OPEN-FILE REPORT 08-02

Authors' Notes

Geologic Map of the Delta Quadrangle, Delta and Montrose Counties, Colorado

by

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Department of Natural Resources
Denver, Colorado
2008

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Description of Map Units, Structural Geology, Geologic Hazards, Mineral Resources, and Ground-Water Resources

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Matthew L. Morgan, David C. Noe, Jonathan L. White, and Shannon M. Townley

A view of the typical landforms developed on the Smoky Hill Member of the Mancos Shale in the northwestern part of the Delta quadrangle. The topography here is mainly low hills and small bedrock knobs capped by alluvial gravels of the ancient Uncompahgre and Gunnison Rivers. The Uncompahgre Plateau is visible in the distance at left and the top of Grand Mesa can be seen in the upper right part of the photograph.

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. 07HQAG0083

FOREWORD

The purpose of Colorado Geological Survey Open File Report 08-02, *Geologic Map of the Delta Quadrangle, Delta and Montrose Counties, Colorado* is to describe the geologic setting, mineral and ground-water resources, and geologic hazards of this 7.5-minute quadrangle located to the southwest of Delta in western Colorado. Staff geologists Matthew L. Morgan, David C. Noe, Jonathan L. White and summer intern geologist Shannon M. Townley, completed the field work on this project during the spring and summer of 2007. Matt Morgan was the principal mapper and author of this report and utilized the maps and field notes generated by all four investigators. Some unit descriptions were coordinated between this area and both the Olathe NW (Noe and others, 2008) and Hoovers Corner quadrangles (White and others, 2008).

This mapping project was funded jointly by the U.S. Geological Survey through the STATEMAP component of the National Cooperative Geologic Mapping Program, which is authorized by the National Geologic Mapping Act of 1997 (award number 07HQAG0083) and the Colorado Geological Survey, using the Colorado Department of Natural Resources Severance Tax Operational Funds. The CGS matching funds come from the severance tax paid on the production of natural gas, oil, coal, and metals.

Vince Matthews
State Geologist and Division Director
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ACKNOWLEDGMENTS

We would like to thank our generous hosts Blaine and Linda Reed and Carol Patterson for their hospitality and use of their residences while completing our fieldwork. Access to private land was graciously arranged and provided by the following persons or agencies: Marc Catiln (Uncompahgre Valley Water Users Association), Dr. Robert Nutting, Shane Atchley, John and Debbie Kane, the Cox family, Austin Royce and Terri Walno, Andy and Annie Moffat, John and Marion Lewis, the City of Delta, Delta County, and Montrose County.

We are appreciative of local geological and geotechnical information that was provided by Laurie Brandt and Nancy Lamm (Buckhorn Geotech), and by Dennis Lambert (Lambert and Associates). Dick Grauch, Bill Cobban, Dave Sawyer, Bridget Ball (USGS) and Rex Cole (Mesa State College) aided tremendously in our interpretations of the Mancos Shale stratigraphy. Michael Machette (USGS) and Andres Aslan (Mesa State College) provided discussions on the Quaternary geomorphology and soils of the area. We would like to thank Allen Stork (Western State University) for helping with the identification of lithic clasts and artifacts.

We thank Laurie Brandt, Nancy Lamm (Buckhorn Geotech), and Vince Matthews for reviews of the map and manuscript. Karen Morgan (CGS) provided GIS and cartographic support and the cross-section profiles for the map plate. Larry Scott (CGS) provided assistance with figures for this book. Suzie Noble (consultant) set the digital stereo models in ERDAS© Imagine Stereo Analyst© for ArcView©.

INTRODUCTION

The Delta 7.5-minute quadrangle is located in Delta and Montrose Counties, Colorado (figure 1). The City of Delta (2005 CENSUS population of 8,135) is located in the north part of the quadrangle at the junction of Federal Highway 50 and State Highway 92. The Uncompahgre River runs through the eastern and northern halves of the quadrangle and flows northward to join the Gunnison River northwest of Delta. The city is named for the "delta" on which it was built, at the confluence of the two rivers. The highest part in the quadrangle (elevation 5,507 feet) is on the dip-slope of the Uncompahgre Uplift in the southwestern corner of the quadrangle, and the lowest point is in the Gunnison River valley bottom (elevation 4,888 feet) in the northwestern part of the quadrangle.

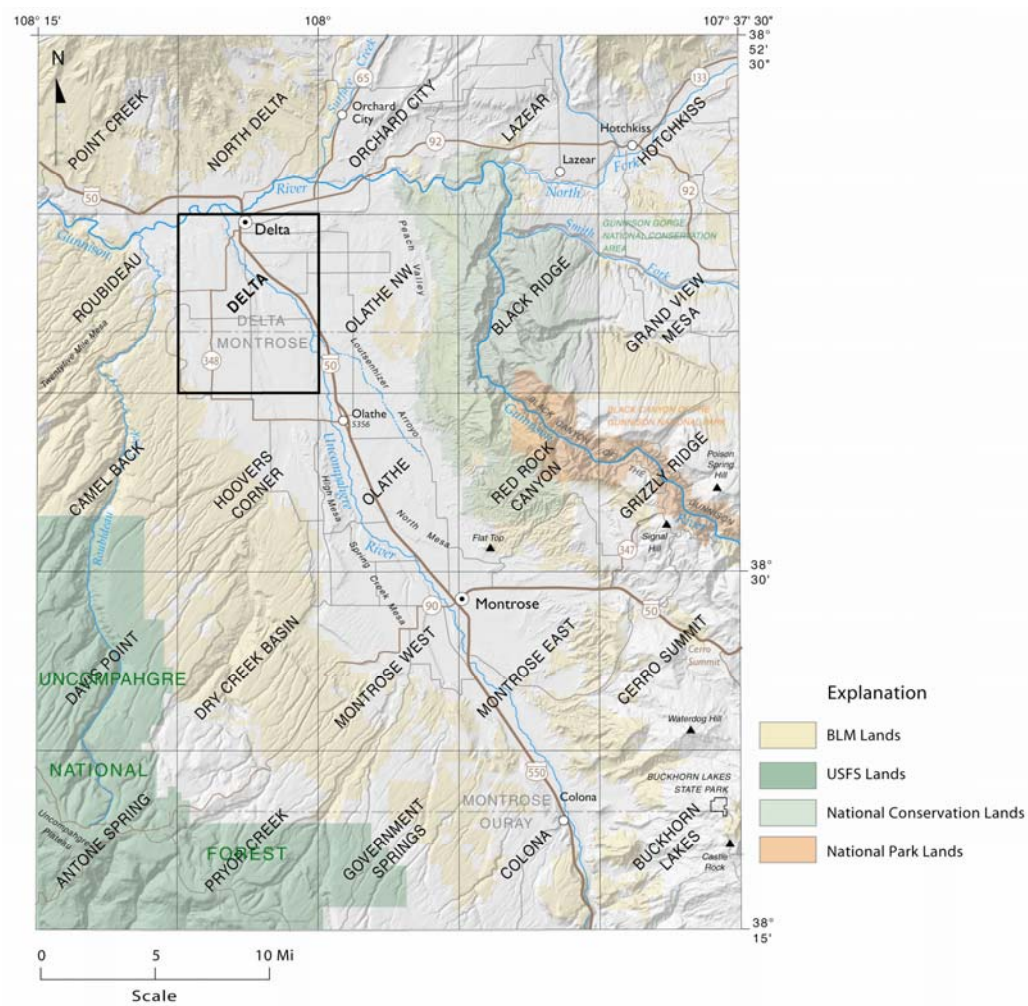

Figure 1. Location of the Delta quadrangle (bold black outline) in relation to major geographic features.

Geologic mapping of the Delta 7.5-minute quadrangle was undertaken by the Colorado Geological Survey (CGS) as part of the STATEMAP component of the National Cooperative Geologic Mapping Act, which is administered by the U.S. Geological Survey (USGS). Geologic maps produced by the CGS through the STATEMAP program are intended as multi-purpose maps useful for land-use planning, geotechnical engineering, geologic hazards assessment, mineral resource development, and ground-water exploration. Figure 2 shows the status of geologic maps of 7.5-minute quadrangles in the Montrose-Delta area, including eight older maps that have been published by the USGS.

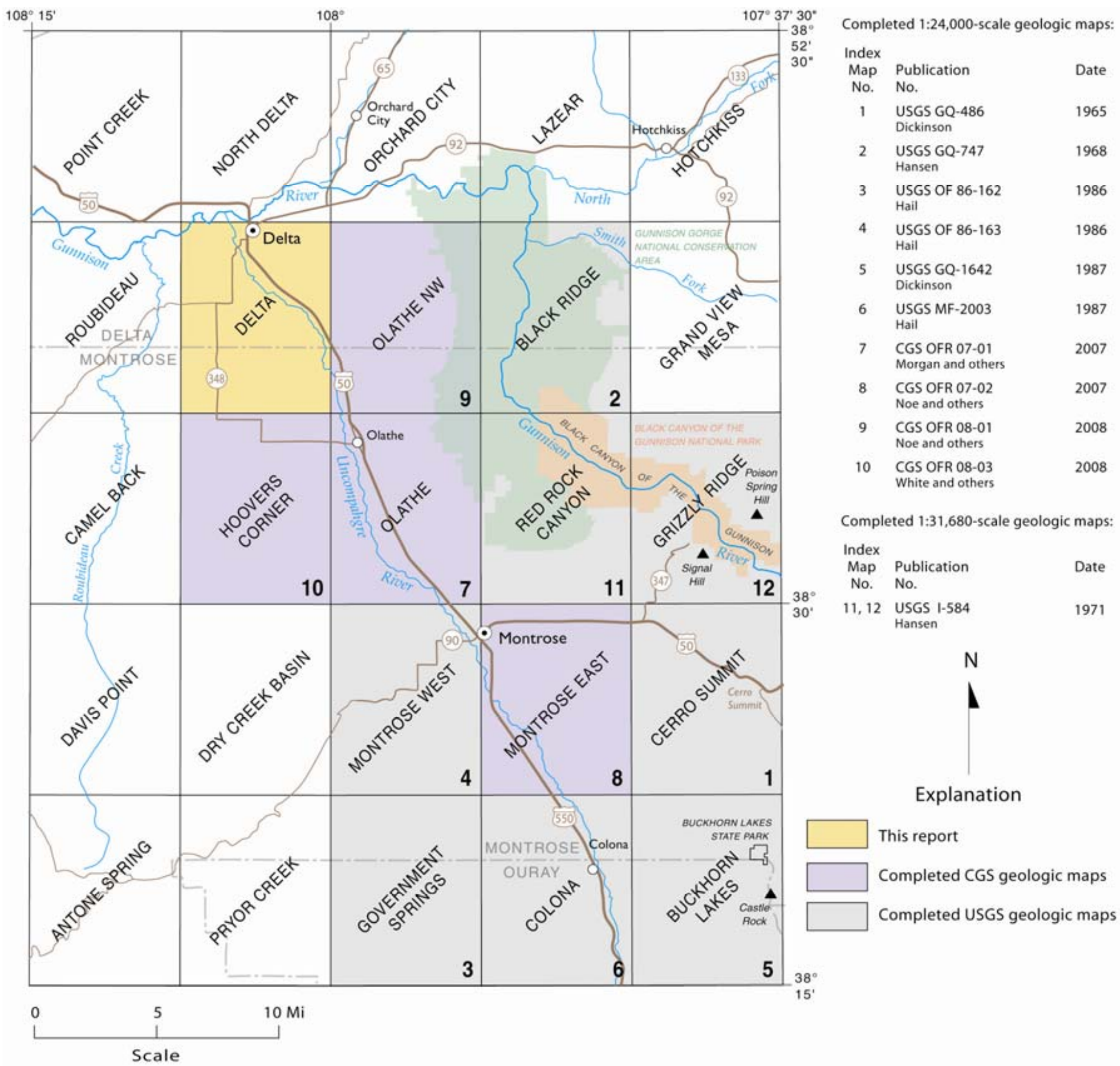

Figure 2. Index of published 1:24,000-scale geologic maps near Delta and Montrose.

The geologic interpretations shown on the Delta quadrangle are based on (1) CGS field investigations in April through July of 2007; (2) prior published and unpublished geologic maps and reports, in particular the USDA National Resources Conservation Service (NRCS) Soil Survey was used as a guide in key areas where deposit exposures were limited; (3) interpretation of black and white 1:20,000-scale Agricultural Stabilization and Conservation Service (ASCS) aerial photography flown in 1966; (4) a 10-meter digital elevation model (DEM); and (5) a 1-meter resolution National Agricultural Imagery Program (NAIP) digital orthophotograph taken in 2005.

Bedrock geology and surficial deposits were mapped in the field on aerial photographs. The photographs were scanned, georeferenced, and imported into Leica Photogrammetry Suite, where they were photogrammetrically corrected and rendered in 3D. Line work was traced directly from the scanned field photos using ERDAS Imagine Stereo Analyst for ArcView and exported as ESRI shapefiles. Universal Transverse Mercator (UTM; North American Datum 1983, Zone 13 North, meters) coordinates are provided for key geologic areas and photographs.

Previous Work

The Delta quadrangle has not previously been mapped at 1:24,000-scale. A 1:62,500-scale photogeologic map of the Delta 15-minute quadrangle was completed by Marshall (1959). Small-scale geologic mapping of the Delta area was done by Williams (1964) at a scale of 1:250,000. Sinnock (1978) mapped the geomorphology and landforms of the quadrangle as part of a larger, regional dissertation study, at a scale of 1:84,210. Meeks (1950) investigated the hydrogeology of surficial and bedrock units along the Uncompahgre River valley and its margins. Morgan and others (2007) mapped the geology of the Olathe quadrangle, located southeast of the Delta quadrangle, at a scale of 1:24,000. The Olathe NW quadrangle (Noe and others, 2008) and the Hoovers Corner quadrangle (White and others, 2008) which lie to the east and south of the Delta quadrangle, respectively, were mapped by the CGS concurrently with this report.

Overview of Geologic Setting and Findings

A map showing major, named physiographic, geomorphic, and geologic features in the Delta quadrangle is shown in figure 3.

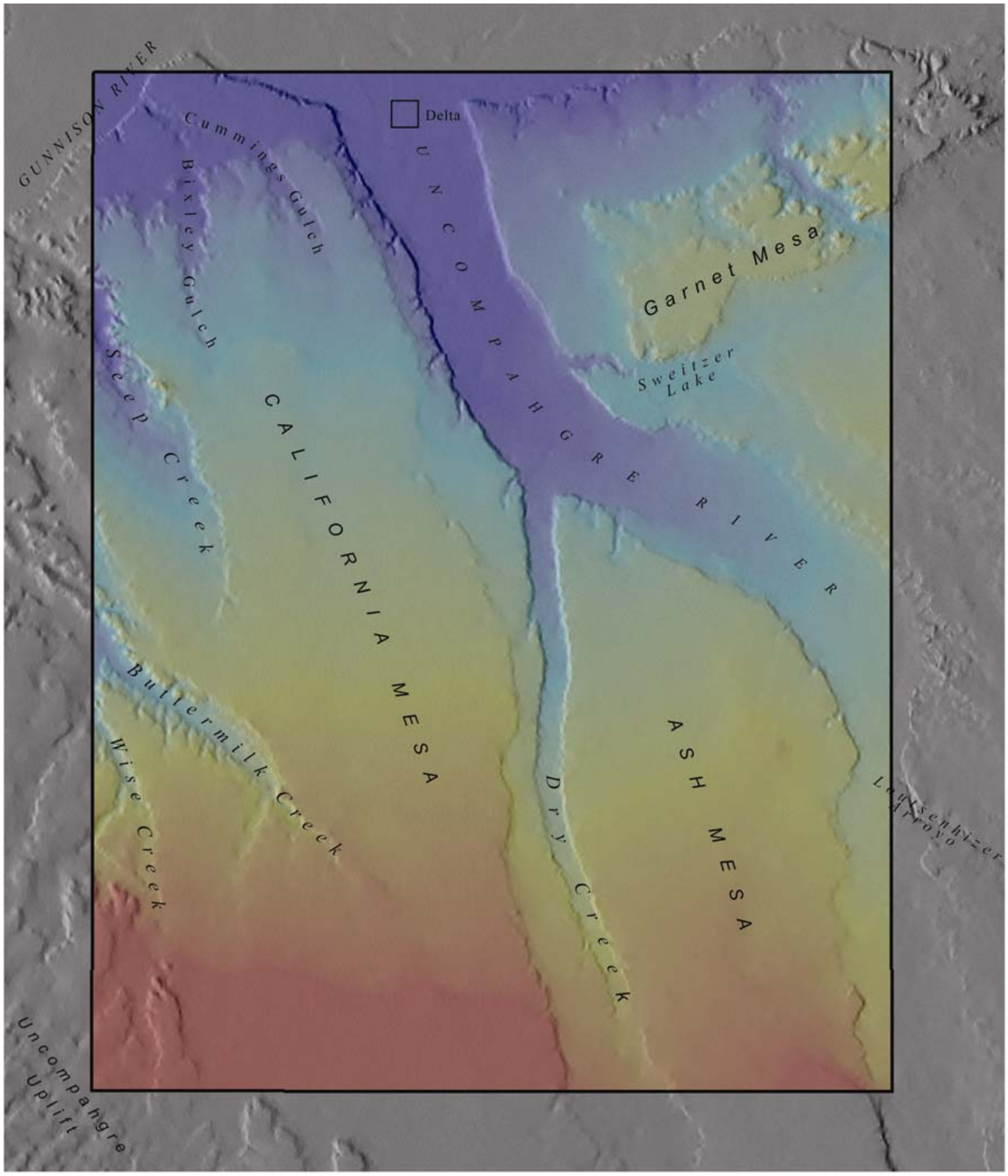

Figure 3. Hillshaded DEM of the Delta quadrangle and surrounding region showing the location of major physiographic, geomorphic, and geologic features discussed in this text.

The Delta quadrangle lies within the Canyonlands section of the Colorado Plateau physiographic province, an area characterized by deep canyons and monoclinal folds (Foos, 2006; Hunt, 1956). The Uncompahgre Uplift, which trends through the southwestern edge of the mapped area, and the Gunnison Uplift along the eastern margin of adjacent Olathe NW quadrangle, are the result of vertical movement of basement blocks during the Laramide

Orogeny. This movement has deformed the overlying Mesozoic rocks into gently to steeply dipping, monoclinal folds that are best exposed in the Olathe NW and Hoovers Corner quadrangles.

The bedrock exposed in the Delta quadrangle records the transition from marginal marine to predominantly marine conditions during Early to Late Cretaceous time. The Mancos Shale and its various subunits were deposited within the epicontinental, Western Interior Seaway and represent muddy shallow-shelf deposits derived from deltas and shorelines that existed further to the west, in Utah (Armstrong, 1968; McGookey and others, 1972; Johnson, 2003). Within the Delta quadrangle, the Mancos Shale forms a variety of topographic landforms – rolling badlands dominate much of the east side of the Uncompahgre River whereas hills, knobs, and valleys are found in the north and west.

Several levels of Quaternary alluvial gravel deposits are found in the mapped area. Most were deposited by the modern and ancestral Gunnison and Uncompahgre Rivers as they migrated over the landscape. Due to topographic inversion, the former channels now form broad terraces and/or ridge-capping boulder-gravel veneers underlain by Mancos Shale. The topographic inversion arises from long-term incision by the Uncompahgre and Gunnison Rivers and their tributaries that commenced approximately 2.5 million years ago (Hansen, 1987).

The Uncompahgre River, which runs through the northeastern part of the mapped area, has five major geomorphic surfaces associated with it (not including the modern flood plain) as it continues to flow northward where it joins the Gunnison River near Delta. Prominent gravel-capped mesas are the remnants of former flood plains and are assigned relative ages on the basis of terrace heights and soil characteristics (where examined). From oldest and highest, to youngest and lowest, these terraces and flood plains are labeled Qau_5 to Qau_1. Similarly, deposits of the Gunnison River also have five geomorphic surfaces of like relative age, labeled Qag_5 to Qag_1, respectively. The deposits from the two rivers have distinct clast lithologies and color variations that allow quick differentiation in the field. Clasts from the Gunnison River deposits are typically shades of gray and are predominantly basaltic in composition. The clasts of the Uncompahgre River tend to be more colorful and are mainly rhyolitic and andesitic in composition. Modern mass-wasting deposits, such as landslides, are common along the edges of the mesas where weathered and weakened Mancos Shale is exposed. The landslides are often caused by irrigation waters saturating the weakened shale and poor irrigation management of the upland terrace surfaces (White and Morgan, 2007).

DESCRIPTION OF MAP UNITS

Geologic time divisions used in this report are shown in Appendix 1. The following conventions are used for describing the surficial deposits and bedrock outcrops. Clast sizes were based on the modified Wentworth grain-size scale (Wentworth, 1922), using a chart from the American Geological Institute (Ingram, 1989). Colors of materials were determined by comparison to Munsell rock and soil color charts (Geological Society of America, 2000; GretagMacbeth, 2000). The stages of calcic soil development are based on the classification of Machette (1985).

SURFICIAL DEPOSITS

Surficial deposits shown on the map are generally more than 5 feet thick but may be thinner locally. Residuum, sheetwash, colluvium, and artificial fills of limited extent were not mapped. Contacts between surficial units may be gradational, and mapped units locally may include deposits of other types. Age divisions for the Holocene used in the Delta quadrangle are arbitrary and informal. They are based chiefly on paleontological data compiled for the southwestern United States. Relative age assignments for surficial deposits are based primarily on the degree of erosional modification of original surface morphology, height above modern stream levels, degree of dissection and slope degradation, and soil development. Wherever possible, we considered and adopted age assignments that have been reported by previous authors, especially Sinnock (1978), who traced stream-terrace levels along the Uncompahgre River valley and correlated them with different glacial moraines about 50 miles to the south of the mapped area, near the town of Ridgway.

HUMAN-MADE DEPOSITS

af **Artificial fill (upper Holocene)** — Riprap, engineered fill, and refuse placed during construction of roads, railroads, buildings, dams, canals, and landfills. Generally consists of unsorted silt, sand, clay, and rock fragments. This unit may also include areas of construction and quarrying operations where original deposits have been removed, replaced, or reworked. Many of the canal embankments and irrigation ditches in the quadrangle were not mapped due to their limited areal extent. The average thickness of the unit is less than 20 feet. Artificial fill may be subject to settlement, slumping, and erosion if not adequately compacted.

ALLUVIAL DEPOSITS

Clastic sediments of clay, silt, sand, and gravel deposited in stream channels, on flood plains, and as alluvial fans and sheetwash along valley sides, in tributary drainages, and on pediment surfaces. Flat-lying terrace alluvium and related deposits on sloped pediments along these drainages were deposited mostly during periods of effectively wetter climate that coincided with Pleistocene glaciations. The approximate terrace heights reported for each unit are the elevation differences measured between the modern creek bed and the top of the original or remnant alluvial surface adjacent to the creek. Thickness reported is the maximum exposed thickness of the unit.

Alluvial Deposits of the Uncompahgre River

The Uncompahgre River, which runs through the eastern and northern halves of the mapped area, has four major terrace levels (Qau_2-Qau_5) in addition to the Holocene floodplain (Qau_1) associated with the modern, incised river valley. Four of these terrace levels exist in the Delta quadrangle (figure 4). One local terrace remnant (Qau) is not correlative with any other mapped terraces. Most of the terraces are associated with Pleistocene glacial episodes (Sinnock, 1978). The gravel-clast compositions within these deposits consist primarily of tuffaceous and porphyritic rhyolite, andesite, metaquartzite, silica-cemented sandstone and lesser amounts of gneiss, granite, vein quartz, and limestone (figure 5). These intermediate volcanics and resistant clasts are derived from the western San Juan Mountains near Ouray to the south, Cimarron Ridge to the southeast, and the Uncompahgre Plateau to the west and southwest.

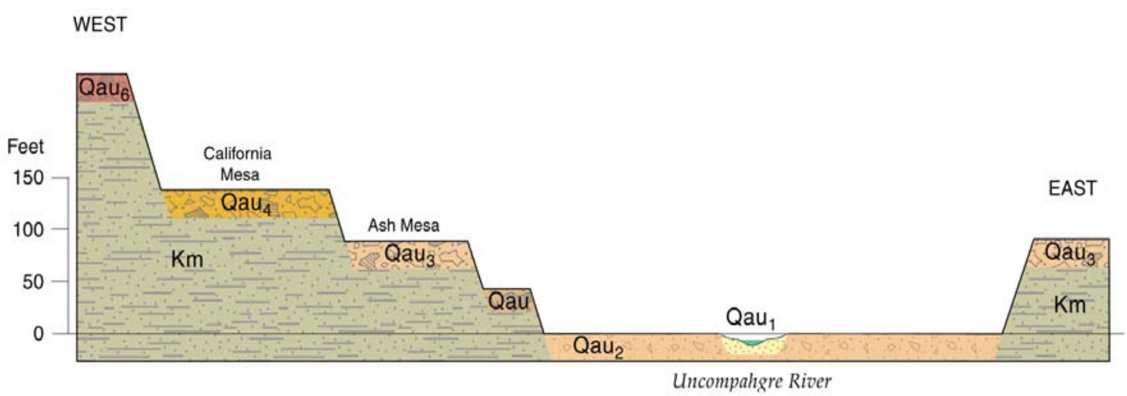

Figure 4. Diagrammatic profile of alluvial deposits associated with the Uncompahgre River. From oldest to youngest these are: Qau_5, Qau_4, Qau_3, Qau_2, and Qau_1 (the current stream channel). Qau is a local terrace remnant and Qau_5 is not present on the Delta quadrangle. See unit description for detailed information.

Figure 5. Unit Qau_3 alluvial gravel deposit associated with the Uncompahgre River. The clasts within the deposit consist mainly of tuffaceous and porphyritic rhyolite, andesite, metaquartzite, silica-cemented sandstone. These clast types are typically shades of red, purple and blue, giving the unit a colorful appearance. Compare this photo with the photograph of the Qag_3 deposit in figure 9 which illustrates the color differences between the Gunnison and Uncompahgre River gravel units. This provides a quick way to identify the different deposits in the field. Also, notice the clast imbrication from right (SE) to left (NW) indicating a rough NW flow direction. [UTMX: 233810.0, UTMY: 4292969.6].

Qau_1 **Alluvium one of the Uncompahgre River (upper to lower Holocene)** — Dark-brown to dark-grayish-brown, poorly to moderately sorted, moderately consolidated clay, silt, sand, and pebble, cobble, and boulder gravel in the currently active stream channel or in low stream-terrace deposits above the current stream channel but within the modern flood plain of the incised, Uncompahgre River valley. The alluvium commonly forms steep-sided walls where dissected by river erosion. Clasts are subrounded to well rounded and the dominant sediment is a sandy gravel with a silty sand matrix. Some boulders reach 3 feet in diameter. Soil development is absent. Many of the clasts are coated by a discontinuous rind of $CaCO_3$, indicating that they were reworked from older deposits. The deposit commonly includes organic-rich layers interbedded with clay, silt, and sand lenses. The unit may form low terraces that reach a maximum height of 6 feet above current stream level. These terraces fine upward, with localized, thin deposits of eolian or overbank sand and silt in the upper few feet. A second, younger group of lower terraces with heights of up to 3 feet have formed since 1987, when the river flows were first regulated by the Ridgway Dam, located 40 miles upstream. Since then, the braided flood plain has filled with sediment and the stream has mostly coalesced into a single channel. Maximum exposed thickness of the unit locally exceeds 10 feet.

Qau_2 **Alluvium two of the Uncompahgre River (lower Holocene to upper Pleistocene)** — Reddish-brown to dark-grayish-reddish-brown, poorly to moderately sorted, moderately consolidated clay, silt, sand, and pebble, cobble, and boulder gravel in stream terrace deposits above the modern flood plain of the Uncompahgre River valley. This deposit forms a broad, flat terrace that is incised into by younger streams and bordered by higher mesas, many of which lie west of the river. It is the primary regolith for agriculture in the Uncompahgre River valley. The alluvium commonly forms continuous and steep-sided, cut-bank walls where it has been dissected by the modern river valley. Clasts are subrounded to well rounded and the dominant sediment is a gravelly sand with a silty sand matrix. Soil development is very weak to absent and a juvenile A horizon is locally present. Many of the clasts within the deposit are coated by a discontinuous rind of $CaCO_3$, indicating they were reworked from older deposits. Agricultural practices have reworked the upper 2 feet of the deposit, making age determinations by soil properties problematic. Sinnock (1978) interpreted this terrace gravel deposit as being associated with the Pinedale glacial advance. Lenses of reworked gypsum and silt are present within the upper 2 feet of the deposit where not removed by agricultural practices. The outer edges of the unit along the older mesas is variably mantled with mixtures of clay, silt, and sand derived from erosion of the Mancos Shale, transported colluvial material from older gravel deposits, or of alluvial mudflow deposits originating from tributary streams. The deposit may include local organic-rich layers interbedded with clay, silt, and sand lenses. The unit forms terraces that reach a maximum height of 10 feet above current stream level, with height decreasing to 4 feet downstream toward the city of Delta. Maximum exposed thickness of the unit locally exceeds 25 feet, and deposits of greater than 120 feet have been encountered in drill holes in the nearby Montrose West quadrangle (Dennis Lambert, Lambert and Associates, personal commun., 2006). The unit generally forms a stable building surface, but there may be localized pockets of collapse-prone sediment, either within the gypsum-rich lenses of the unit, clay- and silt-rich slackwater deposits, or along the outermost edges where fine-grained colluvial and mudflow sediments predominate. Unit Qau_1 is inset into unit Qau_2 and a prominent terrace scarp separates these units. Areas along the edge of the Qau_1-Qau_2 cut bank may be prone to localized slope failure. The unit is a potential source of commercial sand and gravel.

Qau_3 **Alluvium three of the Uncompahgre River (upper Pleistocene)** — Strong-brown to moderate-reddish-brown, poorly to moderately sorted, poorly to moderately consolidated silt, sand, and pebble, cobble, and boulder gravel, in stream terrace deposits above the modern flood plain of the Uncompahgre River valley. The alluvium forms a broad gravel cap on Ash Mesa. Clasts are subrounded to well rounded and the dominant sediment is a bouldery, pebble-cobble gravel with a coarse sand matrix. Some boulders reach 3 feet in diameter. Soil profiles consist of A or Ap/Bk/2Btb/C horizons (figure 6); the cambic horizons reach colors as red as 5YR 6/4 (light reddish brown). A Bt horizon that overlies the Bk horizon (not shown on figure 6) is only occasionally present in the soil profile and appears to have been formed on a loess deposit that was easily removed by erosion or plowing from agriculture. Clast bottoms are coated by a continuous rind of $CaCO_3$ and discontinuous layers of powdery $CaCO_3$ occur in thin 0.2- to 1-inch-thick zones throughout the deposit. The soils are representative of Carbonate Stage I+/II of Machette (1985). Sinnock (1978) interpreted this terrace gravel deposit as being associated with the Pinedale glacial advance. On the basis of degree of reddening of the cambic horizons, presence of Stage I+/II calcic soil, and height above modern stream level, the deposit is probably associated with one of the early Pinedale glacial stades. The unit forms terraces that reach a maximum height of 100 feet above current stream level. The maximum exposed thickness of the unit locally exceeds 25 feet. The unit generally forms a stable building surface, although there may be thin, localized pockets of surficial fine-grained, collapse-prone sediment at the surface. Areas along the outer mesa edges may be prone to slope failure. The unit is a potential source of commercial sand and gravel.

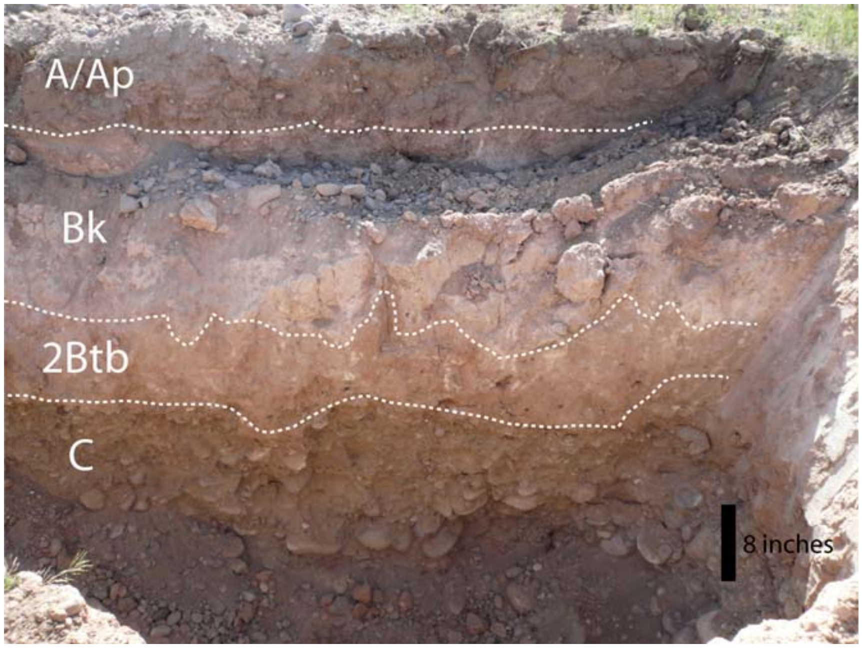

Figure 6. Photograph of the typical soil profile for unit Qau_3 in the Delta quadrangle. The annotated photo outlines the different soil horizons: A or Ap (A horizon disturbed by plowing) horizon, 12 inches thick; Bk horizon, 18 inches thick, visible whitening from $CaCO_3$ accumulation, $CaCO_3$ coats many of the clasts with some accumulation in roots and cracks, $CaCO_3$ nodules present; 2Btb horizon, clay-rich, 12 inches thick, $CaCO_3$ coats undersides of some clasts; C horizon, unaltered parent material. A Bt horizon is occasionally present in the soil profile but has been removed by erosion or agricultural practices at this location. [UTMX: 233718.4, UTMY: 4287097.9].

Qau_4 Alluvium four of the Uncompahgre River (upper middle Pleistocene) — Moderate-brown to moderate-yellowish-pink, poorly to moderately sorted, moderately consolidated silt, sand, and pebble, cobble, and boulder gravel in stream terrace deposits above the modern flood plain of the Uncompahgre River valley. The alluvium forms a broad gravel cap on California Mesa. Clasts are subrounded to well rounded and the dominant sediment is a bouldery, pebble-cobble gravel with a coarse sand matrix. Some boulders reach 3 feet in diameter. See figure 7 for typical soil profile descriptions for units Qau_4 and Qau_5. Sinnock (1978) interpreted this terrace gravel deposit as being associated with the Bull Lake glacial advance. The unit forms terraces that reach a maximum height of 140 feet above current stream level. The maximum exposed thickness of the unit locally exceeds 25 feet. The unit generally forms a stable building surface, although there may be localized pockets of surficial fine-grained, collapse-prone sediment. Areas along the outer mesa edges may be prone to slope failure. The unit is a potential source of commercial sand and gravel.

Qau$_5$ **Alluvium five of the Uncompahgre River (middle Pleistocene)** — Strong-brown to moderate-brown, poorly to moderately sorted, moderately consolidated silt, sand, and pebble, cobble, and boulder gravel in stream terrace deposits above the modern flood plain of the Uncompahgre River valley. Clasts are subrounded to well rounded and the dominant sediment is a bouldery, pebble-cobble gravel with a coarse sand matrix. Some boulders reach 5 feet in diameter and the dominant sediment is a bouldery, pebble-cobble gravel with a coarse sand matrix. Soil development is virtually identical to Qau$_4$ with the exception of increased reddening and clay content of the Bt horizon and increased carbonate content of the Bk horizon in unit Qau$_5$; see figure 7 for soil profile descriptions. Sinnock (1978) interpreted this terrace gravel deposit as being associated with the Bull Lake glacial advance. The unit forms terraces that reach a maximum height of 250 feet above current stream level. The maximum exposed thickness of the unit locally exceeds 25 feet. The unit generally forms a stable building surface, although there may be localized pockets of surficial fine-grained, collapse-prone sediment and areas along the outer mesa edges may be prone to slope failure. The unit is a potential source of commercial sand and gravel.

Qau **Alluvium of the Uncompahgre River, undifferentiated (upper Pleistocene)** — Brown to moderate-reddish-brown, poorly to moderately sorted, poorly to moderately consolidated silt, sand, and pebble, cobble, and boulder gravel in stream terrace deposits above the modern flood plain of the Uncompahgre River valley. The alluvium forms localized, gravel-capped terraces that could not be correlated with other, more widespread surfaces in the area. Clasts are subrounded to well rounded and the dominant sediment is a bouldery, pebble-cobble gravel with a coarse sand matrix. Soil horizons were not examined due to poor exposure. The unit forms terraces that reach a maximum height of 50 feet above current stream level. The maximum exposed thickness of the unit locally exceeds 15 feet. The unit generally forms a stable building surface, although there may be localized pockets of collapse-prone sediment, and areas along the outer mesa edges may be prone to landsliding. The unit is a potential source of commercial sand and gravel.

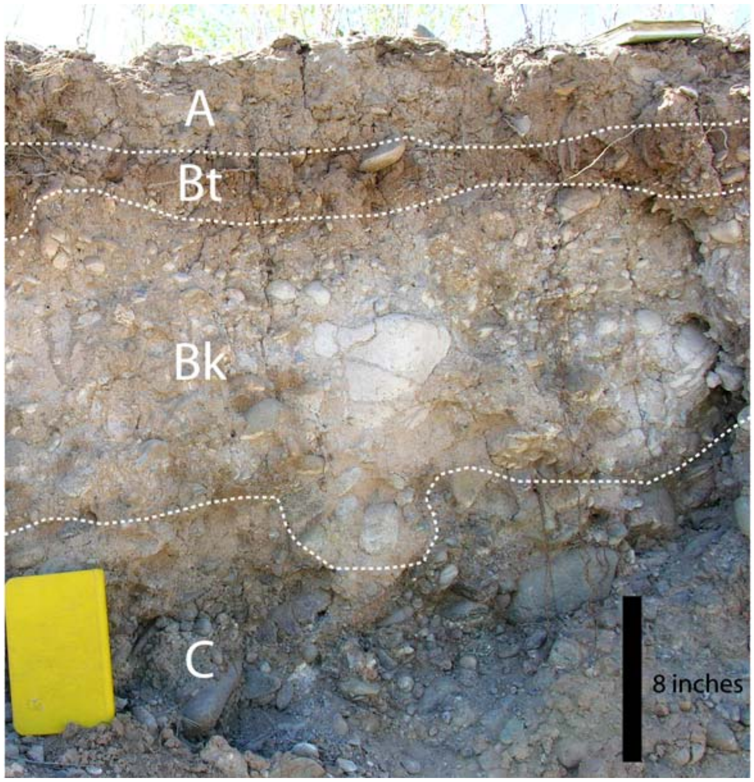

Figure 7. Photograph of the typical soil profile for unit Qau_4 and Qau_5 in the Delta quadrangle. The annotated photo of the Qau_4 profile outlines the different soil horizons: A horizon, 8 inches thick; Bt horizon, 5 inches thick, $CaCO_3$ coats bottoms of clasts with some accumulation in roots and cracks, color is 5YR 4/4 (moderate brown); Bk horizon, 18 inches thick, visible whitening from $CaCO_3$ accumulation, $CaCO_3$ coats undersides and occasionally the tops of clasts and fills cracks of fragmented clasts, $CaCO_3$ nodules present, $CaCO_3$ fills voids and is dispersed throughout the matrix, some volcanic clasts completely decomposed, color is 5 YR 7/4; C horizon, unaltered parent material. [UTMX: 228817.0, UTMY: 4285686.9].

Alluvial Deposits of the Gunnison River

The Gunnison River flows through the far northwest corner of the mapped area and is associated with four major terrace levels in addition to the modern, incised river valley (figure 8). One local terrace remnant (Qag) is not correlative with any other mapped terrace surfaces. All of the major terraces are associated with Pleistocene glacial episodes (Sinnock, 1978). The gravel-clast compositions within these deposits consist primarily of vesicular basalt, andesite, granite, and gneiss, with lesser amounts of rhyolite, schist, porphyry, and quartzite. The percentages of granite and gneiss decrease in the lower three terrace levels with the deposits becoming dominated by vesicular basalt from Grand Mesa, which is located north and east of the mapped area. The andesite clasts were derived from the West Elk Volcanic Field and the rhyolitic ash-flow tuff clasts from the San Juan Mountains. Clasts of granite, gneiss, and schist are likely from the basement rocks exposed in the inner gorge of the Black Canyon of the Gunnison.

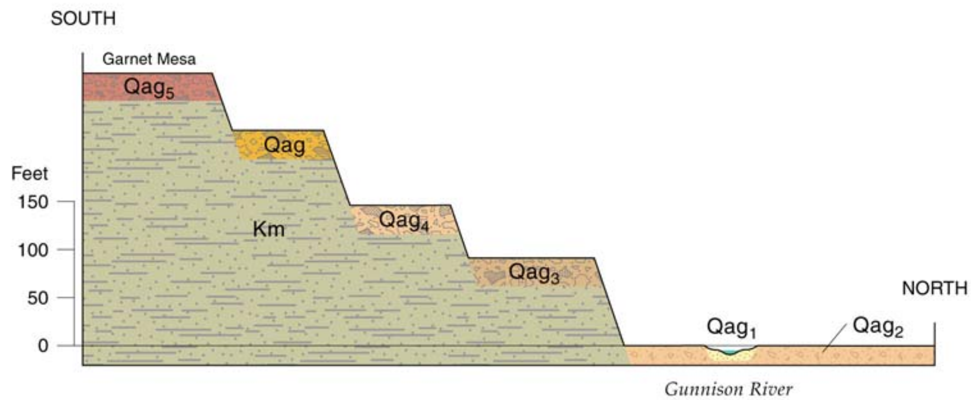

Figure 8. Diagrammatic profile of alluvial deposits associated with the Gunnison River. From oldest to youngest these are: Qag_5, Qag_4, Qag_3, Qag_2, and Qag_1 (the current stream channel). Qag is a local terrace remnant. See unit description for detailed information.

Qag_1 **Alluvium one of the Gunnison River (upper to lower Holocene)** — Gray to dark-brown, poorly to moderately sorted, moderately consolidated clay, silt, sand, and pebble, cobble, and boulder gravel in the currently active stream channel or in low stream-terrace deposits within the modern flood plain of the incised Gunnison River valley. The alluvium commonly forms steep-sided walls where dissected by river erosion. Clasts are subrounded to well rounded and the dominant sediment is a sandy gravel with a silty sand matrix. Some boulders reach 1 ft in diameter. Soil development is absent. Many of the clasts are coated by a discontinuous rind of $CaCO_3$, indicating that they were reworked from older deposits. The deposit commonly includes organic-rich layers interbedded with clay, silt, and sand lenses. The unit may form low terraces that reach a maximum height of 4 feet above current stream level. These terraces fine upward, with localized, thin deposits of overbank sand and silt in the upper few feet. Maximum exposed thickness of the unit locally exceeds 10 feet. The unit is a potential source of commercial sand and gravel.

Qag_2 Alluvium two of the Gunnison River (lower Holocene to upper Pleistocene) — Dark-gray to grayish-tan, poorly to moderately sorted, moderately consolidated clay, silt, sand, and pebble, cobble, and boulder gravel in stream terrace deposits above the modern flood plain of the Gunnison River valley. The alluvium commonly forms continuous and steep-sided, cut-bank walls where it has been dissected by the modern river valley. Clasts are subrounded to well rounded and the dominant sediment is a gravelly sand with a silty sand matrix. Some boulders reach 1.5 feet in diameter. Soil development typically consists of a 6-inch-thick A horizon that contains minor amounts of pedogenic carbonate and gypsum which stabilizes the bank walls. Below the A horizon, the upper 5 feet of the deposit consists of cross-bedded silt and sand that transitions into gravel and cobbles lower in the section. The cross-bedded silt and sand may also contain shale-clast rip-ups and gravel-cobble lenses. Many of the clasts are coated by a discontinuous rind of $CaCO_3$, indicating that they were reworked from older deposits. Sinnock (1978) interpreted this terrace gravel deposit as being associated with the Pinedale glacial advance. The outer edges of the unit along the older mesas consist of mixtures of clay, silt, and sand derived from erosion of the Mancos Shale, transported colluvial material from older gravel deposits, or of alluvial mudflow deposits originating from tributary streams. The deposit includes local organic-rich layers interbedded with clay, silt, and sand lenses. The unit forms terraces that reach a maximum height of 20 feet above current stream level. Although the main river terrace has been abandoned, Holocene deposition has continued to occur along tributary streams. The unit generally forms a stable building surface, but there may be localized pockets of collapse-prone sediment along the outermost edges where fine-grained sediments predominate. Unit Qag_1 is inset into unit Qag_2 and a prominent terrace scarp separates these units. Areas along the edge of the Qag_1-Qag_2 cut bank may be prone to localized landsliding. Maximum exposed thickness of the unit locally exceeds 20 feet. The unit is a potential source of commercial sand and gravel.

Qag_3 Alluvium three of the Gunnison River (upper Pleistocene) — Brownish-gray to light-grayish-red, poorly to moderately sorted, poorly to moderately consolidated silt, sand, and pebble, cobble, and boulder gravel, in stream terrace deposits above the modern flood plain of the Gunnison River valley (figure 9). Clasts are subrounded to well rounded and the dominant sediment is a bouldery, pebble-cobble gravel with a coarse sand matrix. Some boulders reach 2 feet in diameter. Poor exposures of the upper part of the deposit made it difficult to provide a detailed description of the soil profile; however, it is similar to unit Qau_3 of the Uncompahgre River, generally consisting of A/Bt/Bk/C horizons. Clast bottoms are coated by a continuous rind of $CaCO_3$ and $CaCO_3$ filaments are present between some of the clasts. The soils are representative of Carbonate Stage I+ of Machette (1985). Sinnock (1978) interpreted this terrace gravel deposit as being associated with the Pinedale glacial advance. On the basis of the height above modern stream level and Stage I+ calcic soil, the deposit is probably associated with one of the early Pinedale glacial stades. The unit forms terraces that reach a maximum height of 100 feet above current stream level. The maximum exposed thickness of the unit locally exceeds 25 feet. The unit generally forms a stable building surface, although there may be localized pockets of surficial finer-grained, collapse-prone sediment and areas along the outer mesa edges may be prone to slope failure. The unit is a potential source of commercial sand and gravel.

Figure 9. Unit Qag_3 alluvial gravel deposit associated with the Gunnison River. The clasts within the deposit consist mainly of vesicular basalt, andesite, granite, and gneiss, which give the unit an overall monochrome coloration. Compare this photo with the photograph of the Qau_3 deposit in figure 5 which illustrates the color differences between the Gunnison and Uncompahgre River gravel units. Also, notice the clast imbrication from right (E) to left (W) indicating a westward flow direction. [UTMX: 230206.6, UTMY: 4293505.45].

Qag_4 Alluvium four of the Gunnison River (upper middle Pleistocene) — Grayish-brown to light-brown, poorly to moderately sorted, moderately consolidated silt, sand, and pebble, cobble, and boulder gravel in stream terrace deposits above the modern flood plain of the Gunnison River valley. Clasts are subrounded to well rounded and the dominant sediment is a bouldery, pebble-cobble gravel with a coarse sand matrix. Some boulders reach 2 feet in diameter. See figure 10 for soil profile descriptions for units Qag_4 and Qag_5; the unit typically consists of A/Bwk/Bky horizons. The soils are representative of Carbonate Stage I+ of Machette (1985). Sinnock (1978) interpreted this terrace gravel deposit as being associated with the Bull Lake glacial advance. The unit forms terraces that reach a maximum height of 150 feet above current stream level. The maximum exposed thickness of the unit locally exceeds 25 feet. The unit generally forms a stable building surface, although there may be localized pockets of collapse-prone sediment, and areas along the outer mesa edges may be prone to slope failure. The unit is a potential source of commercial sand and gravel.

Qag_5 Alluvium five of the Gunnison River (middle Pleistocene) — Grayish-brown to light-brown, poorly to moderately sorted, moderately consolidated silt, sand, and pebble, cobble, and boulder gravel in stream terrace deposits above the modern flood plain of the Gunnison River valley. The alluvium forms a broad gravel cap on Garnet Mesa. Clasts are subrounded to well rounded and the dominant sediment is a bouldery, pebble-cobble gravel with a coarse sand matrix. Some boulders reach 2 feet in diameter. See figure 10 for soil profile descriptions for units Qag_4 and Qag_5. The unit typically consists of A/Bwk/Bky horizons. The soils are representative of Carbonate Stage I+ of Machette (1985). Sinnock (1978) interpreted this terrace gravel deposit as being associated with the Bull Lake glacial advance. The unit forms terraces that may reach a maximum height of 300 feet above current stream level. The maximum exposed thickness of the unit locally exceeds 25 feet. The unit generally forms a stable building surface, although there may be localized pockets of collapse-prone sediment, and areas along the outer mesa edges may be prone to landsliding. The unit is a potential source of commercial sand and gravel.

Figure 10. Photograph of the typical soil profile for units Qag_4 and Qag_5 in the Delta quadrangle. The annotated photo of the Qag_5 profile outlines the different soil horizons: A/Bt horizon, 3 inches thick; Bwk horizon, 6 inches thick, slight reddening of matrix with some $CaCO_3$ accumulation in pore spaces, color is 7.5YR 4/4 (grayish red); Bky horizon, 10 inches thick, visible whitening from gypsum and $CaCO_3$ accumulation, $CaCO_3$ coats undersides and occasionally the tops of clasts and fills cracks of fragmented clasts, $CaCO_3$ fills voids and weakly binds the matrix, representative of a Stage I+ calcic soil (Machette, 1985), color is 10 YR 4/4 (moderate yellowish brown); C horizon, unaltered parent material. [UTMX: 239149.15, UTMY: 4291722.80].

Qag **Alluvium of the Gunnison River, undifferentiated (upper middle? Pleistocene)** — Grayish-brown to light-brown, poorly to moderately sorted, poorly to moderately consolidated silt, sand, and pebble, cobble, and boulder gravel in stream terrace deposits above the modern flood plain of the Gunnison River valley. The alluvium forms localized, gravel-capped terraces that could not be correlated with other, more widespread surfaces in the area. Clasts are subrounded to well rounded and the dominant sediment is a bouldery, pebble-cobble gravel with a coarse sand matrix. Soil horizons were not examined due to poor exposure. The unit forms terraces that reach a maximum height of 200 feet above current stream level. The maximum exposed thickness of the unit locally exceeds 25 feet. The unit generally forms a stable building surface, although there may be localized pockets of collapse-prone sediment, and areas along the outer mesa edges may be prone to slope failure. The unit is a potential source of commercial sand and gravel.

Alluvial Deposits of Buttermilk Creek

Buttermilk Creek, along the western edge of the mapped area, contains two different alluvial deposits with distinct clast-type assemblages and lithologies (figure 11). The oldest of these, Qab_2, forms terraces approximately 30-50 feet above the modern incised channel of Buttermilk Creek. It was derived, almost entirely, from the older alluvial deposits of the Uncompahgre River. As base-level of the Gunnison River (to which Buttermilk Creek is tributary) dropped, the paleo-stream downcut into the Mancos Shale and shut-off the source for the Uncompahgre River alluvial gravels. This resulted in deposition of unit Qab_1, a mud-dominated alluvium that occupies the main floodplain of Buttermilk Creek.

Figure 11. Photos of the different alluvial deposits of Buttermilk Creek. (A) Alluvium one (Qab_1), displaying the mud-dominated nature of the deposit with minor $CaCO_3$ and gypsum accumulation in the upper part of the deposit. [UTMX: 228373.3, UTMY: 4285663.8] (B) Alluvium two (Qab_2), showing reworked casts from the Uncompahgre River; the boulder-sized conglomeritic clast is a fragment of the chert pebble conglomerate of the Burro Canyon Formation [UTMX: 228374.9, UTMY: 4285366.0]. Hammer is 9.5 inches long.

Qab_1 Alluvium one of Buttermilk Creek (Holocene to upper Pleistocene) — Moderate-yellowish-brown to strong-yellowish-brown, poorly to moderately sorted, moderately consolidated clay, silt, and sandy gravel in the currently active stream channel or in low stream-terrace deposits within the modern flood plain of Buttermilk Creek. The alluvium commonly forms steep-sided walls where dissected by river erosion. Clasts are subrounded to well rounded and the dominant sediment type is a silty sand with a silt matrix. Soil profile consists of either A/C or A/Bky/C horizons (figure 11 A). The Bky horizon is typical of Carbonate Stage I of Machette (1985); $CaCO_3$ and gypsum fills many root casts and sparsely coats some clasts. The deposit commonly includes organic-rich layers interbedded with clay, silt, and sand lenses. Charcoal fragments were found in several exposures. The unit forms low terraces that reach a maximum height of 8 feet above current stream level. Maximum exposed thickness of the unit locally exceeds 15 feet.

Qab_2 Alluvium two of Buttermilk Creek (upper Pleistocene) — Moderate-yellowish-brown to light-brown, poorly to moderately sorted, poorly to moderately consolidated clay, silt, sand, pebble, cobble, and boulder gravel in stream terrace deposits above the modern flood plain of Buttermilk Creek. The alluvium commonly forms planar to slightly convex-up terrace treads (flat surface of the former floodplain level) with moderately to steeply sloping risers (slope that connects the tread to lower surfaces). Clasts are subangular to well rounded and the dominant sediment type is a cobble and boulder gravel in a sandy matrix. Some boulders reach 2 feet in diameter. The gravel clasts within these deposits are primarily tuffaceous and porphyritic rhyolite, andesite, silica-cemented Dakota Sandstone, chert pebble conglomerate of the Burro Canyon Formation (exposed west and southwest of the mapped area), and metaquartzite (figure 11 B). The clasts within this unit are reworked clasts from the Uncompahgre River alluvium. Landsliding from the adjacent hillsides has transported clasts downslope from the higher-level alluvium (Qau_4), a process that provided additional sediment input for this unit. Soil profiles were not examined due to poor exposure. The unit forms terraces that reach a maximum height of 50 feet above current stream level. Maximum exposed thickness of the unit locally exceeds 20 feet. The unit is a potential source of commercial sand and gravel.

Alluvial Deposits of Dry Creek

Dry Creek, a tributary stream of the Uncompahgre River, contains three different alluvial deposits that were transported from the south along the main stream channel. These alluvial deposits originated from the Dry Creek basin that has incised into the eastern flank of the Uncompahgre Plateau to the south and west of the mapped area. Source-area lithologies differentiate the Dry Creek alluvium from the adjacent alluvial deposits of the Uncompahgre River. The alluvial gravel and cobbles are predominantly (>85%) composed of buff-colored sandstone and gray chert-pebble conglomerate from the Dakota Sandstone, Burro Canyon Formation, and Morrison Formation (exposed west and southwest of the mapped area). A small gravel fraction is reworked older Uncompahgre River alluvium from adjacent mesa edges along the lower Dry Creek valley where the creek debouches from its canyon in the Uncompahgre Plateau. The finer-grained alluvium is predominantly brown to tan silt and sand with little clay.

The oldest of these units, Qad_3, is a moderately to well-sorted riverine deposit with well-rounded clasts, and lacks evidence of matrix supported, rapidly deposited, bulked mud flows. We interpret the northward cessation of Qad_3 clasts on the Qau_3 terrace to represent the approximate location of the late Pleistocene paleo-confluence of Dry Creek and the

Uncompahgre River. The tributary mouth of Dry Creek would have riverine deposits composed of sandstone and chert clasts more indicative of the Uncompahgre Plateau source areas; however, further into the paleo-floodplain (Ash Mesa), this clast lithology would be soon overwhelmed and dispersed by the much more voluminous deposition of Qau_3 from the main trunk Uncompahgre River. A similar relationship occurs at the present-day confluence of Dry Creek and the Uncompahgre River where Qad_2 deposits occur on, and grade into, Qau_2 alluvium. Qad_3 occurs near the southern boundary of the mapped area in the Dry Creek valley but terminates northward where gravel- and cobble-sized clasts indicative of Qau_3 alluvium predominate. There is evidence of limited scour of Qau_3 and deposition of Qad_3 above it (White and others, 2008) but there is no appreciable elevation difference that would suggest alluvial fan or lateral levee depositional processes.

Qad_1 **Alluvium one of Dry Creek (upper to lower Holocene)** — Dark-brown to moderate-brown to tan-brown, poorly to moderately sorted, moderately consolidated silt, sand, pebble, and cobble gravel in the currently active stream channel or in low stream-terrace deposits within the modern flood plain of the incised Dry Creek valley. Clasts are subrounded to well rounded and the dominant sediment type is a sandy pebble gravel with a sandy-silt matrix. Some cobbles reach 10 inches in diameter. Soil development is absent. Some reworked volcanic clasts are coated by a discontinuous rind of $CaCO_3$, indicating that they were reworked from older Uncompahgre River deposits (Qau_4 though Qau_5). The unit forms low terraces that reach a maximum height of 3 feet above current stream level. The maximum exposed thickness of the unit locally exceeds 10 feet.

Qad_2 **Alluvium two of Dry Creek (lower Holocene to upper Pleistocene)** — Deep-brown to tan-brown, poorly to moderately sorted, moderately consolidated silt and sand with thin discontinuous layers of pebble, and cobble gravel in overbank and stream-terrace deposits above the current stream channel within the modern flood plain of the incised Dry Creek valley. The alluvium commonly forms steep-sided walls where dissected by river erosion. Clasts are subrounded to well rounded and the dominant sediment type is a sandy pebble gravel in a sandy-silt matrix. Some cobbles reach 10 inches in diameter. A juvenile A horizon is present with color of 7.5YR 2/6 (deep brown). Some of the volcanic clasts are coated by a discontinuous rind of $CaCO_3$, indicating that they were reworked from older Uncompahgre River deposits ($Qau_{4,}$ Qau_5). The unit forms terraces that reach a maximum height of 12 feet above current stream level and grade laterally into the Qau_2 terraces of the

Uncompahgre River. The maximum exposed thickness of the unit locally exceeds 15 feet.

Qad_3 **Alluvium three of Dry Creek (upper Pleistocene)** — Orange-brown to tan-brown gravel, pebbles and cobbles in a sandy matrix. The alluvium commonly forms steep-sided slopes where dissected by river erosion and later Qad_2 and Qad_1 deposition. The sandstone, chert, and chert conglomerate clasts are well rounded to subrounded to rarely subangular. Some boulders reach 18 inches in diameter. Soil profiles within the mapped area were not examined due to poor exposure, however, within the adjacent Hoovers Corner quadrangle (White and others, 2008) the sandy-silt matrix of the deposit is stained reddish- to orange-tan (10YR 7/8). These reddish colors suggest the deposit is of late Pleistocene age. The maximum exposed thickness of the unit locally exceeds 10 feet. The unit forms terraces that may reach a maximum height of 25 feet above current stream level. The unit is a potential source of commercial sand and gravel.

Undifferentiated Alluvial Deposits

Qa **Alluvium, undifferentiated (Holocene to upper Pleistocene)** — Stream-channel and flood plain deposits along valley floors of ephemeral, intermittent, and small perennial streams. Poorly to moderately sorted, weakly to well-stratified, moderately consolidated silt, sand, and pebble, cobble, and boulder gravel. The clasts are derived from older alluvial deposits of the Uncompahgre and Gunnison Rivers. This unit forms small terraces that reach a maximum height of 10 feet above modern stream level, and the deposit may exceed 15 feet in thickness. Areas mapped as Qa may be prone to flooding, erosion, and sediment deposition.

Mudflow-Dominated Alluvium and Alluvial-Fan Deposits

These deposits 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 mudflows, mud and gravel debris flows, or earth flows have been the dominant depositional processes. These widespread, Holocene deposits are mud dominated and gravel poor, with most of the source material being derived from the Mancos Shale. In these areas, it was not possible to differentiate small, thin, localized alluvial-fan deposits and thus they are not mapped separately. The surface gradient of these finer-grained mudflows can be much flattened and the alluvial fan morphology is subtle. The sole exception is a Holocene to late Pleistocene gravel-rich deposit along the southern margin of the mapped area, where sediments derived from sandstone and mudstone beds within the Cretaceous Dakota Sandstone, Burro Canyon Formation, and Jurassic Morrison Formation (exposed southwest and west of the mapped area) have washed down small canyons in the Uncompahgre Plateau and through channels in California Mesa to deposit broad coalesced alluvial fans in the Dry Creek valley.

Qf **Alluvial-fan deposits (upper Holocene)** — Brownish-pink to light-brown, well sorted to locally poorly sorted, poorly consolidated, sandy silt to sandy gravel deposited in alluvial fans at the mouths of arroyos and small, ephemeral streams. The deposits have a fan-shaped morphology. Because of their fine-grained composition, they have very low surface gradients of 1 to 5 degrees. Sediments are deposited primarily as sheetwash with occasional input from muddy debris flows and hyperconcentrated flows. The deposits consist of poorly defined sand and silt layers, typically less than an inch to a few inches thick, which record individual depositional events. There are occasional stringers and lenses of locally reworked gravel. Deposits may locally exceed 10 feet in thickness. This map unit was assigned only to small, well developed, single alluvial fans that have prograded onto dissimilar deposits such as alluvial terraces. Alluvial fans that are in a stratigraphic continuum with more complex, mudflow-and-fan valley-fill systems were mapped as Qamf (see upcoming entry). Areas mapped as alluvial fans are subject to future flash floods and debris flow events. The deposits may be prone to soil collapse when wetted or loaded.

Qafo **Older alluvium and alluvial-fan deposits (Holocene to upper Pleistocene)** — Buff to light-gray to yellow-gray, moderately to poorly sorted, moderately to poorly consolidated, weakly stratified silt, sand, gravel, pebbles, and rare cobbles deposited in coalescing fans within the Dry Creek valley. The sandstone, chert, and chert conglomerate clasts are subangular to subrounded. The typical sediments are silty sand with dispersed matrix-supported gravel, interlayered with clast-supported sandy gravel and pebbles with occasional cobbles. The individual layers record episodic and dynamically differing depositional events as the alluvial fan aggraded. Where exposed, the soil profile consists of an 8- to 10-inch-thick A horizon below a thin agriculturally disturbed (Ap) horizon and an 8-inch-thick Bk horizon with stage I+/II powdery carbonate, overlying a C horizon. Buried Bt and Bk soil horizons and oxidized/red-stained C horizons typically separate the deposit into discreet depositional packages. Selective $CaCO_3$ cementation by subsurface water has created 1-inch to 3-inch-thick resistant stringers in the sediment that have been enhanced in older excavations by later weathering and burrowing. Maximum thickness of the unit is approximately 30 feet. The unit is a potential source of sand and gravel.

Qamf **Alluvial mudflow-and-fan valley-fill deposits (upper to lower Holocene)** — Light-grayish-reddish-brown to pale-orange-yellow, well to occasionally poorly sorted, poorly consolidated, clayey to sandy silt deposited in valley-head and valley-side alluvial fans, tributary stream valleys, and coalescing fans in broad basins. The deposits comprise a complex system of deposits that extends for several miles along tributary stream reaches. Extensive alluvial mudflow deposits occur around Sweitzer Lake State Park (figure 12) and in the Loutsenhizer Arroyo drainage basin where there are two distinct units of differing relative age and lithology.

Figure 12. Qamf alluvial mudflow deposit south of Sweitzer Lake State Park. These deposits cover extensive areas near the Park and are composed of thin layers of clay and sandy silt. The Qamf deposits go through wet and dry periods throughout the year as evidenced by the desiccation cracks formed on the surface. The white patches on the ground are salts brought to the surface through efflorescence. [UTMX: 237171.6, UTMY: 4289087.4].

A bulk ^{14}C sample was taken at the base of a Qamf deposit on the adjacent Olathe quadrangle that yielded a conventional age of 9,810±60 ^{14}C yrs BP (2 Sigma, 95% probability = yrs. B.P. 11,300-11,170) (Beta Analytic Sample #225554). Recent incision from storm events, runoff, and irrigation has formed deeply incised arroyos in the Qamf deposits.

Some of the tributary-stream systems have intermediate basins along their courses. The basin- and valley-fill sediments were deposited primarily by muddy debris flows with occasional input from sheetwash, hyperconcentrated flows, and water-flood flows. The deposits consist of poorly defined silt layers, typically less than an inch to a few inches thick, which record individual mudflow depositional events. Some layers show incipient soil development that was curtailed by burial during subsequent events.

Qamf deposits may exceed 5 feet in thickness in valley-head and valley-side areas and may exceed 25 feet in thickness along the valley reaches and in the basins. The filling of the intermediate and terminal basins has resulted in the near burial of low hills and ridges of Mancos Shale; borehole drilling may be necessary to determine bedrock depth in these areas. Many of the tributary-stream mudflow deposits and coalescing fans have been deeply dissected by stream erosion during the late Holocene, resulting in narrow, steep-walled arroyos that are 5 to 20 feet deep along the valley bottoms in most areas. Areas mapped as Qamf may be subject to future flash floods and debris flow events, especially in non-incised valley-head and valley-side areas and within the deeply dissected modern arroyo channels. The deposits may be prone to significant collapse from dispersion, hydrocompaction, or slope failure when wetted or loaded (Morgan and others, 2007; Morgan and White, 2007). Qamf deposits have been used for agriculture as cropland and pasture. Typically, irrigation is required, and because the deposits are sulfate-rich, the quality of these lands for agriculture is relatively poor.

MASS-WASTING DEPOSITS

These deposits are earth materials that were transported downslope primarily by gravity and not within or under another medium, such as water or ice. Some of these deposits have moved by creep, which is a slow, gradual, progressive downslope movement of earth materials.

Qls Landslide deposits (Holocene to upper Pleistocene) — Heterogeneous deposits consisting of unsorted and unstratified clay, silt, and sand, and cobble- and boulder-size rock fragments. Unit includes rotational and translational slides and complex earthflow mass movements. In most places, landslides show obvious geomorphic expression that disrupts the profile of the slopes. Generally, head scarps (near-vertical detachment scars exposed at the top of and sides of the landslides) are readily recognizable; however, some scarps may be eroded or covered and not pronounced. Other common diagnostic features include hummocky topography, closed depressions, sag ponds, fissures, terracettes, tension cracks, and pressure ridges at the toe of the mobilized mass. The landslides can form in weathered Mancos Shale where gypsum has infilled fracture and bedding planes and caused the shale to split apart and weaken. Weathering, soil piping, water infiltration, and increased pore pressure and lubrication of fracture planes within the shale by irrigation and/or meteoric waters has weakened the shale and caused many of the slope failures. Soil profiles were not developed on any of the examined deposits; however, buried soils do occur and represent multiple slope movements. The relative ages of the landslides are highly variable.

Old landslide deposits are visible in the headscarps of more recent slides along Dry Creek and on the Qau_3 mesa edge that crosses through the eastern side of the City of Delta. Most landslide deposits within the mapped area are mixtures of alluvium from the Uncompahgre and Gunnison Rivers and varying amounts of weathered and disturbed Mancos Shale. Vegetation may be thick due to the amount of water seeping into the deposits. See the “Geologic Hazards” section for a discussion of landslides within the mapped area.

Landslide areas are subject to future movement during episodes of heavy rain or snowfall or may be reactivated by human-made disturbances such as cutting of slopes for roads, quarries, grading for housing developments, and irrigation and septic systems. Poor irrigation or drainage practices may create or remobilize landslide deposits (White and Morgan, 2007). Landslide deposits are prone to settlement when loaded or wetted. The deposits may contain expansive soils where derived from shale and mudstone formations. Thickness of landslide deposits locally exceeds 10 feet.

BEDROCK UNITS

The bedrock geology within the Delta quadrangle is primarily Mancos Shale underlain by the Dakota Sandstone. The Mancos Shale and its members were deposited within a shallow sea (Western Interior Seaway) that divided the North American Continent into two halves during the Middle to Late Cretaceous. On the basis of field observations and biostratigraphy, we divided the Mancos Shale into distinct subunits and assigned them names typically used in the area.

The nomenclature of these stratigraphic members has been imported from the central Front Range Piedmont near Pueblo (Scott and Cobban, 1964, 1986; Scott, 1969; Cobban and Scott, 1972), the Mesa Verde area in southwestern Colorado (Leckie and others, 1997), and the Book Cliffs near Grand Junction (Hettinger and Kirschbaum, 2002).

The U.S. Geological Survey divided the Mancos Shale into lithostratigraphic units on the basis of a 550-foot core (USGS CL-1) that was extracted from the eastern side of "Candy Lane" (R. Grauch, USGS, and B. Ball, USGS, personal commun., 2006, Ball and others, 2006) on the Olathe quadrangle (Morgan and others, 2007). Many of these units could not be identified with certainty in the field and are not used in this report.

A stratigraphic column for the Delta quadrangle is shown in figure 13. The biostratigraphy reported in this section is based on fossil collections made by the authors, as well as fossil collections made by previous workers (Merewether and others, 2006) within a mile of the quadrangle borders, from strata that may be physically traced into the Delta quadrangle.

Mancos Shale (Upper Cretaceous)

Kmp **Prairie Canyon Member** — Gray to light-brownish-gray, noncalcareous, sandy marine shale. Contains small discs of bioturbated sandstone up to several inches in diameter. Concretions are rare except at the top of the unit, which is not exposed in the mapped area. Outcrops occur on the slopes of Garnet Mesa in the northeastern part of the mapped area. The unit typically forms steep, broad-shouldered, rounded ridges with abundant small-scale rilling, or smooth slopes below gravel-capped mesas. The basal contact with the underlying Smoky Hill Member is gradational over a 5 foot interval and appears to be conformable (figure 14).

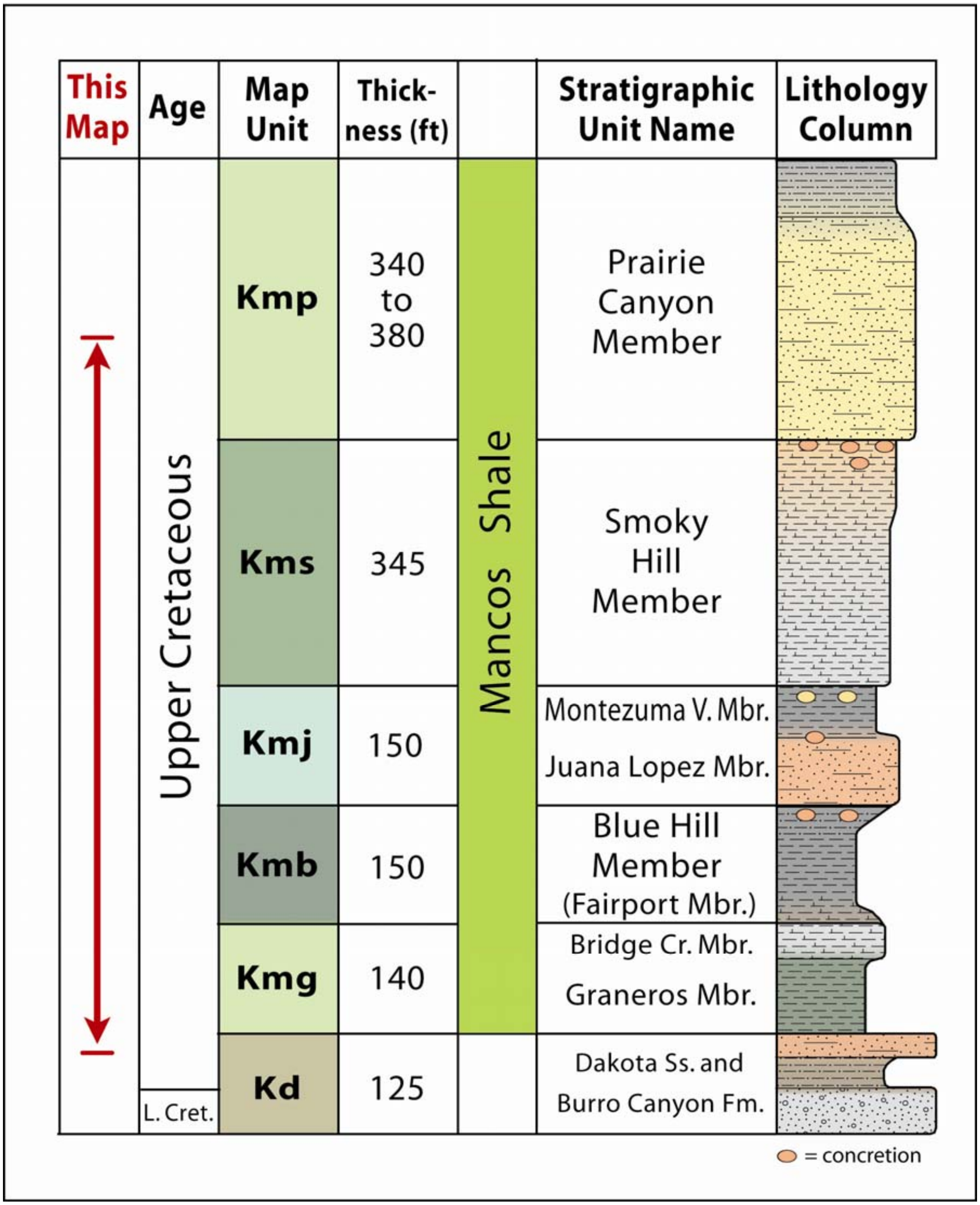

Figure 13. Bedrock stratigraphic column for the Delta quadrangle.

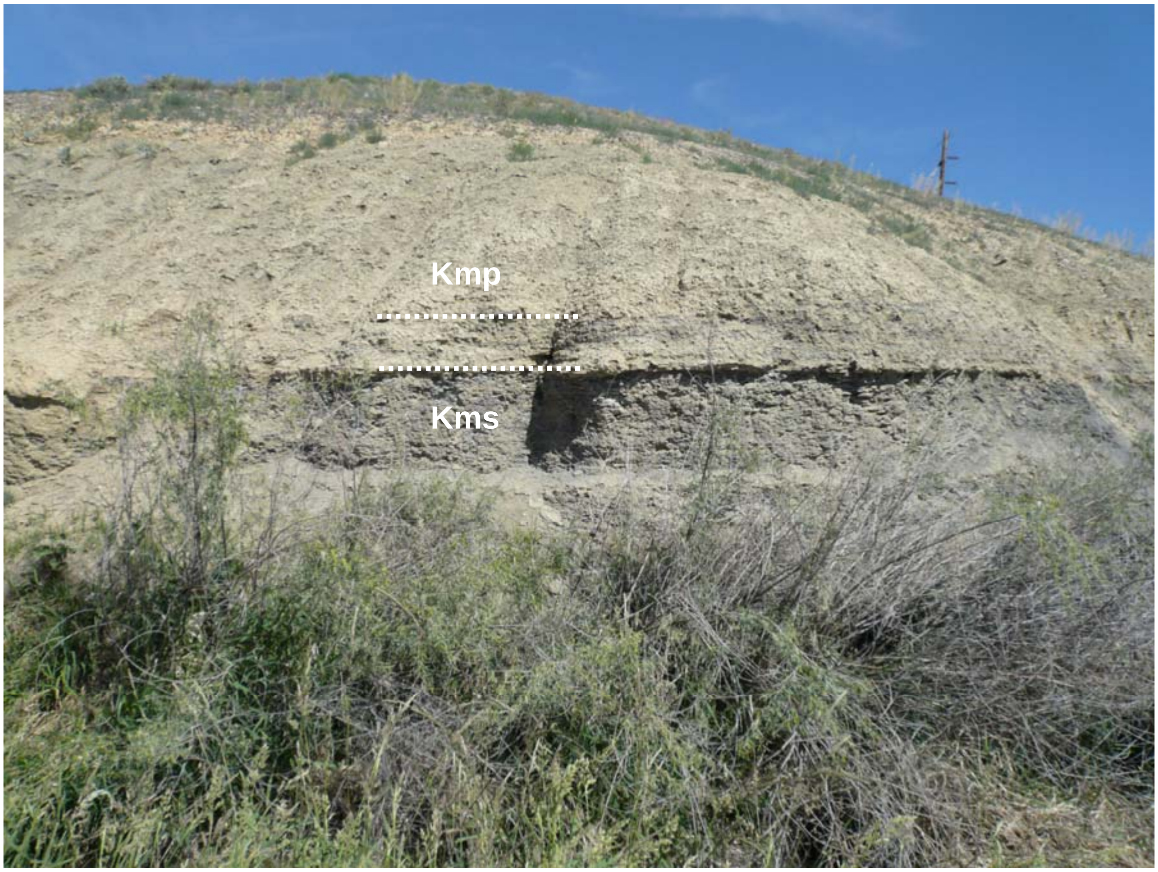

Figure 14. Photograph showing the gradational contact (dashed lines) between the Smoky Hill (Kms) and the Prairie Canyon (Kmp) Members of the Mancos Shale. The transition from calcareous shale (Kms) to sandy shale (Kmp) occurs within a 5 ft interval. The contact is best exposed on the north side of Sweitzer Lake State Park. The contrast in color between the Smoky Hill (gray) and Prairie Canyon (light-brownish-gray) is easily recognizable in the field. [UTMX: 235728.2, UTMY: 4289529.6].

The unit is equivalent to the sandy Mancos "B" interval (Kellogg, 1977) (at least in part) and the Prairie Canyon Member (Cole and others, 1997) in the Book Cliffs, and to the Cortez Member (Leckie and others, 1997) in southwestern Colorado. The lower part is equivalent to the middle and upper chalk and shale units of the Smoky Hill Member of the Niobrara Formation near Pueblo (Scott and Cobban, 1964), while the upper part is equivalent to the lower transition member and Apache Creek Sandstone Member of the Pierre Shale (Scott and Cobban, 1975; 1986). Noe and others (2007) collected *Cataceramus balticus* (inoceramid), and *Baculites sp.* (*haresi*?) in the Montrose area, which indicates that the unit is of Lower Campanian age (approx. 82 ma) (Cobban and others, 2006). Kellogg (1977) and Johnson (2003) interpreted the unit to be a south-to-north prograding shelf-slope deposit. Recent research (for example, Anderson, 2007) postulates that these may be offlobe, mud-rich, delta-front turbidite deposits. The thickness of this unit is approximately 340 to 380 feet but only the lower 60 feet is exposed in the mapped area. This is much thinner than the Prairie Canyon in the Book Cliffs (approx. 1,200 feet thick; Hettinger and Kirschbaum, 2002) and in northern Delta County (967 feet thick; Sawyer and others, in prep.). It is also much thinner than the Cortez Member at Mesa Verde (1,289 ft thick; Leckie and others, 1997).

The Prairie Canyon Member may be prone to landsliding in areas having ground-water discharge and seepage. In drier areas, thin-skinned landsliding and surficial creep of the residual layer is common, but deeper landsliding is uncommon. The unit contains moderately expansive clays, especially in the upper, shaly part of the section.

Kms **Smoky Hill and Fort Hays Limestone Members, undivided** — Blackish-gray to tan, slightly calcareous to silty, marine shale. The Fort Hays Limestone Member constitutes the bottom 50 ft of the unit. It is moderately fossiliferous, consisting of blackish-gray, slightly calcareous shale with abundant plant debris, shell fragments, and fish scales concentrated along bedding planes. Multiple bentonite beds are located throughout the bottom half of the unit. The Smoky Hill Member constitutes the upper 295 feet of the unit and consists of interbedded limestone and shale beds; the limestone beds are typically 12 inches thick and form flat-topped benches underlain by shale. Where exposed, they may weather to a golden color, giving the Smoky Hill a “blonde” appearance. It has been suggested the blonde coloration arises from the presence of the sulfate mineral jarosite, as a product of pyrite weathering; however, this process of coloration is still under investigation (R. Grauch, USGS, personal commun., 2006). The most well developed weathering zone occurs immediately below the ground surface; however, multiple “blonde” zones occur lower in the section where these limestone beds are exposed to weathering. Seams of gypsum, both fibrous and crystalline (selenite), are present throughout the unit.

The unit is equivalent to the Smoky Hill Member at Mesa Verde in southwestern Colorado (Leckie and others, 1997) and is probably equivalent to the lower and middle parts of the Smoky Hill Shale Member of the Niobrara Formation near Pueblo (Scott and Cobban, 1964). The Fort Hays Limestone Member, which underlies the Smoky Hill Shale Member in eastern and central Colorado, was recognized on the basis of lithologic criteria in the mapped area. Molenaar and others (2002) show the Fort Hays as pinching out near Pagosa Springs.

The upper contact of the Smoky Hill Member is gradational and possibly conformable. The lower contact with the Montezuma Valley Member, which was not definitively located within the mapped area, is reported to be a sharp, shale-on-shale contact that is part of a major, regional unconformity (Leckie and others, 1997).

Similar to the overlying Prairie Canyon Member, the Smoky Hill Member may be prone to landsliding in areas having ground-water discharge and seepage. The unit contains low to moderately expansive clays (NRCS, 2008); however, the middle part of the section may contain highly expansive clays.

Fossils collected within this unit include *Cremnoceramus deformis* (bivalve), *Cremnoceramus crassis* (bivalve) and an unidentified inoceremid. The exposed thickness of this unit in the mapped area is approximately 345 feet.

Kmj **Juana Lopez and Montezuma Valley Members, undivided** — Brown to orange-brown to gray, calcarenitic, and calcareous marine shale. On the basis of field observations, this unit is divided into two parts. The lower part (Juana Lopez Member) is a moderately to highly fossiliferous, sandy, calcarenitic shale that exhibits low-angle cross-bedding and laminar bedding. The bedded units probably represent distal turbidite facies (D. Anderson, Colorado School of Mines and B. Ball, USGS, personal commun., 2006). The lower unit forms a distinctive orange-brown ledges where exposed in the mapped area. The upper unit (Montezuma Valley Member) is gray, slightly fissile, silty, moderately calcareous shale, locally containing large concretions up to 3 feet in diameter. This part may correspond to the Montezuma Valley Member of the Mancos Shale at its type section in southwestern Colorado (as defined by Leckie and others, 1997). The contact with the overlying Smoky Hill Member is not well exposed. Fossils collected within this unit include: *Prionocyclus macombi* (ammonite), *Lopha lugubris* (oyster), *Inoceramus dimidius* (bivalve), *Princoyclus bosquensis* (ammonite), and *Mytiloides incertus* (bivalve), *Baculites sp*. The exposed thickness of the unit is approximately 150 feet. The Juana Lopez Member is low to moderately expansive, whereas the Montezuma Valley Member contains moderately expansive clays (NRCS, 2008).

Kmb **Blue Hill and Fairport Members, undivided** — Olive-green to dark-gray, glauconitic, non-fossiliferous, moderately to non-calcareous, silty, marine shale. The upper part of the unit consists of light- to dark-gray, platy, silty shale. Local seams of gypsum have caused the shale to part along bedding planes and fractures. Disc-shaped septarian concretions and calcareous sand lenses occur within the upper 20 feet of this unit. The middle part of the unit is olive-green, fissile shale with distinct bedding planes. The bedding surfaces often contain abundant glauconite grains and occasional coatings of yellow residue, presumably related to sulfide mineralization (pyrite). The glauconite and sulfide residue give the unit its overall olive-green appearance on weathered surfaces. The lower part of the unit is slightly silty, wavy-bedded, fissile shale. Glauconite and sulfide decreases to the base of the unit. Rare cone-in-cone structures (*see* Bates and Jackson (1987) for a complete definition and Ludgi and others (2005) for a discussion and references therein) are found within float derived from the Blue Hill shale. The cone-in-cone structures are found in 2 or 3 discontinuous layers and form a rind around concretions. The Fairport Member in the basal part of the unit was not specifically identified by biostratigraphy. The exposed thickness of the unit is approximately 150 feet. The Blue Hill and Fairport Members contains low expansive clays (NRCS, 2008); however, the upper part of the Blue Hill Member may contain moderately expansive clays.

Kmg **Graneros and Bridge Creek Limestone Members, undivided** — Soft, dark-gray to black to olive-green, slightly calcareous, marine shale that commonly weathers to small platy chips. Discontinuous, 8-inch-thick limestone beds occur in the middle and base of the unit. Most of the unit has distinct bedding planes that may be coated by gypsum crystals. The upper 25 feet of the unit consists of interbedded limestone, calcareous shale, and marlstone of the Bridge Creek Limestone Member. Fossils of *Pycnodote aff. kellumi* (bivalve) were collected approximately 15 feet below the Bridge Creek Limestone Member. Glauconite and sulfide residue are locally present within the upper half of the unit. The exposed thickness of the unit in the mapped area is approximately 140 feet. The Graneros Member contains moderately to highly expansive clays (NRCS, 2008) and the Bridge Creek Member contains areas of low expansive clays.

Kd **Dakota Sandstone (Upper Cretaceous)** —The Dakota Sandstone is composed of well sorted, very fine- to medium-grained, light-brown to yellow-brown, silica-cemented sandstone interbedded with gray to black siltstone and carbonaceous shale. Symmetrical ripple marks and burrows (typically *Thalassinoides*) are present on bedding planes of some sandstone beds. The paleoenvironmental setting for the Dakota Sandstone has been interpreted by Weimer (1970) as a marine regression represented by the increase in clastic sedimentation due to shifting in the distributary channels on the Cretaceous coastal plain. The approximate thickness of the Dakota Sandstone in the mapped area is 100 feet.

The Dakota Sandstone and Burro Canyon Formation are shown as undivided on the cross section (Plate 2). In the adjacent Hoovers Corner quadrangle (White and others, 2008), the Burro Canyon Formation consists of low- to high-angle, cross-bedded medium to fine-grained sandstone and well rounded, chert and quartz pebble conglomerate, interbedded with green-gray to pale-green and rare maroon mudstones. However, it is not exposed within the Delta quadrangle. The Burro Canyon Formation was created by a vast fluvial system; Hansen (1987) suggested the chert and quartz pebbles were transported from as far away as Utah and Nevada. Thickness of the Burro Canyon Formation is approximately 12 to 60 feet in the adjacent Hoovers Corner quadrangle (White and others, 2008).

Jm **Morrison Formation (Upper Jurassic)** — **Shown on cross-section only.**

Jw **Wanakah Formation (Middle Jurassic)** — **Shown on cross-section only.**

Je **Entrada Sandstone (Middle Jurassic)** — **Shown on cross-section only.**

Pc **Precambrian Rocks** — **Shown on cross-section only.**

STRUCTURAL GEOLOGY

Northeasterly tilting and rejuvenated movement along basement faults bounding the Uncompahgre Uplift during the Laramide Orogeny resulted in gentle folding and the shallow northeasterly dip of the Cretaceous rocks in the western part of the mapped area (Tweto, 1977; Stone, 1977). Near the uplift in the southwestern corner of the mapped area, the Dakota Sandstone strikes N60W and dips 3° to the northeast. This gentle dip and general strike of the beds are reflected over much of the map; however, small structures likely related to the Uncompahgre Uplift do affect the Mancos Shale in areas and create variations in the bedding attitudes.

The structure in the area is characterized by anticlinal, synclinal, and monoclinal folds of Laramide and possibly post-Laramide age. The best exposed monocline in the mapped area occurs in secs. 27-28, T.15 S., R. 96 W. where the Juana Lopez Member is downwarped to the south, resulting in a change in dip from nearly horizontal on the syncline apex to 6 degrees S on the steep limb. This structure is best seen along 1250 Road on the adjacent Roubideau quadrangle. Further to the south (secs. 16-17, T. 51 N., R. 11 W.) a small anticline, inferred from bedding measurements, affects the Blue Hill and Juana Lopez Members. In this same general area, smaller-scale, subsidiary folds and faults were found within the Juana Lopez Member (figure 15). The trends of the larger structures is nearly E-W and are likely related to the Uncompahgre Uplift, although on the Delta quadrangle they could not be traced westward into the Uplift proper. However, on the adjacent Hoovers Corner quadrangle (White and others, 2008), similar monoclines and synclines are found in the Uncompahgre Plateau. These NE-SW-trending structures deform the Morrison Formation through Dakota Sandstone and can be clearly traced eastward into Mancos Shale.

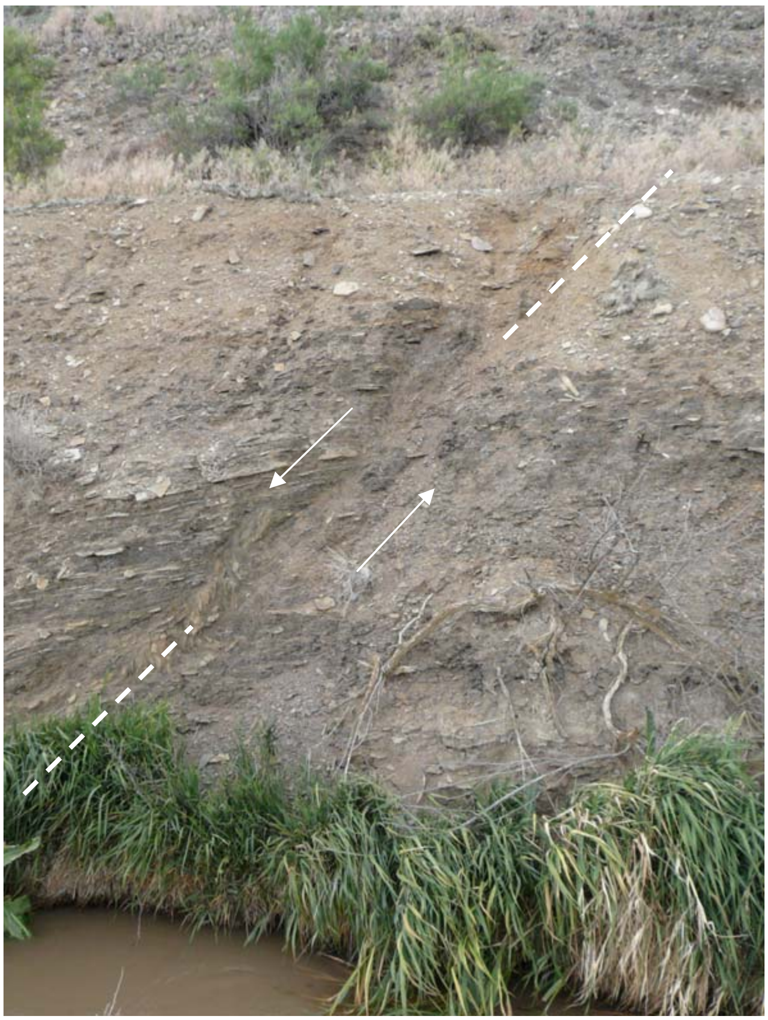

Figure 15. A small fault offsetting beds within the Juana Lopez Member of the Mancos Shale. Total stratigraphic offset is approximately 3 ft. Dashed line gives the approximate location of the fault plane and arrows indicate sense of movement suggestive of normal faulting. This may be a post-Laramide structural feature. [UTMX: 230650.0, UTMY: 4283645.5]

GEOLOGIC HAZARDS

Bedrock structure, hydrogeology, topography, surface drainage, and lithology are important controls on the development of geologically hazardous areas within the Delta quadrangle. Landslides within the Mancos Shale affect most of the mesa edges where residential development is increasing. Mudflows as well as hydrocompactive and swelling soils are also impacting residential and commercial structures throughout the area. Other significant and potentially damaging hazards in the mapped area include corrosive and erodible soils and earthquakes.

Landslides

Landslides are prevalent on the slopes flanking the gravel-capped mesas over much of the quadrangle. The landslide debris is almost exclusively a mixture of weathered and disturbed Mancos Shale and gravelly alluvium. The slope failures are mainly rotational and translational slides where failure typically occurs within the heavily weathered, fractured, and weakened shale (figure 16). Accelerated ground creep and earthflows may also occur if slopes become fully saturated. Ground water infiltrates through the permeable gravel that caps the mesa and perches on the more impermeable shale. The ground water flows laterally to the flank of the mesa where springs and ground seeps occur. Water also slowly seeps into the shale causing further weakening of the bedrock by additional weathering, increased pore pressure, and/or dissolution of gypsum fracture filling (figure 17). Pore pressure and the accelerated weathering of the shale meet a threshold where steep slopes are unable to support themselves and the earth materials begin to shear and move downward. The resulting landslides typically occur along gullies or steep hillsides that rim the mesas.

Occurrences of landslides within the quadrangle follow the morphology of mesa rims underlain by the Mancos Shale and appear independent of geologic structure. Landslides are accelerated by agricultural practices in the Uncompahgre Valley. Additional runoff and infiltration from farmland irrigation further lubricates fractures and increases the pore pressure of the overburden alluvium and weathered bedrock, which reduces the inherent stability of the slope.

Figure 16. Damage to 1575 Road caused by a rotational landslide within the Mancos Shale. The road is now closed to vehicular traffic. [UTMX: 233542.8, UTMY: 4288560.2]

Figure 17. A recent landslide complex near 1600 Road. Multiple landsliding events have created dozens of terracettes (number 3, red hachured lines) and closed depressions and removed several acres of property from nearby homes. Water seeps (number 2), exposed within the main headscarp (number 1, yellow hachured lines) below the Qau_3 gravel surface, lubricated the already weathered and weakened Mancos Shale, and caused the slope failures. [UTMX: 234005.2, UTMY: 4287891.1]

Debris Flows (Mudflows)

Debris flows are dense, heterogeneous mixtures of mud, rock fragments, and plant materials that typically follow preexisting drainages (Varnes, 1978). As the debris flow moves down its valley, its size and power increase, and it incorporates additional materials into the flow. Once the flow reaches an area of lower gradient, the flow drops its load and the suspended sediment is deposited at the mouth of the drainage (Varnes, 1978). Debris flows can form at any point along a drainage including on the sides of valleys. They are the result of torrential rainfall or very rapid snowmelt runoff, where sediment supply is abundant and easily mobilized (Selby, 1993). Many times, soil slips and earthflows within steep basins can also manifest themselves as debris flows during periods of high precipitation.

Much of the area east and southeast of Sweitzer Lake State Park and adjacent to Buttermilk and Seep Creeks on the far west side of the mapped area consists of mud-dominated alluvium and alluvial fan deposits (Qamf). These sediments were derived mostly from the Mancos Shale and were deposited as sheetflow mudflows, mud-and-gravel debris flows in channels, or in local drainage basins. Small, localized debris flows occur in areas mapped as alluvial fans (Qf) and landslides (Qls); however, these debris flows are of limited extent and are not mapped separately. Residents living within or in close proximity to these deposits and their associated drainageways should be aware of the possibility of large precipitation events triggering future debris flows that may inundate these areas with dangerous amounts of water and sediment.

Rockfall

Rockfall deposits are included in the landslide (Qls) deposits in the Delta quadrangle. Much of the rockfall hazard occurs along the mesa edges where loose cobbles and boulders overlie unconsolidated Mancos Shale. Rockfall hazard is also associated with the Dakota Sandstone. Joints within the unit have caused large blocks to spall from cliff faces and it is interbedded with weak shale, siltstone, and coal seams that weather more rapidly and undermine the sandstone. Large precipitation events and freeze-thaw processes may trigger rockfall. Areas mapped as Qls are susceptible to future rockfall events; developers and homeowners should be cautious when building in proximity to these areas.

Earthquakes

Minor seismic activity has been recorded in the Delta-Montrose area. In May of 1992, the U.S. Geological Survey measured an earthquake of magnitude 2.8 approximately 5 miles southeast of Olathe, and on January 13, 1962, a magnitude 4.4 event occurred approximately 6.5 miles southwest of Montrose in the adjacent Montrose East quadrangle

(Kirkham and others, 2004). Both events were felt at intensity IV (Scale I-XII) in Olathe and Montrose (Kirkham and others, 2004). The Olathe event lies along the trend of the Cimarron and Red Rocks faults, which are suspected to have middle to late Quaternary movement (Lettis and others, 1996). On October 11, 1960, the largest instrumentally recorded earthquake in Colorado measured magnitude 5.5 and occurred approximately 15 miles southeast of Montrose (Kirkham and others, 2004). This event was felt at intensity V in Olathe and damaged buildings in Montrose and nearby communities.

Additional information on faulting and earthquakes in this area is described in the CGS Colorado Earthquake Map Server (Kirkham and others, 2004) or the Colorado Late Cenozoic Fault and Fold Database and Internet Map Server (Widmann and others, 2002). Both are available for no charge on-line at *http://geosurvey.state.co.us*.

Swelling Soils

Certain parts of the Mancos Shale and surficial units derived from the Mancos Shale may undergo volumetric swelling when wetted due to the presence of bentonite, smectite, and expansive clay minerals. These clays are prevalent in marine shales of Cretaceous age in the North American mid-continent. Upon wetting, these clay minerals, which are relatively dry under natural climate conditions, draw water into their crystalline matrices and expand to accommodate the added water molecules (Noe, 2007). The hydration and expansion of the microscopic clay platelets can result in high swell pressures in the soil. The expansion of clays results in ground heaving and potential damage to residential, private, and public buildings, retaining walls, paved roads, concrete flatwork, and underground utility pipes.

In the Delta quadrangle, the Graneros and Smoky Hill Members of the Mancos Shale (Kmg and Kms) contain clay-rich zones that may be prone to swelling in near-surface bedrock. Derived soils, particularly the alluvial mudflow (Qamf) deposits, may contain pockets or zones of swelling clays. Derivative maps of the NRCS Soil Survey of the Montrose-Delta area indicate that the Mancos Shale and surficial deposits derived from the Mancos (in particular Qamf deposits) have a moderate (3-6) to high (6-9) linear extensibility. Linear extensibility is a measure of a soils shrink-swell behavior; “moderate” refers to 18-35% mixed or smectitic clays and “high” is >35% mixed or smectitc clays (NRCS, 2008).

Depending upon the clay mineralogy and mode of sediment deposition, there can be wide lateral variability in swell susceptibility. For this reason, the detection and assessment of swelling soil conditions is best accomplished on a site-specific basis to properly design foundations and other civil works. This involves the drilling or excavating test holes, typically to depths of up to 20 feet, recovering samples from critical strata and depths, and testing the properties of those samples. A number of tests including Atterberg limits and swell/consolidation measure the plasticity and swell potential of the samples.

Collapsible Soils and Bedrock

Both the Mancos Shale and surficial units derived from the Mancos Shale are prone to collapse and settlement. Where weathered Mancos Shale is near the surface, growth of gypsum crystals typically occurs along bedding planes and fractures. Increased mineralogical volume changes from the formation of gypsum in this reaction can create crystallization pressures that force or wedge apart bedding planes and fractures, causing the rock to heave. Upon further wetting, subsequent dissolution of the gypsum can create subsurface voids that may cause the weathered claystone to collapse or recompress when loaded (White and Greenman, in prep.).

Surficial deposits derived from the Mancos Shale are especially prone to hydrocompaction and dispersion. In these dry deposits, the addition of water causes soil-binding agents to weaken and the loose soil skeletal fabric to collapse, which allows the soil particles to reorient into a more compact structure. This often results in ground settlement. Collapse typically occurs in matrix-supported deposits where clay-, silt-, and fine-sand-sized particles dominate the matrix. Furthermore, dissolution of gypsum within these deposits may also contribute to long term settlement.

Dispersion is a form of piping erosion and is a function of the mineralogy and specific soil chemistry. In the presence of fresh water, clay particles with high sodium ion content easily mobilize and disperse in water. Pseudokarst land features, such as sinkholes, pipes, soil bridges, and other subsurface voids are typical manifestations of soil dispersion in these collapse-prone units. Some of the voids are large enough to engulf people, cattle, and farm implements. Soils that are susceptible to hydrocompaction and dispersion-collapse phenomena may exist in areas mapped as alluvial fans (Qf), and alluvium and mudflow deposits (Qamf).

Damage such as cracking of foundations and other structural problems can be caused by ground settlement, sinkholes, subsurface voids, and heaving, usually as a result of adverse wetting and structural loading. Dry density, moisture content, and swell-consolidation tests are usually performed to determine the degree of potential hydrocompaction. Crumb tests, pinhole tests, double hydrometer tests, and measurement of soluble salts and calculation of the Sodium Absorption Ratio (SAR) are more specialized tests to determine the potential of soil dispersion (White and Greenman, in prep.). Because of the frequency of subsurface voids and potential for long-term settlement, residents should be cautious when building upon or traversing the units mapped as Qf and Qamf.

Some of the bedrock zones and soil deposits may have both collapse and swelling properties. The actual reaction of the bedrock to introduced water may depend on its clay mineralogy, the natural moisture content, the presence and abundance of gypsum, and applied external load (weight of a structure). The reaction of the soil to wetting may depend on its porosity and internal skeletal fabric, in addition to clay mineralogy, moisture contents, and applied load. Instances occur where certain soil deposits and weathered bedrock may slightly swell upon wetting but quickly settle or collapse upon incremental loading. Such conditions need to be assessed by professional engineering geologists or geotechnical engineers and taken in account during the design of structure foundations, concrete slabs, and road pavements.

Erodible Soils

Wind and water runoff are the biggest causes of erosion; however, these are amplified by development and grazing of vegetated lands where the soil is exposed and easily eroded. Exposed bedrock of the Mancos Shale and its surficial derivatives are susceptible to moderately high erosion, especially where vegetation is naturally absent or has been removed (NRCS, 2008) and where slopes are at least moderately steep. Soils with a high silt fraction are the easiest to erode and produce high rates of runoff. The NRCS estimates that 86 tons per acre per year of soil erosion is possible from the Mancos Shale and silty surficial units. The least susceptible areas of erosion correspond to the gravel-capped mesas and Dakota Sandstone.

There is a close correlation between the severity of wind erosion and the texture of the surface layer, the size and durability of surface clods, rock fragments, humus, and amount of $CaCO_3$ in the soil. In the mapped area, $CaCO_3$ helps bind the matrix of the soil and rock fragments armor the soil and keep erosion to a minimum. Wind velocity, soil moisture and frozen soil layers also influence wind erosion. The estimates for erosion are based primarily on percentage of silt, sand, and organic matter and on soil structure and saturated hydraulic conductivity (NRCS, 2008).

Wind erosion may also adversely affect the respiratory functions of humans and livestock by reducing air quality by increasing airborne dust. Furthermore, soil erosion increases the risk of pollution to surface and ground waters due to the use of pesticides from agricultural and residential treatment of vegetation.

Some local residents report suffering from intermittent bouts of shaking, insomnia, headaches, numbness, chest tightness, and high blood pressure. These adverse health effects may be caused by selenium poisoning or selenosis (MedicineNet.com, 2006). The selenium is found in the Mancos Shale and soils derived from the Mancos Shale. It is commonly inhaled by humans and livestock during and following wind storm events. Precipitation brings the selenium and other salts to the surface resulting in crusts that form on the surface soils when they become dry. Deep percolation from irrigation and significant quantities of ground water movement may increase selenium concentrations in streams, ponds, reservoirs, lakes and wetland areas (Gunnison Basin Selenium Task Force, 2008).

Corrosive Soils

The Mancos Shale and sediments derived from the Mancos Shale typically have high salt and sulfate content and should be considered a potentially corrosive soil. Corrosive soils may damage typical concrete and buried metal. According to a local resident, a one-inch-thick steel pipe was nearly dissolved after only one year of burial two feet below the ground. Residents should frequently examine any pipes or storage tanks (i.e. propane) that are exposed to these soils for signs of corrosion. Areas mapped as Mancos Shale, landslides (Qls) and alluvial-fan and mudflow deposits (Qamf) are prone to high rates of corrosiveness for steel and concrete (NRCS, 2008), in particular, the area south of Garnet Mesa near Sweitzer Lake State Park. The use of PVC pipes and plastic tanks, cathodic protection, or corrosion-resistant coatings is highly recommended in these areas. Most geotechnical consultants in the Delta area specify special corrosion-resistant concrete mixes for foundations and slab-on-grade, as well as protective coatings for buried metalworks. Tests for corrosive soils include sulfate and chloride levels, pH, and electroconductivity measurements.

MINERAL RESOURCES

Sand and gravel are presently the most economically significant mineral resources in the Delta quadrangle. Four active aggregate mines are located in the mapped area; the most productive is the Benton Dawson Pit, which produces 6,500 tons of aggregate per year (Guilinger and Keller, 2004). Production data for the other mines in the area is sparse. From the 1947 through 1956, three oil and gas wells were drilled and subsequently abandoned. No production information is listed for these wells (Colorado Oil and Gas Conservation Commission website at http://oil-gas.state.co.us). According to local residents, clay from the Mancos Shale was used to produce “adobe” bricks for building stone. Many of these turn-of-the-century structures are still standing today throughout the area.

Potential exists for the development of additional sand and gravel operations in the significant alluvial deposits in the mapped area and shale outcrops may provide clay for brick production. Figure 18 shows the locations of the currently active gravel pits and inactive oil and gas wells within the quadrangle.

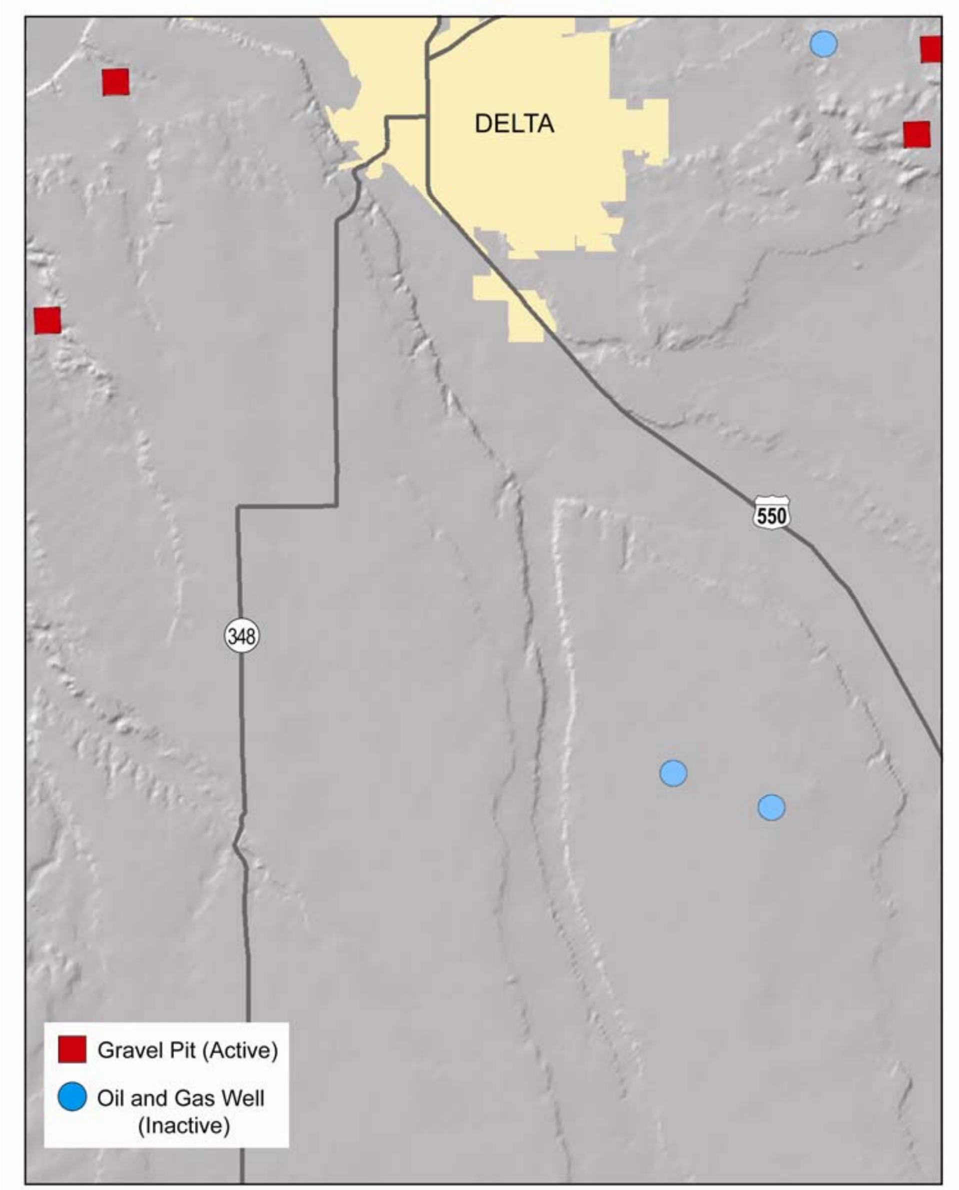

Figure 18. Location of active gravel pits and inactive oil and gas wells in the Delta quadrangle.

SURFACE and GROUND-WATER RESOURCES

The primary source of domestic drinking water within the Delta quadrangle comes from the Gunnison River (M. Catlin, Uncompahgre Valley Water Users Association, personal commun., 2007). The water is stored in the Taylor Park, Blue Mesa, Morrow Point, and Crystal Reservoirs and is then transported to the local communities via the 5.8 mile-long Gunnison Tunnel. A complex system of canals and diversion dams makes the water available for agricultural use.

Other important sources of domestic drinking water are from alluvial and bedrock wells. Depending on location, ground water can be found in two hydrogeologic units: (1) consolidated bedrock aquifers found in the Dakota Sandstone, or (2) Quaternary alluvium. The following sections describe each of these hydrogeologic units and provide information about general hydrogeologic characteristics of the units gathered from available literature. The scope of this discussion is limited to providing a general description of the ground-water resources that might be available within the quadrangle; further details, such as specifics about water quality, surface water, and current water level data can be obtained from available literature. Additional information on ground water in Colorado is in the CGS Ground Water Atlas of Colorado (Topper and others, 2003).

Alluvial Aquifers

A majority of the ground water for domestic use comes from the Quaternary alluvial deposits associated with the Uncompahgre and Gunnison Rivers. These alluvial aquifers are part of the Gunnison River basin, which extends west from the Continental Divide to Grand Junction and south to Telluride (Topper and others, 2003). Much of the alluvial deposits are in direct hydraulic connection with the rivers and form unconfined aquifers where saturated with ground water. The areal extent of the alluvial aquifer roughly coincides with the areal extent of the alluvium; however, the alluvium is not always saturated with ground water and the presence of alluvium at the surface does not imply the presence of an aquifer at depth.

On the basis of records obtained from the Colorado Department of Water Resources (DWR), water levels in wells completed in the alluvial aquifer generally lie between 5 feet and 40 feet below the surface. The areal extent of the alluvial aquifer, therefore, would be expected to be somewhat smaller than that of the alluvium. Well depths drilled into the alluvium average 57 feet and well yields are typically 15 GPM and do not significantly fluctuate by location.

Recharge of the alluvial aquifer occurs via natural precipitation, infiltration from the surface water canal system (Meeks, 1950), and from the Uncompahgre River and its tributaries (Topper and others, 2003). The alluvial water can be high in $CaCO_3$, resulting in hard water and requiring the use of a water softener (Meeks, 1950). Within the mapped area, the Uncompahgre and Gunnison Rivers and Sweitzer Lake are listed as “Selenium Impaired Stream Segments” meaning that the waters “do not meet, or do not expect to meet, applicable water quality standards” (Gunnison Basin Selenium Task Force, 2008). Efforts are currently underway by private, local, state, and federal agencies to find ways to reduce the amount of selenium in these waters. Due to the possibility of natural and human contamination from surface waters and the introduction of salts from bedrock shale units, it is recommended that residents using alluvial water for domestic purposes complete a water quality test.

Bedrock Aquifers

The Dakota Sandstone is the primary bedrock aquifer in the mapped area for both domestic and livestock uses where ground-water from alluvial aquifers is not feasible. Regionally, sandstone bodies in the lower part of Mancos Shale are also used for domestic water, but to a limited extent (Meeks, 1950). Southwest of the mapped area, in Shavano Valley, the Morrison Formation is a common domestic water target (Meeks, 1950). No water wells in the Delta quadrangle produce from either the Mancos Shale or the Morrison Formation.

The Dakota Sandstone generally consists of well sorted, very fine- to medium-grained, light-brown to yellow-brown sandstone interbedded with gray to black siltstone and carbonaceous shale. The porosity of the sandstone beds is highly variable and is not published for the Delta area. On the basis of surface outcrops and well logs, the potential thickness of the Dakota Sandstone aquifer ranges from about 100 to 180 feet in the mapped area (Meeks, 1950). The aquifer may be confined to partially confined, and artesian wells occur in some locations.

Water-level data for the Dakota aquifer can be obtained from the Division of Water Resources (DWR) well permit files. Well-completion reports and pump-installation reports for wells often list the water levels that existed when the wells were completed. These data are one-time measurements and thus, the reported water level is not necessarily representative of current conditions in the well. Water levels in the Dakota aquifer can be expected to vary considerably depending on location and elevation; values listed in the DWR permit database are between 104 and 845 feet below the surface. Well yields from the

Dakota aquifer within the quadrangle typically range from 3 to 6 GPM and average 4 GPM. Ground water from the Dakota Sandstone aquifer is considered "tributary" and directly connected to surface water (Hobbs, 2004). Thus, this ground water is subject to the State of Colorado surface water appropriations system.

According to Meeks (1950) water from the Dakota aquifer tends to contain sodium bicarbonate that can impart a distinctive taste to the water. The quality of the water decreases from west to east, but is typically better near the recharge zone on the east flank of the Uncompahgre Uplift (Meeks, 1950). In general, water quality of the Dakota aquifer in the area is adequate for domestic use with total dissolved solids (TDS) values ranging from approximately 210 to 4,200 mg/L and averaging 1,845 mg/L (Meeks, 1950).

REFERENCES CITED

Anderson, D., 2007, Turbidites in the Western Interior Cretaceous Seaway – the known and the possible (abs.): Presentation for Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, Denver, Colo., January 30, 2007.

Apodaca, L.E., and Bails, J.B., 2000, Water quality in the alluvial aquifers of the Southern Rocky Mountains physiographic province, upper Colorado River basin, water years 1972-92: U.S. Geological Survey Water-Resources Investigations Report 99-4222.

Armstrong, R.L., 1968, Sevier orogenic belt in Nevada and Utah: GSA Bulletin, v. 79, p. 429-458.

Ball, B.A. Cobban, W.A., Grauch, R.I., McKinney, K.C., Livo, K.E., Sawyer, D.A., and Merewether, E.A., 2006, A new core of the Mancos Shale (USGSCL-1), Gunnison Gorge National Conservation Area, Montrose County, Colorado: *in* Larson, N.L. and Landman, N.H., eds, A symposium on the paleontology, geology and stratigraphy of the Late Cretaceous Western Interior seaway, Black Hills Museum of Natural History, Hill City, SD, p. 13-14.

Bates, R.L., and Jackson, J.A., 1987, Glossary of geology, third edition: American Geological Institute, Alexandria, VA.

Cobban, W.A., and Scott, G.R., 1972, Stratigraphy and ammonite fauna of the Graneros Shale and Greenhorn Limestone near Pueblo, Colorado: U.S. Geological Survey Professional Paper 645, 101 p.

Cobban, W.A., Walaszczyk, I., Obradovich, J.D., and McKinney, K.C. 2006, A USGS zonal table for the Upper Cretaceous Middle Cenomanian-Maastrichtian of the Western Interior of the United States based on ammonites, inoceramids, and radiometric ages: U.S. Geological Survey Open-File Report 2006-1250.

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

Dickinson, R.G., 1965, Geologic map of the Cerro Summit quadrangle, Montrose County, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-486, scale 1:24000.

Dickinson, R.G., 1987, Geologic map of the Buckhorn Lakes quadrangle, Montrose County, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-1642, scale 1:24,000.

Foos, Anabelle, 2006, Geology field trip guide to the Colorado Plateau: National Park Service on-line guidebook, http://www2.nature.nps.gov/geology/education/foos/plateau.pdf.

Geological Society of America, 2000, Munsell Soil Color Chart, MC-01.

GretagMacbeth, 2000, Munsell® soil color charts, year 2000 revised washable edition: New Windsor, NY, GretagMacbeth, LLC.

Guilinger, J.R., and Keller, J.W., 2004, Directory of active and permitted mines in Colorado – 2002: Colorado Geological Survey Information Series 68.

Gunnison Basin Selenium Task Force, 2008, http://www.seleniumtaskforce.org/, accessed February 28, 2008.

Hail, W.J., 1986, Geologic reconnaissance map of the Government Springs quadrangle, Montrose and Ouray Counties, Colorado: U.S. Geological Survey, Open-File Report OF-86-162, scale 1:24000.

Hail, W.J., 1986, Geologic reconnaissance map of the Montrose West quadrangle, Montrose County, Colorado: U.S. Geological Survey Open-File Report OF-86-163, scale 1:24000.

Hail, W.J., 1987, Geologic map of the Colona quadrangle, Montrose and Ouray Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-2003, scale 1:24000.

Hansen, W.R., 1968, Geologic map of the Black Ridge quadrangle, Delta and Montrose Counties, Colorado: U.S. Geological Survey, Geologic Quadrangle Map GQ-747, scale 1:24000.

Hansen, W.R., 1971, Geologic map of the Black Canyon of the Gunnison River and vicinity, western Colorado: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-584, scale 1:31680.

Hansen, W.R, 1987, The Black Canyon of the Gunnison – in depth: Tucson, Arizona, Southwest Parks and Monuments Association, 58 p.

Hettinger, R.D., and Kirschbaum, M.A., 2002, Stratigraphy of the Upper Cretaceous Mancos Shale (upper part) and Mesaverde Group in the southern part of the Piceance and Unita Basins, Colorado and Utah: U.S. Geological Survey Geologic Investigations Series I-2764, 21 p., 2 plates.

Hobbs, Jr., Gregory, 2003, Citizen’s Guide to Colorado Water Law: Colorado Foundation for Water Education, 33 p.

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

Ingram, R.L., 1989, Grain-size scales used by American geologists – modified Wentworth scale, *in* Dutro, J.T., Jr., Dietrich, R.V., and Foose, R.M. (Compilers), AGI data sheets, 3rd Edition: Alexandria, VA, American Geological Institute, Sheet 17.1.

Johnson, R.C., 2003, Depositional framework of the Upper Cretaceous Mancos Shale and the lower part of the Upper Cretaceous Mesaverde Group, western Colorado and eastern Utah: U.S. Geological Survey Digital Data Series DDS-69-B, 24 p., 1 plate.

Kellogg, H.E., 1977, Geology and petroleum of the Mancos B Formation, Douglas Creek Arch, Colorado, *in* Veil, H.K., ed., Exploration frontiers of the central and southern Rockies: Rocky Mountain Association of Geologists 1977 Symposium, p. 167-179.

Kirkham, R.M., Rogers, W.P., Powell, L., Morgan, M.L., Matthews, V., and Pattyn, G.R., 2004, Colorado Earthquake Map Server: Colorado Geological Survey Bulletin 52b, http://geosurvey.state.co.us/pubs/eq/.

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.

Lettis, W., Noller, J., Wong, I., Ake, J., Vetter, U., and LaForge, R., 1996, Draft report, Seismotectonic evaluation of Colorado River storage project-Crystal, Morrow Point, Blue Mesa dams, Smith Fork project-Crawford dam, west-central Colorado: unpublished draft report prepared by William Lettis & Associates, Inc., Woodward-Clyde Federal Services, and Seismotectonics and Geophysical Group of the U.S. Bureau of Reclamation in Denver, Colorado, 177 p.

Lugli, Stefano, Reimold, W.U., and Koeberl, Christian, 2005, Silicified cone-in-cone structures from Erfoud (Morocco) — A comparison with impact-generated shatter cones *in* Koeberl, C., and Henkel, H., Impact Tectonics (Impact Studies): Springer-Verlag, Berlin, Germany, p. 81-110.

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

Marshall, C.H., 1959, Photogeologic map of the Delta quadrangle, Montrose and Delta Counties, Colorado: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-282, scale 1:62,500.

McGookey; D.P., Haun, J.D.; Hale, L.A.; Goodell, H.A.; McCubbin, D.G.; Wreimer, R.J.; Wulf, G.R.; and Cobban, W.A., 1972, Cretaceous system, *in* Mallory, W.W.; Nolte, C.J.; Jensen, F.S.; and Griffith, E.G. (eds.), Geologic atlas of the Rocky Mountain region: Denver, Rocky Mountain Association of Geologists, p. 190-228.

MedicineNet.com, 2006, Definition of Selenosis: http://www.medterms.com/script/main/art.asp?articlekey=39069, accessed November 1, 2006.

Meeks, T.O., 1950, Reconnaissance of ground-water conditions in the Uncompahgre Valley, Colorado: U.S. Department of Agriculture, Soil Conservation Service Regional Bulletin 112, Geological Series 3, 21 p.

Merewether, E.A., Sawyer, D.A., and Cobban, W.A., 2006, Molluscan fossils and stratigraphic descriptions from the Upper Cretaceous Mancos Shale, west-central Colorado: U.S. Geological Survey Open-File Report 2006-1326.

Morgan, M.L. and White, J.L., 2007, Development of the Loutsenhizer drainage basin and associated collapsible soils, Montrose and Delta Counties, western Colorado: Geological Society of America Abstracts with Programs, v. 39, n. 6, p. 195.

Morgan, M.L., Noe, D.C., and Keller, S.M., 2007, Geologic map of the Olathe quadrangle, Montrose County, Colorado: Colorado Geological Survey Open-File Report OF-07-01, scale 24,000.

National Resources Conservation Service, 2008, On-line soil survey data for Montrose County: http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx. Accessed January 21, 2008.

Noe, D.C., 2007, A guide to swelling soil for Colorado homebuyers and homeowners, second edition: Colorado Geological Survey Special Publication 43, 52 p.

Noe, D.C., Morgan, M.L., and Townley, S.M., 2008, Geologic map of the Olathe NW quadrangle, Delta County, Colorado: Colorado Geological Survey Open-File Report OF-08-01, scale 1:24000.

Noe, D.C., Morgan, M.L., and Keller, S.M., 2007, Geologic map of the Montrose East quadrangle, Montrose County, Colorado: Colorado Geological Survey Open-File Report OF-07-2, scale 1:24000.

Sawyer, D.A., Kellogg, K.S., Cobban, W.A., Merewether, E.A., and Hansen, W.R., in prep., Geologic map of the Mancos Shale in the Gunnison Gorge National Conservation Area, Delta and Montrose Counties, Colorado: U.S. Geological Survey Open-File Report (number not assigned).

Scott, G.R., 1969, Geologic map of the southwest and southeast Pueblo quadrangles, Colorado: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-597, scale 1:24,000.

Scott, G.R., and Cobban, W.A., 1964, Stratigraphy of the Niobrara Formation at Pueblo, Colorado: U.S. Geological Survey Professional Paper 454-L, 27 p.

Scott, G.R., and Cobban, W.A., 1975, Geologic and biostratigraphic map of the Pierre Shale in the Canyon City-Florence basin and Twelvemile Park area, south-central Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-937, scale 1:48,000.

Scott, G.R., and Cobban, W.A., 1986, Geologic and stratigraphic map of the Pierre Shale in the Canyon City-Florence basin and Twelvemile Park area, south-central Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-937, scale 1:100,000.

Selby, M.J., 1993, Hillslope materials and processes: Oxford, Oxford University Press, 451 p.

Sinnock, S., 1978, Geomorphology of the Uncompahgre Plateau and Grand Valley, western Colorado, USA: Ph.D. Dissertation, Purdue University, West Lafayette, IN, 201 p., 2 map plates, scale 1:84,210.

Stone, D.S., 1977, Tectonic history of the Uncompahgre Uplift: Rocky Mountain Association of Geologists 1977 Symposium, p.11-21.

Topper, R., Spray, K.L., Bellis, W.H., Hamilton, J.L., and Barkmann, P.E., 2003, Ground water atlas of Colorado: Colorado Geological Survey Special Publication 53, 210 p.

Tweto, Ogden, 1977, Tectonic history of west-central Colorado: Rocky Mountain Association of Geologists 1977 Symposium, p.11-21.

Varnes, D.J., 1978, Slope movement types and processes, *in* Schuster, R. L., and Krizek, R. J., eds, Landslides – analysis and control: Washington D.C., TRB, National Research Council, p. 11-33.

Weimer, R.J., 1970, Dakota Group (Cretaceous) stratigraphy, southern Front Range, South and Middle Parks, Colorado: The Mountain Geologist, v. 7, no. 3, p. 157-184.

Wentworth, C.K., 1922, A scale of grade and class terms for clastic sediments: Journal of Geology, v. 30, p. 377-392.

White, J.L., and Greenman, C., in prep, Collapsible Soils in Colorado: Colorado Geological Survey Engineering Geology Bulletin.

White, J.L., and Morgan, M.L., 2007, Landslides in the Uncompahgre valley of western Colorado and impacts to mixed agricultural and residential land usage: Geological Society of America Abstracts with Programs, v. 39, n. 6, p. 195.

White, J.L., Williams, F., Morgan, M.L., and Townley, S.M., 2008, Geologic Map of the Hoovers Corner Quadrangle, Montrose County, Colorado: Colorado Geological Survey Open-File Report 08-03, scale 1:24,000.

Widmann, B.L., Kirkham, R.M., Morgan, M.L., and Rogers, W.P., with contributions by Crone, A.J., Personius, S.F., and Kelson, K.I., and GIS and Web design by Morgan, K.S., Pattyn, G.R., and Phillips, R.C., 2002, Colorado Late Cenozoic fault and fold database and Internet map server: Colorado Geological Survey Information Series 60a, http://geosurvey.state.co.us/pubs/ceno/.

Williams, P.L., 1964, Geology, structure, and uranium deposits of the Moab quadrangle, Colorado and Utah: U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-360, scale 1:250000.

Appendix 1. Geologic time chart adopted by the Colorado Geological Survey.

Era	Period		Series/Epoch		Age (Ma)
CENOZOIC	Quaternary		Holocene		0.0115
			Pleistocene	u/l	0.126
				middle	0.781
				l/e	1.81 ± 0.005
	Tertiary	Neogene	Pliocene		5.33 ± 0.005
			Miocene		23.0 ± 0.05
		Paleogene	Oligocene		33.9 ± 0.1
			Eocene		55.8 ± 0.2
			Paleocene		65.5 ± 0.3
MESOZOIC	Cretaceous		Upper/Late		99.6 ± 0.9
			Lower/Early		145.5 ± 4.0
	Jurassic		Upper/Late		161.2 ± 4.0
			Middle		175.6 ± 2.0
			Lower/Early		199.6 ± 0.6
	Triassic		Upper/Late		228.0 ± 2.0
			Middle		245.0 ± 1.5
			Lower/Early		251.0 ± 0.4

U.S. Geological Survey Geologic Names Committee, 2007, Divisions of geologic time - major chronostratigraphic and geochronologic units: U.S. Geological Survey Fact Sheet 2007-3015.

Pleistocene internal ages from International Commission on Stratigraphy, 2007, International stratigraphic chart: downloaded December 2007 from www.stratigraphy.org/cheu.pdf.

Era	Period		Series/Epoch	Age (Ma)
PALEOZOIC	Permian		upper/late	260.4 ± 0.7
			middle	270.6 ± 0.7
			lower/early	399.0 ± 0.8
	Carboniferous	Pennsylvanian	Upper/Late	306.5 ± 1.0
			Middle	311.7 ± 1.1
			Lower/Early	318.1 ± 1.3
		Mississippian	Upper/Late	326.4 ± 1.6
			Middle	345.3 ± 2.1
			Lower/Early	359.2 ± 2.5
	Devonian		Upper/Late	385.3 ± 2.6
			Middle	397.5 ± 2.7
			Lower/Early	416.0 ± 2.8
	Silurian		upper/late	422.9 ± 2.5
			lower/early	443.7 ± 1.5
	Ordovician		Upper/Late	460.9 ± 1.6
			Middle	471.8 ± 1.6
			Lower/Early	488.3 ± 1.7
	Cambrian		Upper/Late	501.0 ± 2.0
			Middle	513.0 ± 2.0
			Lower/Early	542.0 ± 1.0
PRECAMBRIAN	Proterozoic		Neoproterozoic	1,000
			Mesoproterozoic	1,600
			Paleoproterozoic	2,500
	Archean		Neoarchean	2,800
			Mesoarchean	3,200
			Paleoarchean	3,600
			Eoarchean	~4,000