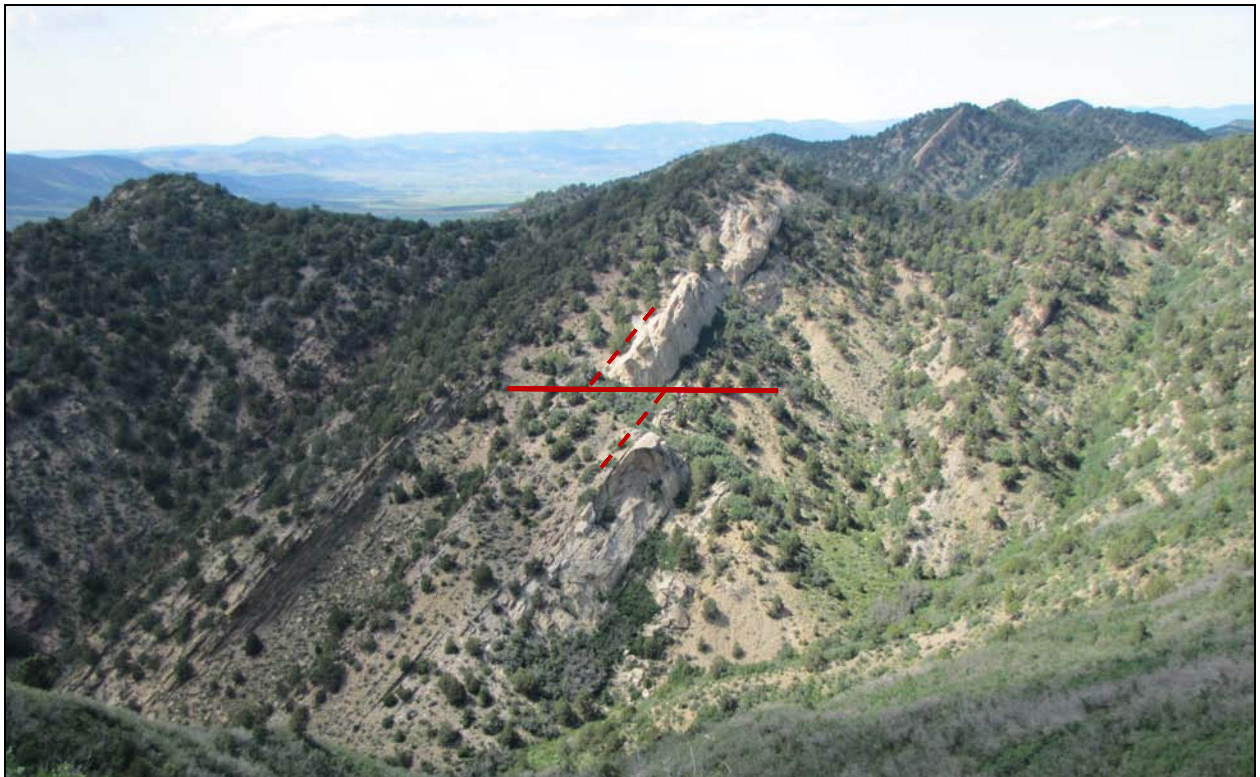


Figure 3. Normal fault offset of tilted Trout Creek Sandstone (Kit) member of the Iles Formation (Ki) in the Grand Hogback monocline. View is north to northwest towards the White River. The lowland is Powell Park in the middle background. Note prominence of the Kit sandstone in outcrop along the background Grand Hogback ridgeline. [UTMX 247840, UTMY 4423450]

Within the steeply dipping limb of the Grand Hogback monocline syntectonic flexural slip surfaces are difficult to find. Stratigraphic-thinning flexural slips were identified nearby in the Rattlesnake Mesa quadrangle (White and others, 2013). In dipping strata above Red Canyon Creek, re-cemented brecciated zones were noted in the basal Entrada/Glen Canyon sandstone at the contact with the underlying Chinle Formation (**Figure 4**), which may be attributed to flexural-slip deformation along bedding.

Another structural feature in the LO7 Hill map areas is the northern extension of the Twelve mile fault zone described and mapped by Murray (1966). Changes in topography in the southern third of the map area can be seen in **Figure 2.** The sharper-defined ridgeline on the east side of the hogback in the north becomes irregular, more deeply incised, and eroded with several small drainage basins. Parallel-to-strike high-angle thrust sheets extend into the LO7 Hill map area from the south. While the precise fault locations could not be discerned, their locations are approximated based on: 1) the faulting out and disappearance of the Trout Creek Sandstone member of the Iles Formation in outcrop, 2) where a band of overturned strata in the Williams Fork Formation occurs that is not related to flexural creep (*see* *description of landslide deposits*), and 3) stratigraphic thinning of the exposed upper Mancos Shale interval and apparent faulting out of the Morapas Sandstone member in outcrop.

Figure 4. Contact of undivided Entrada and Glen Canyon Gp. sandstones (JTReg) with underlying red Chinle Formation (TRc). Note intense fracturing and brecciation of JTReg sandstone near contact (behind and above person). Photo above shows close-up of re-cemented breccia. [UTMX 252750, UTMY 4424570]

The last major structural feature is informally called the Hay Flat Monocline. This west to east trending monocline lies within the White River Uplift and was mapped by Murray (1966). It begins at the Entrada/Glen Canyon ridgeline where it is first expressed as a tight, asymmetrical, overturned, faulted(?), fold of the Weber Sandstone. Eastward, the Hay Flat plateau is approximately 500 feet higher in elevation so it is assumed the angle of the axial plane flattens and the fold widens to a fault-propagated monocline. However, except for the fold in the Weber Sandstone, strata along this monocline is obscured by the dense vegetation and regolith on the north-facing slope, so it is uncertain whether a fault offsets Maroon strata at the ground surface. The structure is easily seen in topography, especially off map to the east in the adjacent Veatch Gulch quadrangle.

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 LO7 Hill quadrangle are Quaternary (Holocene and Pleistocene) in age. They are wide spread on the LO7 Hill quadrangle because of the erodible nature of the local bedrock and topographic elevation differences that can foster rapid and extensive deposition of sediments in alluvial, colluvial, and mass-wasting environments (**Figure 5**). The deposits shown on the map are generally more than 5 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. No 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.

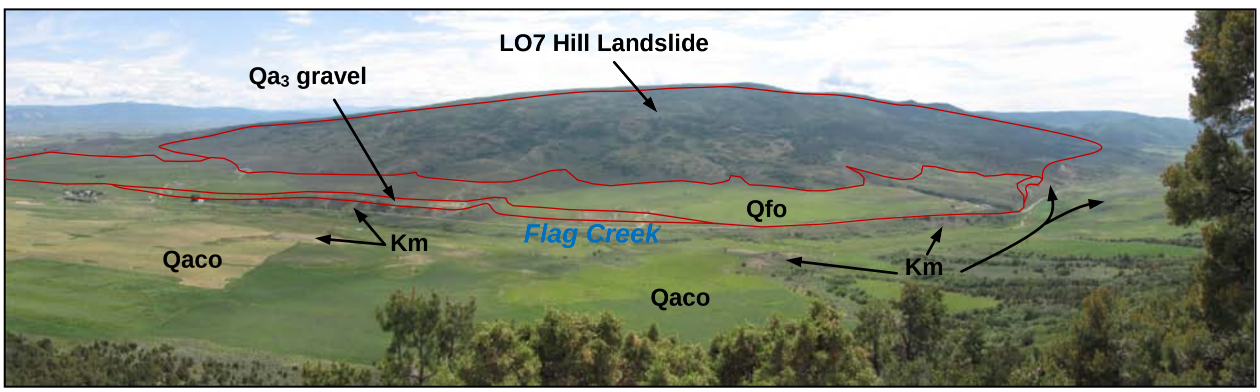


Figure 5. Eastward view of Lower Flag Creek valley adjacent to LO7 Hill. Mancos Shale (Km) underlies the valley floor but only outcrops below bluffs of terrace gravels and fan deposits (Qfo). Elsewhere, tributary channels have incised into old Qaco sheetwash surfaces, exposing weathered claystone below where the slope has a dark gray color. Note the hummocky ground surface on the large landslide that covers most of LO7 Hill. [UTMX 248280, UTMY 4429200]

HUMAN-MADE DEPOSITS

af **Artificial fill and disturbed areas (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 mining and 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 glaciations. These sediments are generally unconsolidated, but cemented zones were noted in some of the older units.

Stream alluvium consists of cobble, gravel, sand, silt, and clay transported and deposited by perennial first-order tributary streams of the LO7 Hill quadrangle that flow northward to the White River. The main perennial streams are Flag Creek and Sheep Creek. The Flag Creek basin is more areally extensive, and has a higher-altitude longitudinal profile into the White River Uplift. It contains several elevation stages of Pleistocene-aged terrace deposits above the current base level of the creek. Within the Meeker quadrangle, 4 terrace levels of the tributary Flag Creek were mapped, with the highest at an elevation of 105 feet above Flag Creek (White and Hodge, 2013). The profile of these same terrace levels rise higher above the base level of Flag Creek in the LO7 Hill map area. Sheep Creek, however, is much more limited in areal extent. Its headwaters lie locally just off the southern boundary of the map. Its alluvial deposits are only in the narrow arroyo floor that is incised into fine-grained valley fill (Qaf) sediments. No older terrace gravels were identified or mapped.

Flag Creek clast provenance is distinctive for tributary streams of the White River in the Meeker area (White and Hodge, 2013). The Flag Creek basin extends southward along the Mancos Shale strike valley and into the White River Uplift where Lower Cretaceous, Triassic, Jurassic, and Upper Paleozoic rocks are exposed. Larger clast percentages include hard, dark-gray siliceous siltstones of the Mowry Shale; sandstones and pebble conglomerates of the Dakota and Morrison formations; some older red-bed sandstones and siltstones of the Chinle, Moenkopi, and Maroon formations; and reworked quartzitic pebbles and cobbles eroded from conglomerate beds of the Maroon Formation.

Qa_1 **Alluvium one of 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 flood plains in Flag Creek. The Qa_1 deposit in Sheep Creek arroyo was too narrow for the map scale and not mapped. This unit typically incises into valley fill, alluvial fan deposits, or bedrock, creating 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 along the northern map boundary, toward the confluence with the White River.

Qa_2 **Alluvium two of streams (late Pleistocene) –** Tan to buff colored alluvium that ranges gradationally from clast-supported cobbly gravel in very coarse silty sand to a finer-grained silty sand with only scattered gravel. This unit is exposed at very discontinuous strath terrace remnants along Flag Creek from 40-80 feet above the base-level. In most locations, the exposure is just a subtle bump in the valley-slope topography where the slope surface is rich with riverine gravel and cobble. Some clasts exposed at the surface are coated by thin discontinuous crusts of white $CaCO_3$, which indicates that soil development includes a calcic Bk horizon. Thicknesses are likely less than 10 feet.

Qa_3 **Alluvium three of streams (late to middle Pleistocene) –** Tan to brown, cobbly to pebbly gravel in very coarse silty sand. The Qa_3 river terrace is reported at 70 feet above the base Flag Creek level on the Meeker quadrangle (White and Hodge, 2013) but quickly rises in the LO7 Hill map area to an elevation that is about 130 feet above base level. It is the most common terrace level exposed along Flag Creek. Clasts exposed at the surface were coated by discontinuous, sometimes thick crusts of white $CaCO_3$, which indicates that soil development includes a calcic Bk horizon. Thicknesses were measured from 24 to 30 feet.

Qa_4 **Alluvium four of streams (early middle Pleistocene) –** Tan to buff-colored cobbly to bouldery gravel in very coarse silty sand. The terrace is reported to be 105 feet above the adjacent base-level floodplain of Flag Creek on the Meeker quadrangle (White and Hodge, 2013). Further up into the Flag Creek basin in the LO7 Hill map area, the tread level appears to rise to the 170- to 180-foot level above base level. Clasts exposed at the surface were coated by discontinuous thick crusts of white $CaCO_3$, which indicates that soil development includes a calcic Bk horizon. Thickness is about 20-25 feet.

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 ephemeral streams. Thickness is variable, likely not exceeding 10 feet.

MUDFLOW-DOMINATED ALLUVIUM AND ALLUVIAL-FAN DEPOSITS

These surficial deposits cover broad areas within the LO7 Hill quadrangle and 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 muddy 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, roughly stratified and channelized, pebbly to cobbly gravel more typical of riverine environments. Most of the source material is derived from Williams Fork Formation and Wasatch Formation on the west side of the Grand Hogback, and from the Mancos, Dakota, and Morrison formations on the east side of the hogback. Many of these fan deposits along the east bank of Flag Creek are from landslide sources, and can include earth-flow sediments. These deposits are also heterogeneous and may have different properties depending on depositional dynamics and source areas of the sediments. Sediments that are low density, silt rich, and dry may be susceptible to ground settlement by hydrocompaction if they become wetted. Where derived from the Mancos Shale and Morrison Formation, and rich in swelling-clay minerals, these sediments may be expansive upon wetting. Both types of ground movements can damage structure foundations or concrete flatwork.

Qaf **Alluvial and alluvial-fan deposits, undifferentiated valley fill (Holocene)** — Brown to 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 fanned over the valley floor. This unit is best exposed in arroyo escarpments of Sheep Creek. Soil development reflects the aggrading nature of the deposit with multiple poorly-developed Bt soil horizons. The highest escarpment in this unit is about 32 feet. Actual unit thickness may exceed 40 feet.

Qafo **Old alluvium 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 depositional environments. Clasts are generally angular to subangular of local upslope bedrock sources. These older rocky deposits occur on higher mesas and dissected ridgelines that are erosional remnants of earlier Pleistocene paleovalleys. Qafo deposits are typically much coarser and bouldery than the more recent Qaf deposit, reflecting the climatic conditions of the Pleistocene glacial periods. The typical sediments deposited near steeper bedrock slopes ranged 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 deposits range from matrix-supported mud flows to a stream-deposited, moderately sorted, interlayered fine- to coarse-grained sand with sporadic granule lenses. Channels of better sorted, imbricated, well-rounded riverine gravels may occur in the deposit. 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 main tributary valleys.

This unit is more resistant than the underlying Mancos Shale and Wasatch Formation bedrock, so topographic reversal occurs as base-level downcutting of streams continue, leaving wide flat surfaces and alluvium-capped mesas. Clasts exposed at the surface were coated by discontinuous crusts of white $CaCO_3$, which indicates that a calcic Bk horizon is present. Unit thickness may be less than 5 feet and up to 25 feet.

Qf **Alluvial-fan deposits (Holocene)** — Gray, poorly sorted to unsorted, unconsolidated, sandy to silty clay with dispersed matrix-supported gravel. This unit was mapped for only one alluvial fan at the mouths of a small ravine in the gravel-capped Mancos Shale bluff above. The deposit has a fan-shaped morphology. Sediment was deposited primarily as a muddy debris flow and/or earth flow.

Qfo **Old alluvial-fan deposits (late to middle Pleistocene)** — Tan to brown-tan to dark reddish brown, poorly sorted to unsorted, unconsolidated, sandy to clayey silt with dispersed matrix-supported gravel. This unit can range gradationally to a much coarser clayey to sandy, clast-supported bouldery gravel. Clasts are generally angular to subrounded. Broad aprons of this unit occur on the east side of Flag Creek where sediments fanned out from the above LO7 Hill landslide complex (**Figures 5**) and larger tributary streams such as the East Fork Flag Creek. This deposit was primarily from debris/mud flow processes but may also include both riverine-type gravel deposits and earth-flow deposits where subsequent deposition and/or erosion has obscured the landslide flow morphology. Where this deposit is located atop Mancos bluffs along Flag Creek, chalky soil zones were commonly noted and angular to subangular rock clasts exposed at the surface were coated by discontinuous crusts of white $CaCO_3$, which indicates that a calcic Bk horizon is present. This deposit also has partially buried earlier well-rounded terrace gravels of Flag Creek. Rapid mud deposition is indicated by the unsorted nature of the deposits with angular clasts generally dispersed and supported within a finer-grained matrix. In outcrop at the confluence of East Fork Flag Creek and Flag Creek, the unit reaches over 80 feet in thickness (**Figure 6**). This deposit may be mantled by a thin discontinuous veneer of Qac and windblown deposits.

Figure 6. Thick old alluvial-fan (Qfo) deposit adjacent to Flag Creek Road (CR 13). Note that the deposit is relatively unsorted and the rocks are predominantly angular in shape. [UTMX 249350, UTMY 4427650]

ALLUVIAL/COLLUVIAL AND MASS-WASTING DEPOSITS

Earth materials that were transported downslope primarily by gravity and not within or under another medium, such as water or ice. These deposits are formed in combinations of the following depositional systems: 1) downward transport of slope material by gravity creep and sheetflooding into colluvial wedges at the base of slopes, 2) rockfall forming talus slopes, 3) shear-plane landsliding along defined zones of weaknesses in the underlying bedrock or unconsolidated sediments, and 4) clay-rich earthflows where the entire sliding mass is very wet, wholly or partially fluidized, and flowed down the slope. This category also includes those undifferentiated hillside surficial units that exhibit both alluvial and colluvial depositional environments.

Qc **Colluvial deposits (Holocene)** — Heterogeneous tan to tan-gray deposits consisting of unsorted and unstratified clay, silt, and sand, with dispersed matrix-supported angular gravel to boulder-sized rock fragments. Colluvium is generally rocky talus 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 5 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. Qc soils may be susceptible to settlement.

Qco **Old colluvial deposits (late to middle Pleistocene)** — Heterogeneous tan, reddish tan, tan-gray deposits consisting of clast-supported bouldery-pebbly gravel in an unsorted sandy clay matrix. These older colluvial deposits typically occur as remnants of an old erosional surface that covered the valley sides. Most deposits occur on the Mancos Shale slope below the Iles Formation escarpment, or the Wasatch slope below the Green River Formation. These rocky deposits contain sandstone clasts so are more resistant to weathering than the underlying Mancos Shale. Where they exist, this unit has been eroded to form relict faceted slopes. Some Qco units may include small landslide deposits when the diagnostic landslide morphology has been obscured by subsequent erosion. Unit thicknesses is variable but likely doesn't exceed 20 feet.

Undifferentiated alluvial and colluvial deposits are heterogeneous and may have different properties depending on depositional dynamics and source areas of the sediments. Qac soils that are low density, silt rich, and dry may be susceptible to ground settlement by hydrocompaction if they become wetted. Where derived from the Mancos Shale and Morrison Formation, and rich in swelling-clay minerals, these sediments may be expansive upon wetting. Both types of ground movements can damage structure foundations or concrete flatwork.

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. Deposit is poorly sorted, very weakly stratified, and clasts are angular and of local upslope 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 rough and likely reflects short-term climatic changes when downslope movement and deposition of sediment is enhanced. These deposits are commonly found on flatter slopes at the base of steeper slopes, including valley fill and along upland slopes. Soil development is weak. Unit thicknesses is variable but likely doesn't exceed 15 feet.

Qaco **Old alluvial and colluvial deposits, undifferentiated (late to middle 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 developed calcic Bk soil horizon. That soil development and the reddish hue of the surface soils assign this deposit a late Pleistocene age. This deposit is commonly found on higher surfaces at the flattening slopes below the Iles and Green River escarpments. Thickness is highly variable and likely does not exceed 10 feet.

Qls **Landslide deposits (Holocene to late Pleistocene)** — Landslide deposits can range from creep deformation of what is still relatively intact strata to a chaotic mixture of rock fragments in a sandy to silty clay matrix that formed by the downward movement of rock and unconsolidated surficial deposits. Where landslide deposits become saturated with water, they can behave plastically and "flow" down hillsides as earth flows. In the LO7 Hill quadrangle landslide deposits are found in three types of terrains: 1. dip-slope planar failures along inclined bedding of weak shale and mudstone, 2) creep that has deformed and overturned strata to the point where toppling landslides occurred, generally at locations where erosion has undermined the lateral support of adjacent near-vertical bedding, and 3) rotational failures and slumps in fine-grained clayey soil and weak rock formations where shear planes were able to develop through bedding. If development occurs on landslides, buildings and other structures generally experience catastrophic damages if, or when, ground movements occur.

The largest landslide complex is on LO7 Hill. These features cover both sides of the hill, which is an asymmetrical north-plunging anticline. Along the western hillside, bedding dips transition from about 35° westward on a north to south strike, to a northerly 7° dip at the LO 7 Hill anticline axis. The exposed formations are the Dakota and underlying Morrison. Hummocky ground, scarps, and grabens occur throughout this complex. Extensive Pleistocene, dip-slope shearing and translational movement along weak Morrison Formation bedding planes have rumpled and rubblized the slope. Further down the slope, the landslide toe has bulldozed into Mancos Shale units and caused buckling and back-tilting deformation of strata (**Figure 7**). In many areas, large slabs of strata have slid but remained relatively intact. These fractured slabs, some acres in size, still have an approximation of the original bedding orientation. Those landslide locations where strikes and dips were measured on blocks of disturbed strata are shown on the map. The depth of the bedding shear zones and thickness of the disturbed strata is unknown but a hundred feet or more may be possible is some locations.

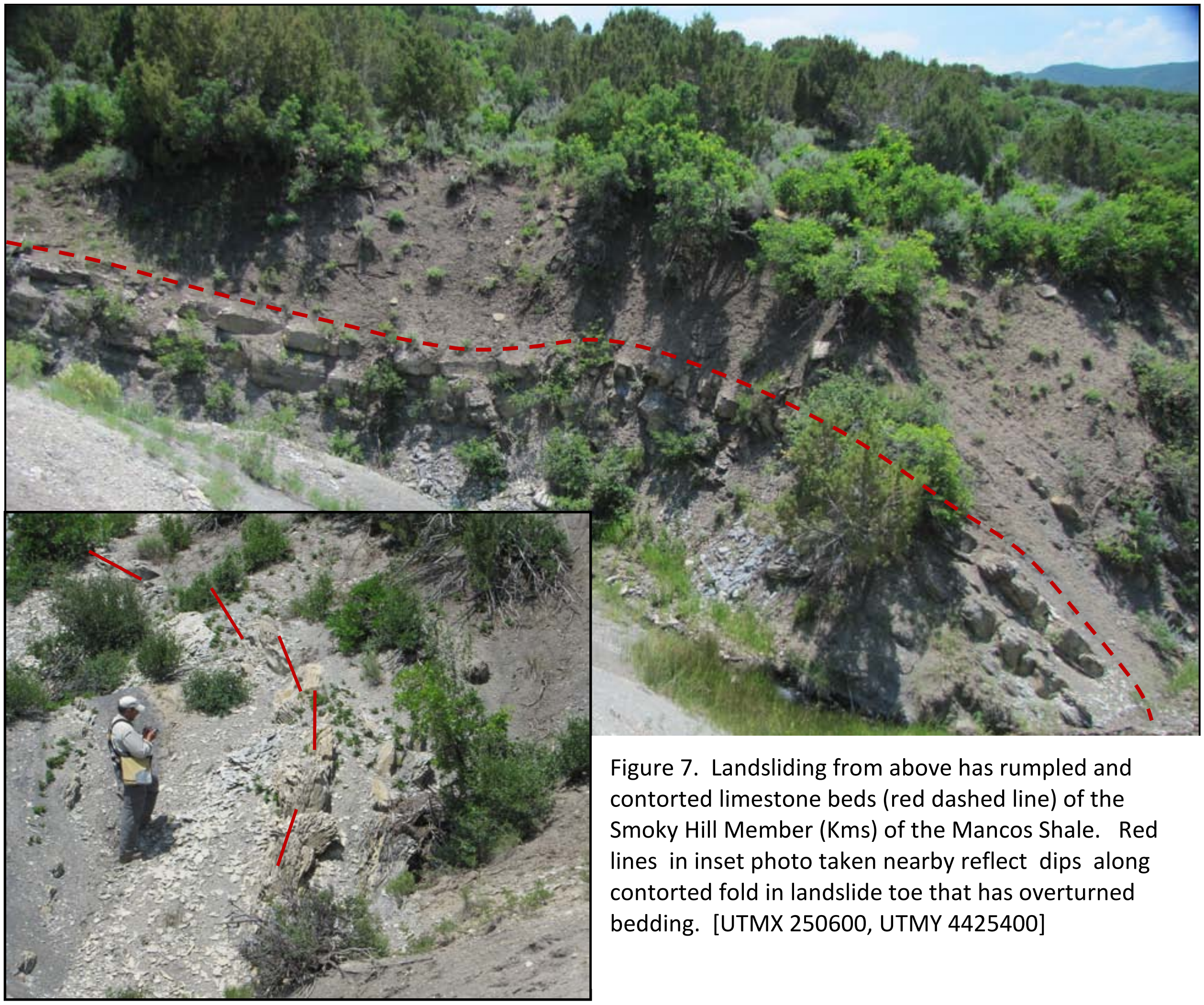


Figure 7. Landsliding from above has rumpled and contorted limestone beds (red dashed line) of the Smoky Hill Member (Kms) of the Mancos Shale. Red lines in inset photo taken nearby reflect dips along contorted fold in landslide toe that has overturned bedding. [UTMX 250600, UTMY 4425400]

The landslide deposits within the tilted Mesaverde Group bedrock formations are quite different. The Williams Fork Formation is composed of sandstone beds interbedded with thicker beds of weak, low shear-strength shale, mudstone, and minor coal seams. The dip of the Williams Fork Formation is near vertical along the western margin of the Grand Hogback. The downcutting of Sheep Creek has stripped away the rockmass that buttressed these near-vertical rocks. The removal of the lateral support resulted in creep movements towards Sheep Creek. This rockmass creep has deformed the strata and caused overturning of bedding (**Figure 8**). In several areas, the overturning deformation reach a toppling threshold where complete slope failure and rubblizing of the steep-dipping strata occurred. 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. The depth to intact strata in the creep zones can be up to 30 feet.

Other large landslides in the map area occur along the front of the Glen Canyon/Entrada ridgeline where the weak, steeply-dipping Mancos Shale members have failed. These landslide complexes on the east side of the Flag Creek valley also commonly extend upwards to failure within the Morrison Formation, which then also results in the displacement and rubblization of the overlying Dakota Sandstone. Landslide thickness in these areas may exceed 50 feet.

Figure 8. Disturbed strata of the Williams Fork Formation (Kw) visible from State Highway 13. Overturning creep is best illustrated where relict bedding can still be discerned in the creep-disturbed front slope along strike, and subsequent erosion and ground lowering of adjacent drainage tributaries has exposed fins of the same intact near-vertical sandstone beds from the side. Red dashed line approximates creep boundary where the beds above have been disturbed and overturned. The hinge line of the Grand Hogback Monocline is about 6,500 feet to the left (west). [UTMX 247320, UTMY 4421580]

BEDROCK UNITS

The bedrock exposed in the LO7 Hill quadrangle extends from the Piceance Basin to the White River Uplift and consists of rock formations from the Early Cenozoic, Mesozoic, and Late Paleozoic Periods. The bedrock units are listed from the youngest to the oldest, beginning with the Tertiary Green River Formation along the southwest margin of the quadrangle and ending with the Early Permian to Pennsylvanian Maroon Formation along the southeast margin. **Figure 9** contains a stratigraphic column of the LO7 Hill quadrangle that includes member units and unit thicknesses.

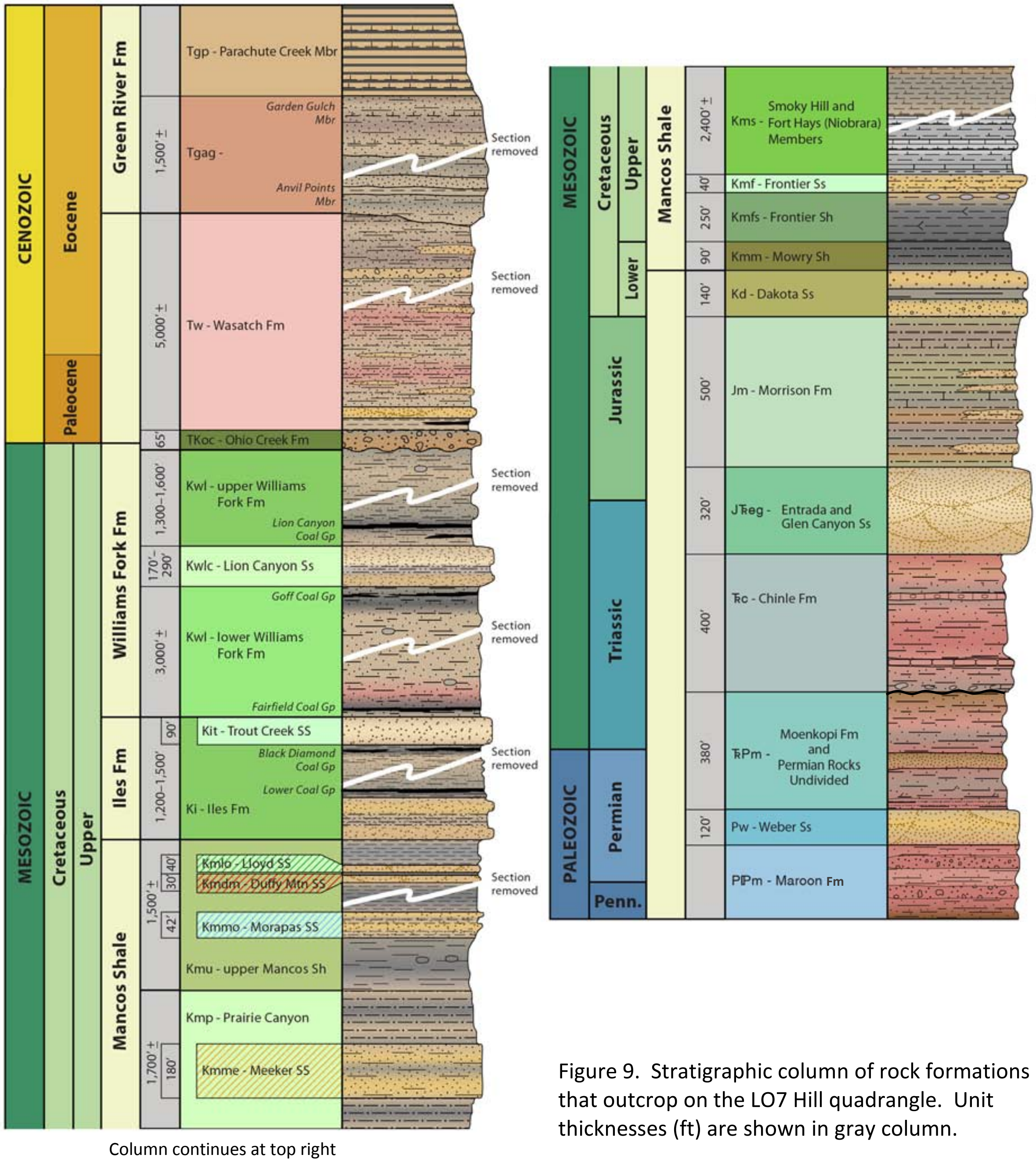


Figure 9. Stratigraphic column of rock formations that outcrop on the LO7 Hill quadrangle. Unit thicknesses (ft) are shown in gray column.

GREEN RIVER FORMATION (EOCENE)

The Green River Formation forms the western escarpment of the map area. This unit's escarpment southward becomes the Roan Cliffs on the west side of Government Creek and north side of the Colorado River. The base of the Green River Formation has been placed at an easily seen transition from the prominently red-banded, fine-grained mudstone of the Wasatch Formation to thicker beds of more uniformly colored, fluvial and near-shore lacustrine sandstone (**Figure 10**). The base of the Green River Formation, as it is mapped in the LO 7 Hill quadrangle, was predominantly deposited in lacustrine shoreface environments, and is likely equivalent to the Doodlebug Gulch member of the Wasatch Formation, an informal unit defined by Shroba and Scott (1997) in the Rifle area. Because of the inability to define a mappable contact between the Garden Gulch Member and Anvil Points Member, both members are included in one map unit. While the oil shale Parachute Member does outcrop on the LO7 Hill quadrangle, the oil-rich Mahogany Bench interval does not.

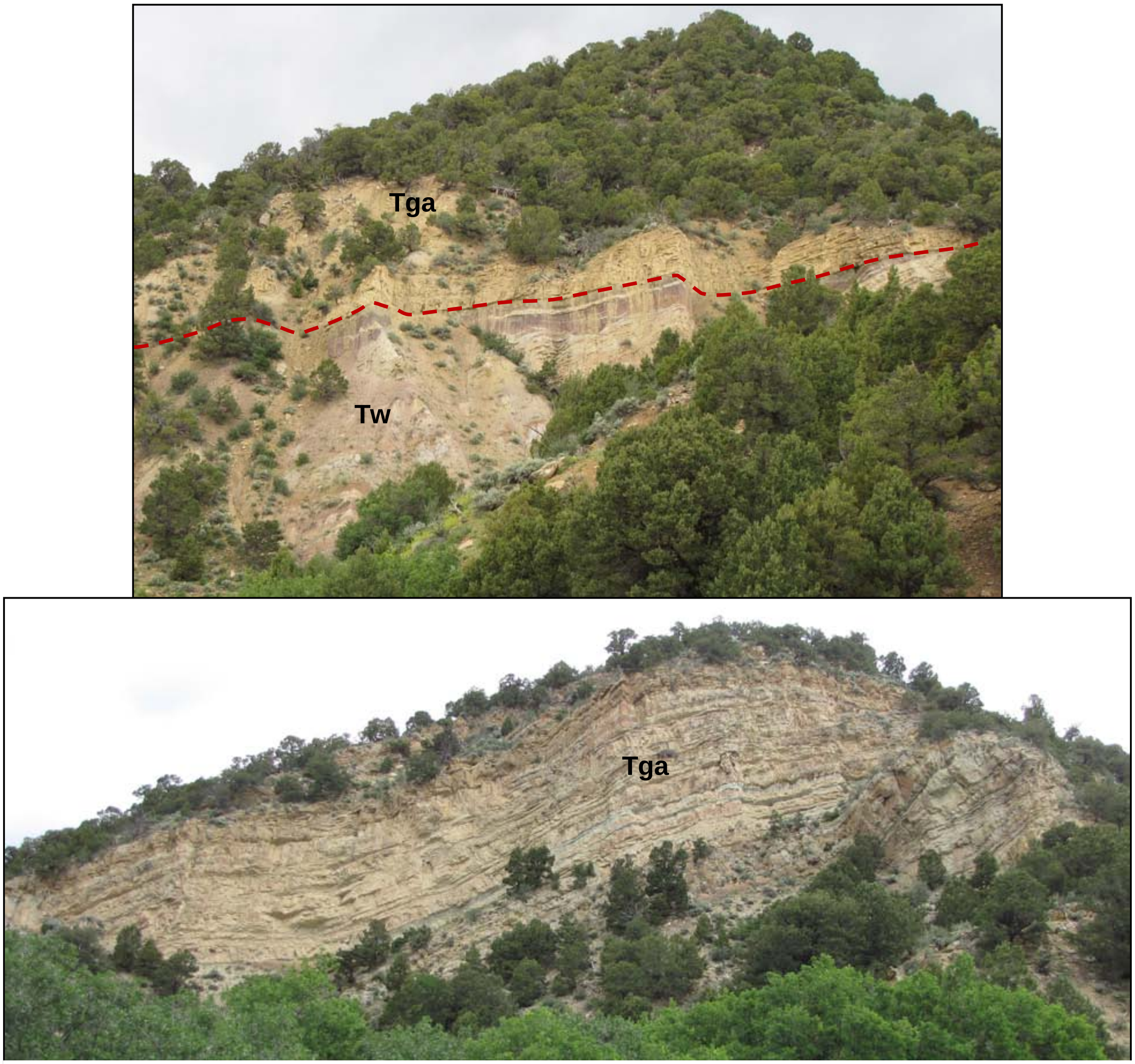


Figure 10. Anvil Points Member of Green River Formation (Tga) at contact with underlying Wasatch Formation (Tw). Note contact of reddish banded mudstone with overlying buff colored sandstone in upper (u) photo. [UTMX 245040, UTMY 4421650] Lower (l) photo shows an exposure of Tga sandstone and thinly interbedded shale above the contact. [UTMX 244880, UTMY 4421290]

Tgp **Parachute Creek Member** — Banded, dark gray marlstone, dark brown oil shale, very dark gray shale, and minor thin beds of orange-tan to gray sandstone and orange-tan tuffaceous siltstone. Brown-gray oil shale and dark-gray shale is finely laminated to papery and weathers light gray where exposed. The prominent banding of the Parachute Creek member is easily seen in aerial photography atop the Tgga escarpment.

Tgga **Garden Gulch and Anvil Points Members (undivided)** — Light gray to tan, thick to thin bedded, fine to coarse-grained sandstone and minor shale predominant the Anvil Points Member at the base of the unit (**Figure 10**). While the gradational, interfingering boundary of the two members was not mapped, the upper portion of the unit is the Garden Gulch equivalent with a finer grained, more off-shore lacustrine environment of deposition: containing lesser amounts of sandstone and more interbedded shale, marlstone, tuffaceous siltstone, silty dolomite, and sporadic thin oil shale beds. Fossil plant and leave fragments, as well as rare insects, were noted. Unit is about 1,800 feet thick and forms the major escarpment of the Piceance Basin along the western edge of the map area. While the contact of the Anvil Points and Garden Gulch Members was not mapped, its approximate location can be seen by a subtle reduction in the slope grade of the escarpment as lithologies changes upwards from predominantly more-resistant sandstone beds of the Anvil Points, to interbedded lithologies of the Garden Gulch.

EARLY TERTIARY ROCKS AND THE K/T DISCONFORMITY

There is some uncertainty in the professional literature with the stratigraphic hierarchy and mapping of early Tertiary Rocks (Ohio Creek, Fort Union, and Wasatch Formations) in the vicinity of Meeker (White and Hodge, 2013). The Fort Union Formation was mapped on the Meeker quadrangle northward from the White River water gap. However, the Fort Union sandstones beds described in White and Hodge (2013) thin towards the White River valley. Southward of the river, the once prominent sandstones are either missing or thinned so as to not be exposed in outcrop. Similarly, the interval of paludal drab-colored olive-brown mudstone, carboniferous shale, and minor lignitic coal is progressively obscured and/or buried by valley fill deposits. This early to middle Paleocene package of rocks was included within the Wasatch Formation south of the White River water gap, and is equivalent to the Atwell Gulch Member mapped near Rifle (Johnson and Florez, 2003). However, the thin but persistent Ohio Creek Conglomerate (Tweto, 1975) remains a distinct and mappable unit and so continues to be separated from basal Wasatch strata on the LO7 Hill quadrangle. This differs from the mapping to the south (O'Sullivan and Smith, 1985; O'Sullivan, 1985; Shroba and Scott, 1997; Shroba and Scott, 2001; and Perry and others, 2003) that includes this conglomerate within the basal sandstone of the Wasatch Formation. In mapping to the north (Pipiringos and Rosenlund, 1977) the conglomerate is included within the basal Fort Union Formation. The Ohio Creek Conglomerate, as it is mapped for LO7 Hill quadrangle, is assumed to be equivalent to the unnamed Paleocene gravel defined by Johnson and Flores (2003). However, palynological analysis of pollen samples recovered for this map indicate that the base of the Ohio Creek is still Late Cretaceous in age (Late Maastrichtian) (**Appendix B**).

WASATCH FORMATION (LOWER PALEOCENE TO EOCENE)

The Wasatch Formation was mapped as a single undivided unit in the LO7 Hill quadrangle map area. The formation is poorly indurated, erodes easily, and forms a low-lying, north-to-south strike valley that Sheep Creek drains between the Grand Hogback and the Green River escarpment (**Figure 2**). Exposures are generally obscured or very poor, except where more resistant channel sandstones form ridges. The unit is usually covered with variable thicknesses of valley fill deposits (Qafo and Qaf), colluvial/alluvial slope-wash (Qaco and Qac), and unmapped regolith and topsoil. The Wasatch Formation was deposited in an initial paludal environment that transitioned to fluvial systems in a broad alluvial plain within the Paleocene to Eocene synorogenic Piceance depositional basin as the Rocky Mountains continued to rise.

Tw **Wasatch Formation** — Banded gray-white, red, reddish tan, pink, yellow-gray, and purple sandy mudstone containing lenses and channels of sandstone. Mudstones are soft, and typically contain reddish paleosol horizons that give outcrops a thickly banded appearance (**Figure 10**). Sandstones are gray-white to orange-tan to tan and range from fine to coarse grained. Sandstone is generally friable but can contain calcareous beds that are more indurated. Noted in the approximate middle of the unit, sandstone beds can contains pebbles up to 4 inches in diameter, both dispersed and in thin conglomeritic lenses. Pebbles are well rounded to rounded white, black, gray, and occasional red chert, as well as petrified wood, andesites, and orange-brown iron-stained clay rip-up clasts. Sandstone beds are predominantly cut-and-fill fluvial channel sandstones with curved bottoms that pinch out within the mudstone. Cross bedding is common. Sandstone outcrops also commonly exhibit soft-sediment deformation. Plant and wood fossil imprints are common, some of which are carbonized (black). The base of the unit that conformably overlies the Ohio Creek Conglomerate is more drab-colored, including olive-gray brown mudstone and carboniferous shale with buff-colored, medium- to coarse-grained sandstone beds that contain ferrous concretions and secondary cementation. Fossil leaves were also noted. This lower unit is equivalent to the Fort Union Formation to the north (Pipiringos and Rosenlund, 1977; White and Hodge, 2013) and the Atkins Gulch Member to the south (Johnson and Flores, 2003). Fossil pollen collected near the base of this unit to the north and south of the map area yielded a diverse assemblage of pollen types that suggest an early to middle Paleocene flora (O'Sullivan and Smith, 1985; White and Hodge, 2013).

OHIO CREEK CONGLOMERATE (UPPER CRETACEOUS TO LOWER PALEOCENE)

TKoc **Ohio Creek Conglomerate** —Tan to gray, well-sorted very-coarse-grained sandstone with dispersed gravel with common beds and lenses of pebble to cobble conglomerate. Unit is generally well cemented and, along the inclined bedding of the Grand Hogback, forms a prominent north to south ridgeline through the map area. Clasts are well rounded, multicolored, and include black, gray, red, and white chert, tan to brown petrified wood, and pink to red andesites. Also fairly common were white to pink quartzites and arkosic quartzites that have been identified by the authors as originating from the Cambrian Sawatch Quartzite.

While less common, early Paleozoic and Precambrian pebbles were also identified, including crystalline metamorphic and granitic igneous rocks and early Paleozoic silicified algal limestone. Rare fossil bones fragments were also seen as clasts in the conglomerate. One of which was tentatively identified from photo as reptilian (Joe Sertich, written communication) (**Figure 11).** This unit scoured into and disconformably overlies the Williams Fork Formation **(Figure 12**). The conglomeritic unit was measured at a maximum thickness of 85 feet but is typically around 65 feet. Pollen recovered from a thin shaly seam located in the basal 3 feet of the conglomerate shown in top left photo of Figure 12 was identified to contain Late Maastrichtian palynomorphs (D. Kline, written communication, **Appendix B**). Nearby, pollen sampled in basal Wasatch mudstone strata within just a few feet of the conglomerate top yielded early to middle Paleocene dates (O'Sullivan and Smith, 1985; White and Hodge, 2013).

Figure 11. Conglomerate of the Ohio Creek (TKoc). Exposures are of the base of the unit that is dipping near vertically along the Grand Hogback. Reptilian bone is shown just right of pen in upper left photo. [UTMX 246020, UTMY 4427980]

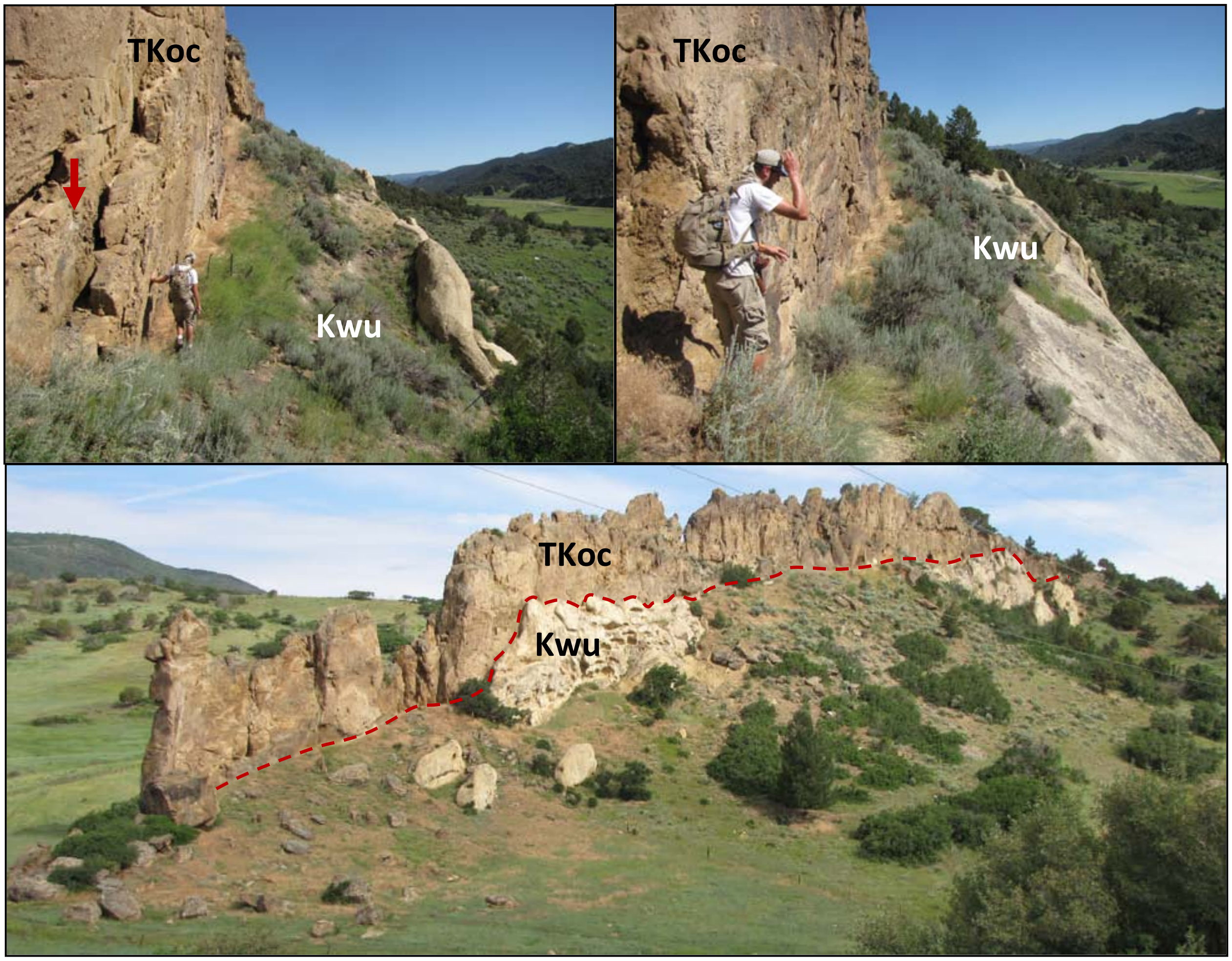


Figure 12. Ridge outcrop of near-vertical Ohio Creek Conglomerate (TKoc). Person in upper (u) left photo has hand on TKoc at the basal disconformable contact with underlying upper Williams Fork (Kwu) mudstone. Red arrow is location of shale seam where sample # 1302 was take for palynological analysis. Note mudstone thickness below contact and proximity to bed of gray-white sandstone [UTMX 246020, UTMY 4427020]. In top right photo taken about 400 feet to north, mudstone has thinned [UTMX 246010, UTMY 4427130]. In lower (l) photo taken 1 mile to south of first photo, the mudstone is missing and the TKoc unit has scoured into the gray-white Kwu sandstone (red dashed line) [UTMX 246080, UTMY 4424890].

WILLIAMS FORK FORMATION (UPPER CRETACEOUS)

The Williams Fork Formation is the youngest formation of the Mesaverde Group that forms the Grand Hogback. It was deposited in terrestrial coastal plain and near-shore estuary environments. In the LO7 Hill quadrangle map area the Williams Fork Formation has been subdivided into an upper unit (Kwu), the Lion Canyon Sandstone Member (Kwlc), and a lower unit (Kwl). The Lewis shale is not present in the Meeker area as the Cretaceous sea was further northeast. The seaway transgressed to the Meeker area only briefly, which is marked by shore face and marine units of the Lion Canyon Sandstone on the Meeker quadrangle (White and Hodge, 2013). The Lance Formation is time equivalent to the upper unit of the Williams Fork Formation above the Fox Hills Sandstone (upper Lion Canyon Sandstone equivalent) in the Yampa Coal Field (Brownfield and others, 2000). Palynological data in Newman (1965) strongly suggest a biochronologic correlation between the lower Lance Formation near Hayden and the upper Williams Fork near Meeker. The last Late Cretaceous transgressive flooding in the Meeker area extended westward only to the LO7 Hill quadrangle. The Lion Canyon Sandstone very rapidly pinches out southward and disappears as a mappable unit along the hogback. Where it becomes indeterminate the Williams Fork Formation is mapped as a single undivided formation (Kw).

Kwu **Williams Fork Formation, upper unit** — Interbedded gray to dark gray mudstone, buff to tan sandstone, brown carbonaceous shale, and minor coal deposited in terrestrial near-shore and coastal-plain environments. This unit correlates with the Lance Formation to the northeast, across the Axial Basin Uplift. The top of this unit has been differentially eroded prior to the disconformable deposition of the Ohio Creek Conglomerate (**Figure 12**). At the base of the unit near the contact with the Lion Canyon Sandstone Member, a package of coal seams are poorly exposed. Hancock and Eby (1930) named these coal seams the Lion Canyon coal group.

Kwlc **Lion Canyon Sandstone Member** — To the north, the Lion Canyon Sandstone was divided into three units; thick upper and lower sandstone units separated by a middle, thinly interbedded sandstone and shale interval (White and Hodge, 2013). The upper progradational sandstone of this unit correlates with the Fox Hills Sandstone across the Axial Basin Uplift and the shaly middle interval, correlates as the westward terminus of the Lewis Shale marine transgression (Brownfield and others, 2000). On the LO7 Hill quadrangle, the middle interval is missing and the sandstone units have thickened. The Lion Canyon Sandstone is a massive sandstone unit over 300 feet in thickness where it is exposed along Highway 13. However, this entire sandstone-facies package quickly pinches out southward. Midway in the quadrangle where the unit becomes obscured and covered by Sheep Creek valley fill (Qaf), it apparently thins out, becomes indeterminate within the greater Williams Fork Formation, and ceased to become a mappable unit.

Where visible along Highway 13, the well-sorted cross-stratified, thick bedded to massive, sandstone contains a middle interval that is less indurated and weathers to more rounded slopes. Access was not available to the authors to examine the outcrop near Highway 13. Northward the unit was eroded by Sheep Creek and buried by thick valley fill (Qaf).

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 the Trout Creek Sandstone (Kit) of the Iles Formation. 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 (**Figure 13**). 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 Group along the Grand Hogback. Above the clinker zone, the lower unit becomes increasingly finer-grained mudstone with fewer and thinner sandstone beds. This interval is prone to instability. As a result, overturned creep zones and thin-skinned landslides are very common where near-vertical Kwl strata are exposed adjacent to Sheep Creek valley.

Figure 13. Grand Hogback exposure of Fairfield coal seams and red-colored Fairfield Coal Group Clinker Zone in the upper Williams Fork (Kwu). Underlying dipslope exposure in lower right corner is the Trout Creek Sandstone Member of the Iles Formation (Kit). Green middle-background valley is Powell Park along the White River. [UTMX 247900, UTMY 4430900]

Kw **Williams Fork Formation, undivided** — This unit corresponds to the entire Williams Formation southward from where the Lion Canyon Sandstone member pinches out and the upper and lower units of the Williams Formation could not be recognized in the field as separate mappable units.

ILES FORMATION (LATE CRETACEOUS)

The Iles Formations is the oldest of the Mesaverde Group of Upper Cretaceous rocks. The thick sandstone units of the Iles Formation mark the eastern edge of the Grand Hogback ridgeline above Meeker (White and Hodge, 2013) and also form the east escarpment of the Grand Hogback in the LO7 Hill quadrangle map area. The Iles Formation records a major depositional cycle where sediments changed from shallow-marine lithofacies to progradation shoreface and coastal-plain lithofacies, and then back to a marine depositional setting. This cycle reflects a major regression and transgression sequence of the Cretaceous Western Interior Seaway. 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. Estuary and swamp conditions occurred where coal could form. Marine, interbedded shale and sand sediments below the Trout Creek Sandstone Member mark 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 sandstone 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.

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, ripple-marked sandstone interbedded with mudstone that becomes 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 above Meeker. The coal zone is referred to as the "Lower Coal Group" by Hancock and Eby (1930). The upper section of the Iles is finer grained that reflects a cyclic coastal swamp, tidal-influenced estuary, and lower-energy fluvial environments. Sandstone beds are thinner, becoming interlaminated with mudstone. Some thicker sandstones 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) after the Black Diamond Coal Mine near the town of Meeker. Sporadic red clinker zones also occur in the upper section of the Iles related to burning of these coal beds. The Iles Formation becomes increasingly shaly 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 (**Figure 3**), except for the southern quarter of the quadrangle where it is poorly exposed, and probably disturbed or missing where faulted out by the Twelve Mile Fault complex (Murray, 1966).

MANCOS SHALE (LATE CRETACEOUS)

The Mancos Shale was deposited during the marine transgression of the Cretaceous North American Western Interior seaway with member formations deposited in various deep shelf, shelf-bar, and near shore environments (Warner, 1964; Boyles and others, 1981). Members mapped within the Mancos

Shale include the Mowry, Frontier, Smoky Hill, Prairie Canyon, Upper Mancos, and the Morapas Sandstone. 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. In the southern part of the quadrangle the shale facies of the Frontier and the Mowry shale were obscured and mapped as one unit. The Loyd, and Duffy Mountain sandstones mapped in the Meeker and Rattlesnake quadrangles (White and Hodge, 2013; White and others, 2013) were not mapped on this quadrangle. The Meeker Sandstone becomes increasingly shaly with much thinner sandstone beds and lost much of its distinctiveness within the sandy Prairie Canyon member. A map line trace approximates the Meeker unit, which is the sandiest interval of the Prairie Canyon Member. The Loyd Sandstone was only identified in a couple of gully exposures, the locations of which are shown as map points. It could not be reliably traced along the inside of the hogback below the Iles/Mancos contact. The Duffy Mountain sandstone was not recognized and is either buried under surficial deposits or the unit pinches out and does not occur in the map area.

Surface exposures of the Mancos Shale were generally poor on the LO7 Hill quadrangle because the shale is easily eroded and there is widespread cover of regolith or Quaternary deposits. For most units, there are diagnostic lithologic changes where unit boundaries were 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.

The Mancos Shale commonly contains bentonite seams and high percentages of smectite clay. These types of clay are expansive and can shrink or swell depending on moisture content. The shale and clay soils derived from the Mancos Shale are well known for its swelling-soil geologic hazard.

Kmu **Mancos Shale, upper unit** — Gray to dark-gray, platey to subblocky, noncalcareous shale with minor sandstone and orange-tan limy fossilifereous concretions. This unit is undifferentiated marine 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 Morapas. Only the Morapas Sandstone was mapped on the LO7 Hill quadrangle though two locations where Loyd Sandstone was verified are shown on the map as points. In the lower half of the map quadrangle, the upper Mancos Shale interval that is exposed has been thinned by an interpreted, along-strike thrust fault. The upper Mancos Shale commonly contains expansive clay minerals.

Kmlo **Loyd Sandstone Member** — The fine-grained Loyd Sandstone is distinctive in its green-gray color, having abundant orange-brown fossiliferous concretions, and being friable with the lower massive-bedded section typically weathering to a spheroidal to lumpy appearance in outcrop (Dyni and Cullins, 1965; White and Hodge, 2013, White and others, 2013). The Loyd Sandstone is mostly obscured by colluvial cover from the Iles Formation escarpment above and does not outcrop except in freshly scoured gullies. However, two outcrop locations were verified. Shown on the map as points, it reveals that the unit does extend through the entire quadrangle map area.

Kmmo **Morapas Sandstone Member** — Tan to buff to tan-gray, slightly calcareous, marine sandstone that occurs as an upward coarsening sequence. Near Meeker there are two coarsening-upwards sequences (White and Hodge, 2013). Up section, the shale transitions to bioturbated silty to sandy mudstone interlaminated with poorly to moderately sorted, very fine-grained sandstone and sandy mudstone. Continuing 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. There are common mud rip-up clasts in the coarser sandstone intervals. The Morapas crops out sporadically in the LO7 Hill quad but was positively identified along the strike valley of Flag Creek from the northern to southern borders of the quadrangle. A portion of the southern part of the map where the sandstone is missing is attributed to faulting along an on-strike, thrust fault, that has been interpreted to lie in the Flag Creek valley. The Morapas Sandstone is wholly enclosed within the upper Mancos Shale. It has been interpreted to have been deposited in a marine shelf-bar environment (Boyles and others, 1981).

Kmp **Prairie Canyon Member** — Dark gray to tan-gray, noncalcareous, platey, sandy to silty, bioturbated marine shale with interlaminated, 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. Ripples form lenticular "pinch and swell" structures. Marine mollusk fossil fragments are rare. Invertebrate animal-burrow and surface track ichnofossils are common in the sandstone beds. The Prairie Canyon Member is characterized by very fine-grained sandstone-lamina chips in ground exposures. This abundance of sandstone chips are not seen in the underlying Smoky Hill Member or the overlying, undifferentiated upper Mancos Shale. Where the sandstone beds thicken, there is an increase in topographic relief (low hills). At those locations, small (<6" diameter) slabs of thin sandstone typically litter the slopes. There is a subtle hump in topography along the Flag Creek valley where the Meeker Sandstone beds occur. Top and basal contacts of the Prairie Canyon were obscured on the LO7 Hill 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), the Prairie Canyon Member (Cole and others, 1997) in the Book Cliffs, and to the Cortez Member (Leckie and others, 1997) in southwestern Colorado.

Kms **Meeker Sandstone Member** — The Meeker Sandstone, described by Dyni and Cullins (1965), was mapped on the Meeker quadrangle (White and Hodge, 2013) but is only shown as a line trace on this map where the higher percentage of very thinly bedded to interlaminated, very fine grained, sandstone occurs. The Meeker sandstone equivalent is wholly enclosed, stratigraphically, within the Prairie Canyon Member, and because of the thinning of the sandstone beds, poor exposure, and apparent gradation into the surrounding sand-laminated lithology of the Prairie Canyon, unit boundaries were not discerned. Southward in the map area, the Meeker sandstone lithofacie become indistinguishable within the sandy Prairie Canyon unit.

Kms **Smoky Hill Member** — Light gray to very dark gray, calcareous shale, marlstone, and shaly 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, relatively homogeneous, fissile to platy, shale with common *Inoceramus sp.* fragments; the larger fragments of which are typically encrusted with *Pseudoperna congesta* oysters. Thin bentonite beds occur and there can be stratigraphic intervals with high percentages of swelling-clay minerals. In the middle and lower intervals, the shale becomes increasingly limy and chalky. Where limy, the shale exposures become increasingly blocky and weathers with a subspheroidal appearance. Limestone beds have a speckled appearance from ostracoda microfossils. The last prominent limestone bed near the base of the unit is considered the Fort Hays Limestone equivalent 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 Carlisle Shale along the Front Range.

This Smoky Hill Member is stratigraphically equivalent to the Niobrara Formation along the Front Range, which includes the upper Smoky Hill member, the Niobrara Limestone, and the basal Fort Hays limestone. The depositional environment of this unit is considered the deeper shelf of the Cretaceous Western Interior Seaway. The larger inoceramid fossil fragments in the Smoky Hill are petroliferous and breaking the shell fragments to reveal the prismatic crystalline structure also releases a strong oil odor. The limy interval is 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.

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 top unit is in conformable contact with the overlying Smoky Hill Member and marks the first occurrence of thin beds of fossil-hash sandy calcarenite and very calcareous, gray to gray-brown, fossiliferous sandstone. 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. A cast of one ammonite was 8 inches in diameter. *Prionocyclus sp*., *Lopha lugubris*, and *Inocermid sp.*, were identified, which indicates 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 fossil assemblage of the Juana Lopez Member described in the Uncompahgre and Gunnison valleys (White and others, 2009, and Noe and others, in prep.).

With stratigraphic depth in the middle interval, the calcarenite and calcarenitic sandstone are replaced by thicker beds of tan to tan-gray, well sorted, fine to medium grained, non-to-moderately calcareous, marine sandstone. 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, may contains oscillating ripple marks, and locally abundant marine invertebrate track and burrow ichnofossils. Flute-cast 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* were still noted. With increasing depth 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 limy concretions occur near the contact of the sandstone and shale facies (**Figure 14**). These limy concretions, up to 5 feet in long diameter, exhibit radial cone-in-cone structure. The Frontier sandstone is found in the LO7 Hill quadrangle as dip-slope ridgelines forming cuestas that rim the plunging LO7 Hill anticline and along the Entrada/Glen Canyon ridgeline to the south, except where covered and obscured by landslide deposits.

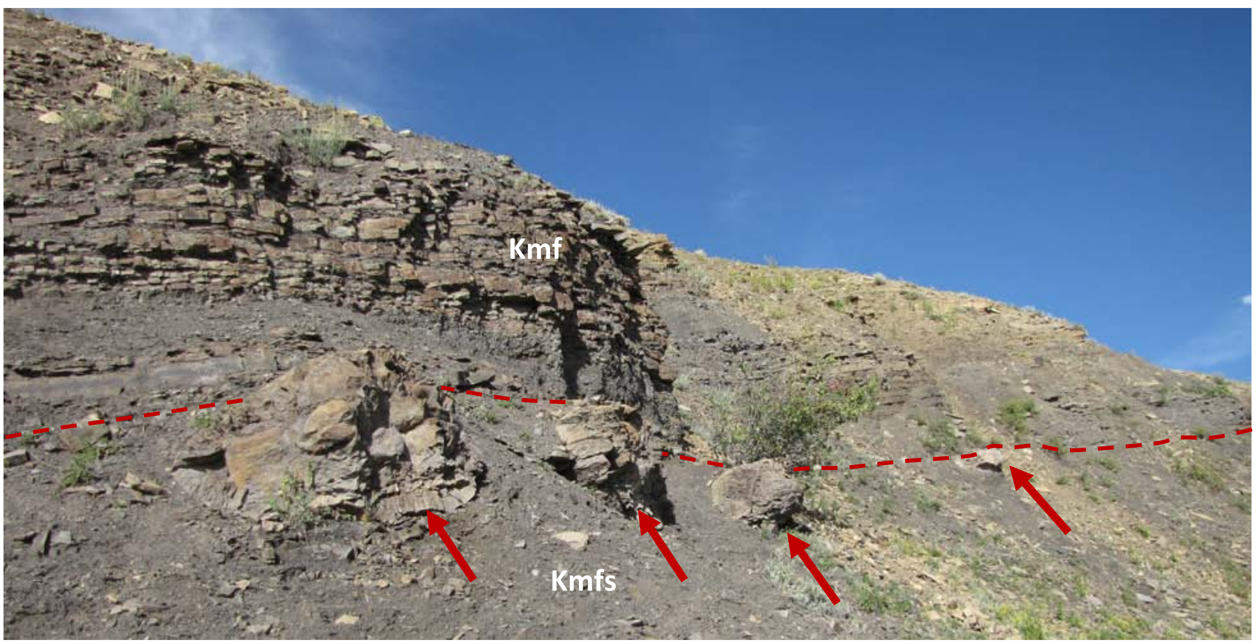


Figure 14. Prominent concretion horizon below contact of Frontier sandstone facies (Kmf) and shale facies (Kmfs). Contact is shown by red dashed lines. Concretions by red arrows. Note radial structure in closest concretion. [UTMX 251930, UTMY 4431400]

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 where the slope is poorly vegetated. This thick shale is poorly indurated, and the finely fissile fabric quickly crumbles so it outcrops as smoothed, rounded, poorly vegetated, slopes. Near the base of the unit, there are infrequent thin beds of hard siliceous shale. 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 a steeper slope littered by small (>1½ inch) Mowry blocks.

Kmm **Mowry Shale Member** — Dark gray to brown-gray, hard, siliceous shale interlaminated with light-gray coarse siltstone to very-fine-grained sandstone. In outcrop certain intervals of the shale can weather with a silvery sheen. Tight joint spacing causes the thinly bedded and hard Mowry to break into small orthogonal blocks. These 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-stained bentonite and soft, fine-fissile shale. The light-gray interlaminated silt and very-fine-grained sand give the Mowry a thinly banded appearance in hand samples. These light-colored bands can be cross laminated, or distorted, pinched, even swirled, by both soft-sediment deformation and bioturbation. The Mowry top was picked where the blocky siliceous shale predominated in outcrop.

Kmfm **Frontier Member (shale facies) and Mowry Shale -undivided**— Map unit in the southern part of the quadrangle where the contact between the two shale units was obscured and could not be reliable determined.

DAKOTA SANDSTONE (LOWER CRETACEOUS)

The Dakota Sandstone was mapped as a single formation for the LO7 Hill quadrangle map. In the literature, many authors have given the Dakota group status, and have named the Dakota Sandstone and underlying Cedar Mountain/Burro Canyon as member formations. The entire Dakota Group was seen in outcrops as three main sandstone units divided by two shaly units. The Dakota Sandstone package consists of an upper sandstone unit, a middle dark-gray shaly unit, and a lower conglomeritic sandstone unit that marks an erosional disconformity with underlying strata. Two lower lithofacie packages indicative of the Cedar Mountain were sporadically observed in the LO7 Hill quadrangle: a distinctive green-gray shale unit and a basal, sometimes conglomeritic, sandstone unit (Buckhorn Conglomerate), which also disconformably overlies the Morrison Formation.

The sandstones in the Dakota are brittle and thus are highly fractured and jointed in the map area. Hardness can also vary widely, from very-hard, blocky orthoquartzites to friable sandstone prone to differential erosion and a rounded "slickrock" appearance. There are also abundant shear zones (some with little or no vertical displacement) with slickensides and deformation banding. Secondary chert replacement was also noted in sandstone strata of the Dakota. Outcrops of the unit are best preserved on lower ridgelines at water gaps such as East Fork Flag Creek. Along the Entrada/Glen Canyon ridgeline, it is usually poorly exposed, disturbed, or occurs as remnants within landslide rubble.

Kd **Dakota Sandstone** — The formation top was picked where a 2-foot-thick, buff-colored fine- to medium-grained sandstone bed occurs within increasingly sandy, laminated siltstone at the conformable base of the Mowry Shale. The top major sandstone unit is about 30 feet thick, buff to gray-white to orange-tan, medium grained, siliceous, and cross bedded. Bed thickness transitions from medium to massive with depth. The second unit is a finer-grained unit composed of dark gray to gray-black, sometime carbonaceous shale and mudstone that is interbedded with finer-grained thin-bedded sandstone. The third unit is the second major sandstone that is about 25 feet thick, buff to orange brown to brown in color with common staining giving a reddish brown to pink or yellow-tan hue. The sandstone is medium-bedded, siliceous, is commonly planar to trough cross bedded, and is medium to very coarse grained with lenses and thin beds of chert-pebble (<1 inch diameter) conglomerate. A disconformity marks the base of the conglomeratic sandstone and the top of the underlying Cedar Mountain Member. This forth unit is a green to dark green-gray shale with finer grained, thinly interbedded, gray-tan sandstone. Within this unit is an odd calcrete horizon that contains near-spherical purplish green to green-gray nodules composed of radial-form crystalline calcium carbonate. Typically they occur in globular clusters the size of a bunch of grapes, but some individual nodules can be upwards of 10 inches in diameter (**Figure 15**). Currie (1998) has interpreted this calcrete horizon as an ancient calcic paleosol. The lowest, and third major sandstone is about 25 feet thick, thin to thickly bedded, and cross bedded. It also becomes very coarse grained and rarely contains sporadic lenses of chert-pebble conglomerate.

Figure 15. Large calcium-carbonate nodule from the lower Cedar Mountain equivalent unit within the Dakota Sandstone. [UTMX 251040, UTMY 4424340]

MORRISON FORMATION, UNDIVIDED (UPPER JURASSIC)

Jm **Morrison Formation** — Interbedded shale, mudstone, and thin sandstone and limestone beds. The upper part of the unit, approximately 165 feet thick, is equivalent to the Brushy Basin Member and is typically a range of colors from maroon red, dark green-gray, lavender-gray, and light reddish-gray. The shale/mudstone may contain very hard siliceous beds and fine grained, coarse grained, to sometimes gritty, sandstone beds 2-3 feet thick, as well as thin beds of dark gray to green-gray micritic limestone. The lower half of the unit is likely equivalent to the Salt Wash Member, as it contains thicker gray-white, very fine- to fine-grained sandstone beds that are interbedded with minor variably-colored green-gray to maroon-red mudstone. No evidence of the Curtis Formation was observed in the LO7 Hill quadrangle map area.

ENTRADA AND GLEN CANYON SANDSTONE - UNDIVIDED (JURASSIC AND TRIASSIC)

The top of the Entrada Sandstone was identified by the cessation of the variegated-colored mudstone beds of the Morrison Formation and the change to large-scale, cross-bedded eolian sandstone. While a contact between the Entrada and the Glen Canyon was not discerned or mapped there are some diagnostic differences. The Entrada Sandstone is generally more friable and outcrops as a slope while the Glen Canyon is hard, more resistant, and forms the edge of the major topographic ridgeline (**Figure 2**).

JŦeg **Entrada Sandstone and Glen Canyon Group Sandstone** — Cream to pale orange to peach colored, fine-grained well-sorted sandstone. The sandstone is massively bedded but exhibits cross bedding that is indicative of eolian dune-depositional environments. The upper Entrada-equivalent portion of the unit is generally peach colored but weathers to a lighter gray-white color, and is generally more friable. The dune cross bedding is also smaller scale, including tough and planar sets (**Figure 16**). The lower Glen Canyon-equivalent rocks have larger-scale cross-bed dune sets with long sweeping foresets, are buff colored, much harder, and easily split along bedding foresets. Good quality dimension stone has been quarried from this unit in the map area. Exposures in the major quarry reveal dune ripple marks, large-scale cross-bed sets, as well as prominent mineral staining in the form of joint-controlled dendrites and liesegang bands (**Figure 17**). Also observed in quarry rock was the presence of a dunal ichnofacies where both insect (*Diplichnites)* and vertebrate trackways were observed (**Figure 18**). Observed ichnofossils are comparable to those collected and described by Faul and Roberts (1951) in the same geologic unit, which they had named with uncertainty as being the Navajo Sandstone.

Figure 16. Typical exposures of Entrada Sandstone in JŦeg unit. Note smaller scale cross bedding compared to Figure 17. [UTMX 252150, UTMY 4424440]

Figure 17. Lower Glen Canyon Group sandstone of JTeg map unit A) Quarry location on JTeg ridgeline looking south. Note flaggy nature of dune foresets in natural outcrop (foreground) and within quarry. B) Red dashed line marks contact of large-scale dune sets. Note how slabs are detaching along foresets. C) Joint-controlled liesegang bands in quarry exposure. D) Dendrites along jointing. E) Rock block illustrating 3D geometry of liesegang bands. [UTMX 251820, UTMY 4418600]

Figure 18. Ichnofossils collected in the Glen Canyon sandstone. Top left image shows two sets of arthropod tracks. Bottom left image has various tetrapod tracks, the best preserved are shown in close up to the right. [UTMX 251820, UTMY 4418600]

CHINLE FORMATION, UNDIVIDED (UPPER TRIASSIC)

The top of the distinctively red Chinle Formation can be easily discerned in outcrop from the peach to tan colored cliff-forming Entrada and Glen Canyon sandstones (J₸eg) above (**Figure 4**), except where buried by scree slopes. The disconformable contact of the Chinle and the Moenkopi is more problematic to map, especially in vegetated slope areas, since the red color is very similar. However, near the base of the Chinle is a very resistant chert replacement bed and approximately 30 feet below that, a basal bed of conglomeritic sandstone. Both of these lower units are more resistant to weathering and form a subtle slope break above Red Canyon that, to the south, becomes a perceptible on-strike lineation in the vegetated slope below the steeply-dipping Entrada/Glen Canyon sandstone ridgeline.

Ꞧc **Chinle Formation** — Red to maroon-red micaceous siltstone, shale, and mudstone with minor sandstone, limestone and dolomite. The upper thicker part of the formation is referred to as the red siltstone member by Stewart and others (1972). About 125 feet from the top there is a prominent gray white to pink bed of dolomite. Approximately 50 feet below that, the unit contains a prominent 3-foot thick bed of light red to reddish gray, limestone pebble conglomerate that contains white calcium carbonate-filled fractures (**Figure 19**). This bed is laterally discontinuous and interbedded with red limy mudstone. Below the limestone conglomerate the unit contains red coarse siltstone to very fine sandstone beds that form ledges. The base of the unit is known as the mottled member by Stewart and others, 1972). The mudstone becomes increasingly mottled downward with streaks of gray, purple-gray, and green-gray. The mudstone also becomes increasingly micaceous and contains more sand. Most prominent in outcrop is a thin (<2 feet), very hard, silicified algal limestone that is mostly exposed as an irregular bed of secondary, vuggy, translucent to opaque chert that ranges in color from gray, white, and yellow to red (**Figure 20**). The basal sandstone bed is the Gartra Member (Stewart and others, 1972) and is variably streaked to mottled colored (cream, pink, lavender, and green-gray), medium to very coarse

Figure 19. Limestone pebble conglomerate in the Chinle Formation. Lower photo is a close-up view. [UTMX 252820, UTMY 4424530]

grained, and interbedded to interlaminated with red micaceous mudstone. It is cross-bedded and sometimes conglomeritic, containing rip-up clasts and dispersed quartz and chert pebbles (≤1 inch).

Figure 20. Block from chert bed in lower Chinle Formation. Dropper bottle for scale is approximately 4 inches tall. [UTMX 253930, UTMY 4425000]

MOENKOPI FORMATION AND UNDIVIDED PERMIAN ROCKS (LOWER TRIASSIC- PERMIAN)

The stratigraphic nomenclature of the Permo-Triassic redbeds in the Meeker area is uncertain. Both the Moenkopi Formation and State Bridge Formation have been referenced in the literature for this stratigraphic interval in this area, depending on the direction of the study from either Central Colorado or Northeast Utah/Uinta Mountains. Outside of the map area, other workers, as well as formation picks in the oil and gas industry, have also separated strata of the Phosphoria and Park City Formations. This map uses the same nomenclature by Reheis (1984) in the nearby Sawmill Mountain Quadrangle geologic map to the northeast. South of the White River Uplift, the State Bridge Formation name is used for the same correlatable rock package (Kirkham and others, 1997; Bryant and others, 2002; and Perry and others, 2003).

ҬPm **Moenkopi Formation and undivided Permian rocks** — Red to lavender red, sometimes mottled green-gray, ripple marked, interlaminated to interbedded siltstone, mudstone, and shale with sandstone, algal limestone, and dolomite beds. The upper half is predominantly red to lavender-red to brown-red, thick- to thinly-bedded siltstone, mudstone, and shale with occasional thin beds of light gray to buff to light reddish tan, very fine-grained sandstone. Within the thinly interbedded to interlaminated zones, wavy (pinch-swell) or flaser bed forms and green-gray shale parting are common. The lower half of the unit contains intervals of rocks that are lighter colored, light gray to buff to light reddish tan. The most prominent band, 65-80 feet thick, is easily seen in the predominantly red formation. It is composed of an upper 8- to 10-foot-thick, fine- to very-fine-grained, noncalcareous, thin-to-medium-bedded, ledge-forming sandstone that overlies a thick package of light gray to tan-gray calcareous siltstone and mudstone. Near the base of this light colored unit is a ledgy 3-foot thick, light tan-gray, algal limestone bed. The lower part of the map unit contains additional mottled red, green-gray, to light tan-gray mudstone. The base of the unit is marked by another 3-foot thick, silty, lumpy-bedded algal limestone bed overlying a 5-foot bed of gray shale that is in contact with the underlying Weber Sandstone.

WEBER SANDSTONE (LOWER PERMIAN)

The Weber Sandstone is given formation status in the LO7 Hill quadrangle. On the south side of the White River Uplift along the Grand Hogback, this unit is mapped as the Schoolhouse Tongue member of the Maroon Formation (Scott and others, 2001; Bryant and others, 2002). The Weber Sandstone contains both eolian and fluvial depositional intervals.

Pw **Weber Sandstone** — Gray-white to light tan, very fine- to coarse-grained, well sorted, cross-bedded, sometimes calcareous sandstone. Unit commonly contains dune crossbedding but transitions upwards to thinner planar cross bedding more indicative of fluvial environments. Upper part is interbedded with marked differences in grain size. Beds can be very fine grained, to coarse grained with thin, granule to very fine pebble, conglomeritic lenses. Unit can be gray to dark gray where there is abundant dead oil staining (**Figure 21**). Those rocks release a strong petroliferous odor when freshly broken. Unit thickness was measured at 120 feet.

Figure 21. Exposure of Weber Sandstone along Red Canyon road (CR 74). Inset photo on left shows bands of heavy dark-gray oil staining. [UTMX 252640, UTMY 4423600]

MAROON FORMATION (LOWER PERMIAN - PENNSYLVANIAN)

The oldest formation exposed on the LO7 Hill quadrangle is the Maroon Formation that exists in the southeast corner of the quadrangle. The unit is best exposed along East Fork Flag Creek and its upper tributaries, and the high hills above Hay Flats Trail in the White River National Forest.

PPm **Maroon Formation** — Red, brown-red, pink, and maroon, fine to very coarse-grained beds of arkosic sandstone and micaceous mudstone, interbedded with red shale and pebble to cobble conglomerate. The conglomerate contains well-rounded quartz, chert, and Precambrian igneous and metamorphic clasts up to 6 inches diameter along long axis. Upwards of 400 feet of Maroon Formation is exposed on LO7 Hill quadrangle along East Fork Flag Creek. However, the base of the formation does not occur on the map. Murray (1966) reports a total thickness of about 1,600 feet from an oil and gas well log drilled on Meeker Dome to the north.

OLDER BEDROCK UNIT SHOWN ON GEOLOGIC CROSS SECTION

Cross Section A-A' runs along the southern part of the quadrangle from near the southwest corner of the quadrangle to the east boundary, through the Grand Hogback and onto the western flank of the White River Uplift. The cross section is shown on **Plate 2**. Additional older bedrock units that do not crop out within the quadrangle are included as a single subsurface unit on the cross section.

Lower Paleozoic Rocks — Undivided unit that includes the Pennsylvanian Morgan/Minturn Formation, Eagle Valley Evaporite, the Belden Shale, and possibly the Mississippian Leadville Limestone and Devonian rocks.

REFERENCES

Boyles, J.M., Kauffman, E.G., Kiteley, L. W., and Scott A.J., 1981, Depositional systems, Upper Cretaceous Mancos Shale and Mesaverde Group, Northwestern Colorado, 1981 Fall field trip guidebook: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists.

Brownfield, M.E., Roberts, L.N.R., Johnson, E.A., and Mercier, T.J., 2000, Assessment of the Distribution and Resources of Coal in the Fairfield Coal Group of the Williams Fork Formation, Danforth Hills Coal Field, Northwest Colorado, Chapter M, *in* Kirschbaum, M. A., Roberts, L.N.R., and Biewick, L.R.H., eds., Geologic Assessment of Coal in the Colorado Plateau: Arizona, Colorado, New Mexico, and Utah, compiled by Colorado Plateau Coal Assessment Group: U.S. Geological Survey Professional Paper 1625-B, Version 1.0, pp. M1-M28. [CD-ROM].

Bryant, B., Shroba, R.R., Harding, A.E., and Murray, K.E., 2002, Geologic map of the Storm King Mountain quadrangle, Garfield County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-2389, Scale 1:24,000.

Boyles, J.M., Kauffman, E.G., Kiteley, L. W., and Scott A.J., 1981, Depositional systems, Upper Cretaceous Mancos Shale and Mesaverde Group, Northwestern Colorado, 1981 Fall field trip Guidebook: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists.

Cole, R.D., Young, R.G., and Willis, G.C., 1997, The Prairie Canyon Member, a new unit of the Upper Cretaceous Mancos Shale, west-central Colorado and east-central Utah: Utah Geological Survey, Miscellaneous Publication 97-4, 23 p.

Collins, B.A., 1976, Coal deposits of the Carbondale, Grand Hogback, and southern Danforth Hills coal fields, eastern Piceance Basin, Colorado: Quarterly of the Colorado School of Mines, v. 71, no.1, 138 p.

Currie, B.S., 1998, Upper Jurassic-Lower Cretaceous Morrison and Cedar Mountain Formations, NE Utah-NW Colorado: Relationships between nonmarine deposition and early Cordilleran foreland-basin development, Journal of Sedimentary Research, Vol. 68, No. 4, p. 632-652.

Dyni, J.R. and Cullins, H.L., 1965, Meeker and Loyd sandstone members of the Mancos Shale, Moffat and Rio Blanco Counties, Colorado: U.S. Geological Survey Bulletin 1194-J, 7 p.

Faul, H., and Roberts, W.A., 1951, New fossil footprints from the Navajo(?) Sandstone of Colorado: Journal of Paleontology, Vol. 25, No. 3, pp. 266-274.

Fenneman, N.M. and Johnson, D.W., 1946, Physiographic divisions of the conterminous U. S. : U.S. Geological Survey special map series, scale 1:7,000,000.

Hancock, E.T., and Eby, J.B., 1930, Geology and coal resources of the Meeker quadrangle, Moffat and Rio Blanco Counties, Colorado: U.S. Geological Survey Bulletin 812-C, p. 191-242, 1 plate, scale 1:62,500.

Kellogg, H.E., 1977, Geology and petroleum of the Mancos B Formation, Douglas Creek Arch, Colorado and Utah, *in* Veal, H.K., ed., Exploration Frontiers of the Central and Southern Rockies: Rocky Mountain Association of Geologists, p. 167-179.

Leckie, R.M., Kirkland, J.I., and Elder, W.P., 1997, Stratigraphic framework and correlation of a principal reference section of the Mancos Shale (Upper Cretaceous), Mesa Verde, Colorado: New Mexico Geological Society Guidebook 48, p. 163-216.

Murray, F.N., 1962, Geology of the Grand Hogback Monocline near Meeker, Colorado: Boulder, Co, University of Colorado, unpublished M.S. thesis.

Murray, F.N., 1966, Stratigraphy and structural geology of the Grand Hogback Monocline, Colorado: Boulder, Colo., University of Colorado, unpublished Ph.D. dissertation, 219 p., 2 plates, scale 1:63,360.

National Resources Conservation Service, 2009, On-line Soil Survey Geographic Database (SSURGO) for Rio Blanco County available at: http://soils.usda.gov/survey/geography/ssurgo/, downloaded May 2009.

Newman, K.R., 1965, Palynological correlation of late Cretaceous and Paleocene formations, Northwestern Colorado, *in* Cross, A.T., *ed.*, Palynology in oil exploration: Society of Economic Paleontologist and Mineralogists symposium, San Francisco, CA, March 26-27, 1962, pp. 169-180.

Noe, D.C., White, J.L., and Nelson, S., in preparation, North Delta quadrangle geologic map, Delta County, Colorado: Colorado Geological Survey, scale 1:24,000.

O'Sullivan, R.B., 1974, Preliminary geologic map of the Segar Mountain quadrangle, Rio Blanco County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-570, scale 1:24,000.

O'Sullivan, R.B., 1985, Preliminary geologic map of the Rio Blanco quadrangle, Rio Blanco and Garfield Counties, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-1816, scale 1:24,000.

O'Sullivan, R.B. and Smith, M.C., 1985, Preliminary geologic map of the west half of the thirteenmile Creek quadrangle, Rio Blanco and Garfield Counties, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-1789, scale 1:24,000.

Perry, W.J., Shroba, R.R., Scott, R.B., and Maldonado, F., 2003, Geologic map of the Horse Mountain quadrangle, Garfield County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-2415, scale 1:24,000.

Pipiringos, G.N., and Johnson, R.C., 1975, Preliminary geologic map of the Buckskin Point quadrangle, Rio Blanco County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-651, scale 1:24,000.

Pipiringos, G.N., and Rosenlund, G.C., 1977, Preliminary geologic map of the White Rock quadrangle, Rio Blanco and Moffat Counties, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-837, scale 1:24,000.

Reheis, M.C., 1984a, Geologic map and coal sections of the Sawmill Mountain quadrangle, Rio Blanco County, Colorado: U.S. Geological Survey Coal Investigations Map C-99, scale 1:24,000.

Reheis, M.C., 1984b, Geologic map and coal sections of the Thornburgh quadrangle, Moffat and Rio Blanco Counties, Colorado: U.S. Geological Survey Coal Investigations Map C-100, scale 1:24,000.

Scott, R.B., Shroba, R.R., and Egger, A., 2001, Geologic Map of the Rifle Falls Quadrangle, Garfield County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-2341, Scale 1:24,000.

Scott, R., Santucci, V.L., and Connors, T., 2001, An Inventory of paleontological resources from the national parks and monuments in Colorado. *In* Santucci, V.L and McClelland, L., (eds.), Proceedings of the 6th Fossil Resource Conference: U.S. National Park Service, Geological Resources Division Technical Report NPS/NRGRD/GRDTR-01/01, September 2001, pp. 178-199.

Shroba, R.R., and Scott, R.B., 1997, Revised preliminary geologic map of the Rifle quadrangle, Garfield County, Colorado: U.S. Geological Survey Open-File Report 97-852, scale 1:24,000.

Shroba, R.R., and Scott, R.B., 2001, Revised preliminary geologic map of the Silt quadrangle, Garfield County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-2331, scale 1:24,000.

Stewart, J.H., Poole, F.G., 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., 5 plates.

Tweto, O., Moench, R.H., and Reed, J.C., 1976, Geologic Map of the Leadville 1 x 2 degree quadrangle, northwestern Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-999, 1:250,000 scale.

Tweto, O., 1975, Laramide (Late Cretaceous-Early Tertiary) orogeny in the Southern Rock Mountains, *in* Curtis, B.F., *ed*., Cenozoic history of the Southern Rocky Mountains, Geological Society of America Memoir 144, pp 1-44.

Warner, D.L., 1964, Mancos-Mesaverde (Upper Cretaceous) intertonguing relations southeast Piceance Basin, Colorado: American Association of Petroleum Geologists Bulletin, Vol. 46, No. 7, pp. 1091-1107.

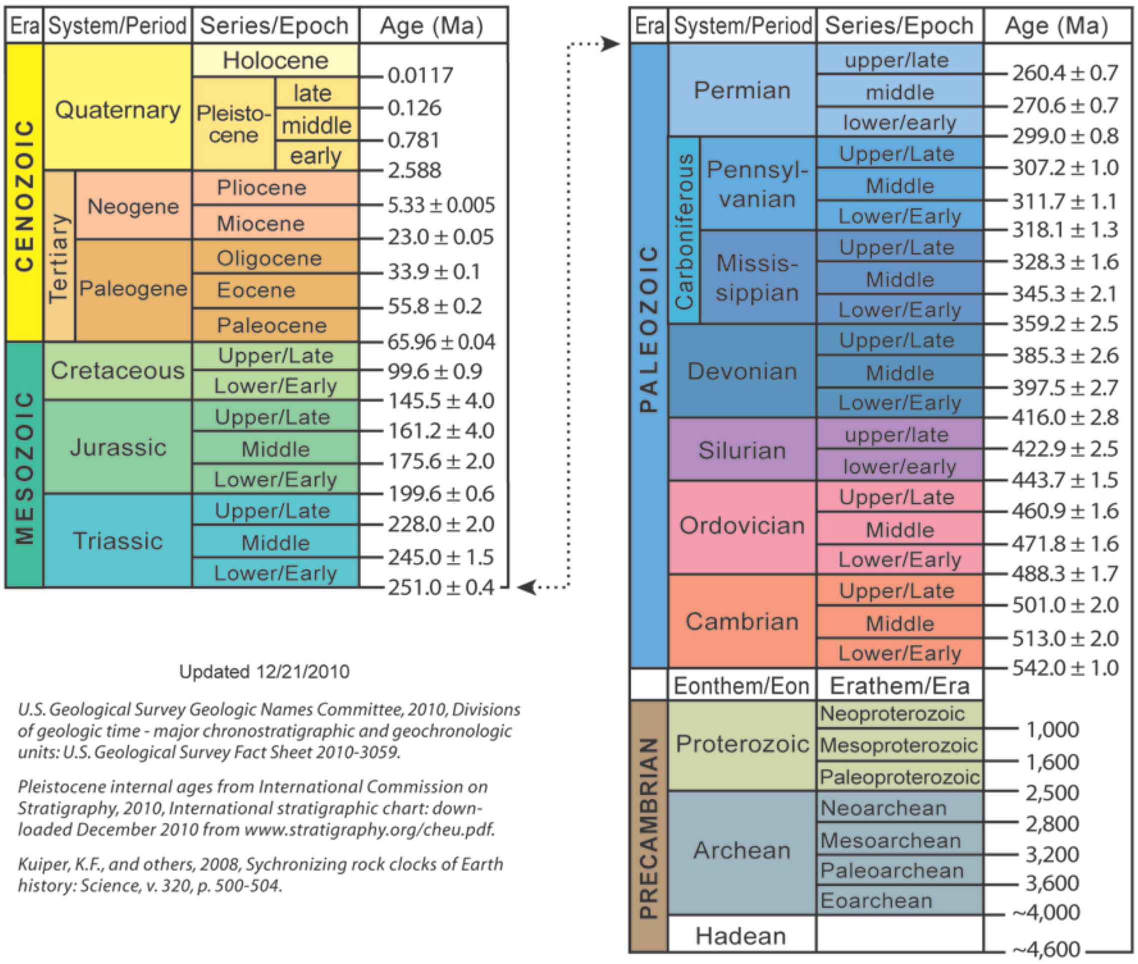
White, J.L., 2008, Geologic Map of the Hoovers Corner Quadrangle, Montrose County, Colorado: Colorado Geological Survey Open-File Report 08-03, Scale 1:24,000.

White, J.L. and Hodge, J., 2013, Meeker Quadrangle Geologic Map, Rio Blanco County, Colorado: Colorado Geological Survey, Scale 1:24,000.

White, J.L., Hodge, J., and Zawaski, M.J., 2013, Rattlesnake Mesa Quadrangle Geologic Map, Rio Blanco County, Colorado: Colorado Geological Survey, Scale 1:24,000.

APPENDIX A

DIVISION OF GEOLOGIC TIME ADOPTED BY THE COLORADO GEOLOGICAL SURVEY



Updated 12/21/2010

U.S. Geological Survey Geologic Names Committee, 2010, Divisions of geologic time - major chronostratigraphic and geochronologic units: U.S. Geological Survey Fact Sheet 2010-3059.

Pleistocene internal ages from International Commission on Stratigraphy, 2010, International stratigraphic chart: downloaded December 2010 from www.stratigraphy.org/cheu.pdf.

Kuiper, K.F., and others, 2008, Sychronizing rock clocks of Earth history: Science, v. 320, p. 500-504.

APPENDIX B

PALYNOLOGY REPORT FOR SAMPLE COLLECTED FROM THE LO7 HILL QUADRANGLE

REPORT ON PALYNOLOGICAL ANALYSES OF A SAMPLE FROM THE MEEKER (*sic*) QUADRANGLE COLORADO

Douglas E. Kline
Research Assistant, Denver Museum of Nature & Science
March 20, 2012

This report covers two samples submitted for palynological analysis by Jonathan White of the Colorado Geological Survey. Age determination was requested. The samples were from an outcrop locality in the Meeker (*sic*) quadrangle, Colorado. Sample preparation was conducted by Global Geolab of Alberta, Canada. DBP number, field number, and results are given below.

DBP no.	Field no.	Results
DBP-2012-019&020	LO7 #1302	The original sample (DBP-2012-005) yielded no stratigraphically significant palynomorphs. Additional samples were processed from the original matrix and ten slides were produced. In the analysis of these slides, two stratigraphically significant palynomorphs were observed, which were *Kurtzipites trispissatus* and *Ephedra multipartite*. Based on the presence of these two palynomorphs and the absence of *Momipites spp.*, the age of the sample appears to be Maastrichtian.

Discussion: *Kurtzipites trispissatus* and *Ephedra multipartite* are both included in Nichols' Wodehouseia spinata assemblage. This assemblage represents the end of the Maastrichtian. It is troubling that no specimens of *Tschudypollis spp.* (*Proteacidites*) were observed in the sample, because *T. spp.* had a wide distribution in Colorado during this time and generally is more abundant in samples than the two reported species. Confidence in the age determination would also increase with a broader representation of the 40 palynomorphs that make up the Wodehouseia spinata assemblage. Given these concerns, the confidence in a Masstrichtian age determination is moderate.

DBP-2012-021	WP 1463	This sample was effectively barren. No stratigraphically palynomorphs were observed.