OPEN-FILE REPORT 08-03

Authors' Notes

Geologic Map of the Hoovers Corner Quadrangle, Montrose County, Colorado

by

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Colorado Geological Survey
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

by
Jonathan L. White, Felicie J. Williams, Matthew L. Morgan, and Shannon M. Townley

The topography of the Hoovers Corner quadrangle is marked by a series of flat broad gravel-capped mesas and large alluvial fans that mantle the underlying Mancos Shale, which are set against the dip slope of the resistant Dakota Sandstone that marks the uplifted east flank of the Uncompahgre Plateau. This southwest view shows the terrace gravels of High Mesa on the left, a small landslide along its western flank where green vegetation exists, exposures of the Juana Lopez member of the Mancos Shale, the irrigated farmlands of Dry Creek valley and California Mesa beyond, and the Uncompahgre Plateau in the background.

This mapping project was funded jointly by the Colorado Geological Survey and the U.S. Geological Survey through the National Geologic Mapping Program under STATEMAP Agreement No. 07HQAG0083.

FOREWORD

The purpose of Colorado Geological Survey Open File Report 08-03, *Geologic Map of the Hoovers Corner Quadrangle, Montrose County, Colorado* is to describe the geologic setting, mineral and ground-water resources, and geologic hazards of this 7.5-minute quadrangle located west of the town of Olathe, on the west side of the Uncompahgre Valley in west-central Colorado. Staff geologists Jonathan L. White, Felicie J. Williams (consulting geologist), Matthew L. Morgan, and summer intern geologist Shannon M. Townley, completed the field work on this project during the summer and fall of 2007. Jon White 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 Delta quadrangle (Morgan and others, 2008) to the north and Olathe quadrange (Morgan and others, 2007) to the east.

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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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF APPENDICIES

LIST OF PLATES

ACKNOWLEDGMENTS

We would like to thank our generous hosts Carol Patterson and Blaine and Linda Reed for their hospitality and use of their residences while completing our fieldwork. We also thank the many private landowners who granted permission to access their land for this project. Access to critical areas, quarries and open excavations, and pertinent local information were provided or arranged by the following persons or agencies: Jerry Anders, David and Dawn Bowman, the Brack family, Joe Brown, the Burch family, the Castle families, Marc Catiln (Uncompahgre Valley Water Users Association), the Fisher families, Dave Garrett, Dr. David Goode, Richard Gore, the Gray families, John Hawk, Donald Hopping, Jeff Keehfuss, Marvin Longwell, Steve and Dean Mosher, Dennis Murphy (BLM), Nellie Neal, Larry and Teri Reed, Bob and Margie Sturgeon, Ben Woods, and Montrose County.

We are appreciative of local geological and geotechnical information that was provided by Laurie Hauptmann and Nancy Lamm (Buckhorn Geotech). 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 thank Andres Aslan, Vince Matthews (CGS), and Dave Noe (CGS) 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. Mark Bauer (consultant) set the digital stereo models in ERDAS© Imagine Stereo Analyst© for ArcView©.

Tragedy struck our mapping team during our field season to map the Hoovers Corner quadrangle in 2007. This map is in memory of Mike Williams, geologist and science teacher at Fruita Monument High School.

INTRODUCTION

The Hoovers Corner 7.5-minute quadrangle is located in Montrose County, Colorado (figure 1). The quadrangle is located southwest of the town of Olathe, midway between the larger cities of Delta (2005 CENSUS population of 8,135) and Montrose (2005 CENSUS population of 15,749). Both towns are located along Federal Highway 50 that follows the Uncompahgre River, which is just off the map to the east. Hoovers Corner was named for a major rural road intersection along State Highway 348 in the mapped area. The highest part in the quadrangle (elevation 6,835 feet) is on the dip-slope of the Uncompahgre Uplift in the southwestern corner of the quadrangle, and the lowest point is in the Uncompahgre River valley bottom (elevation 5,285 feet) in the northeastern corner of the quadrangle.

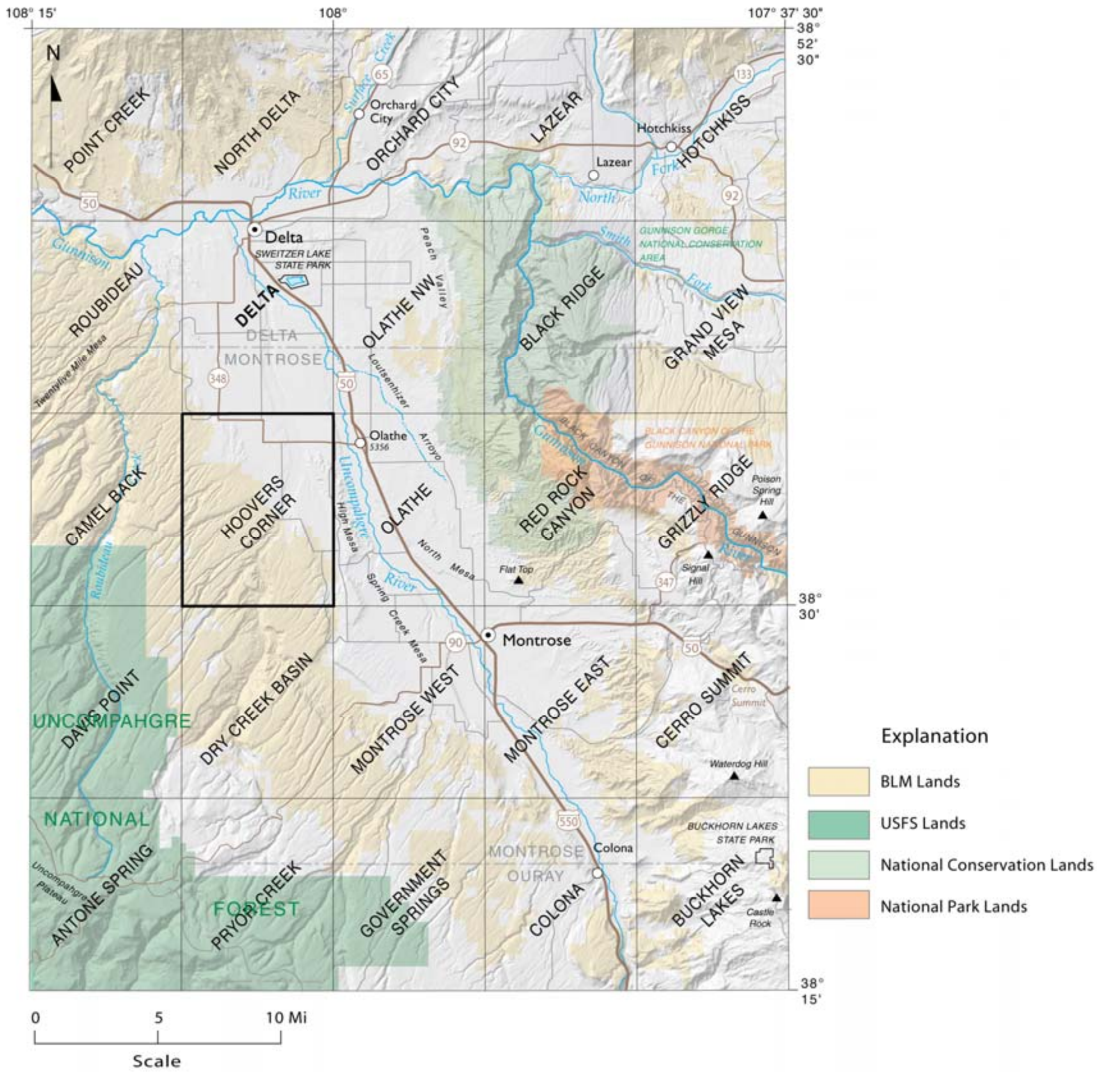

Figure 1. Location of the Hoovers Corner quadrangle (bold black outline) in relation to adjacent 1:24,000-scale topographic quadrangles and major cultural and geographic features.

Geologic mapping of the Hoovers Corner 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.

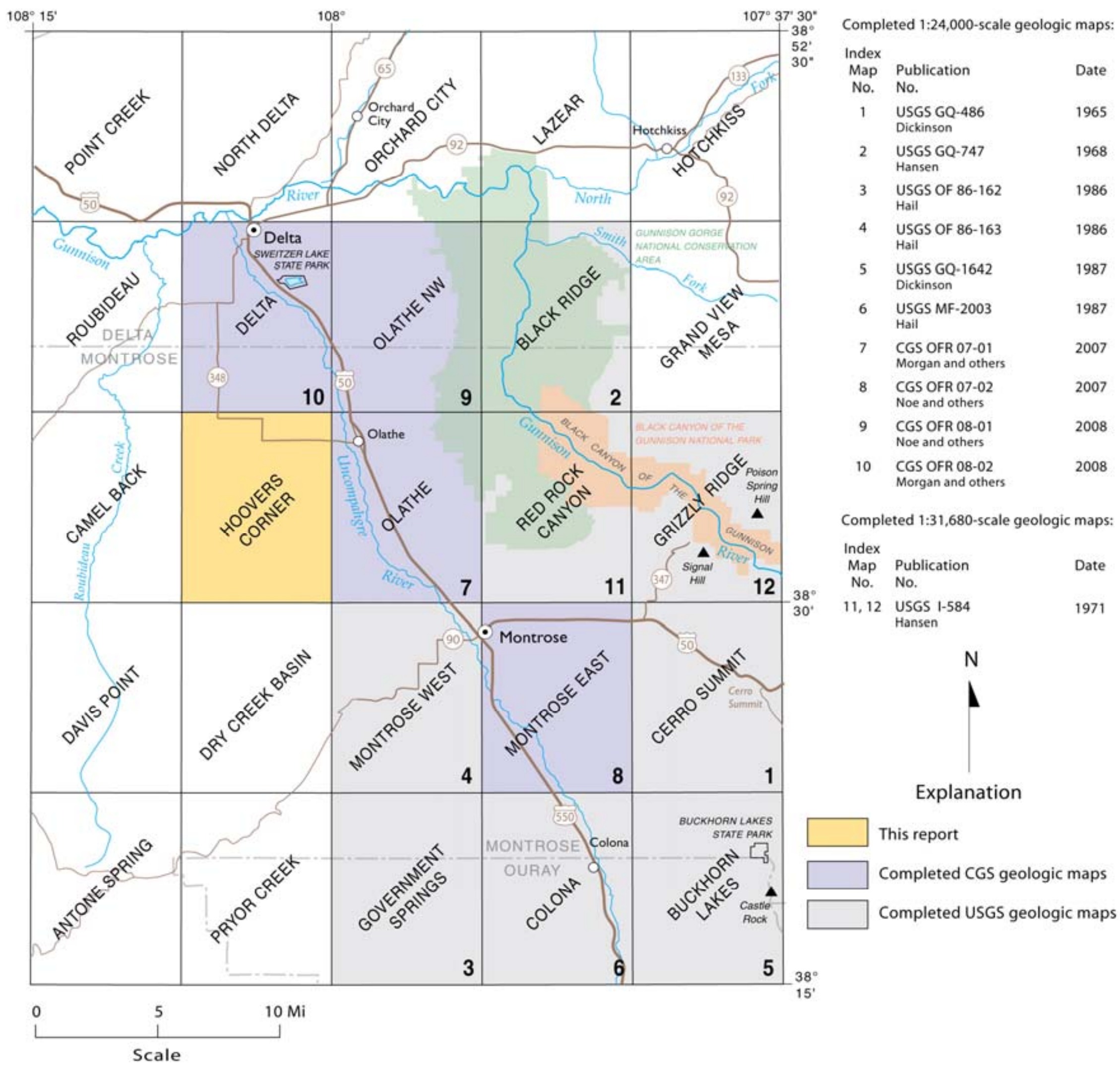

Figure 2. Index of published 1:24,000-scale geologic maps near Delta and Montrose.

The geologic interpretations shown on the Hoovers Corner quadrangle are based on (1) CGS field investigations in April through October of 2007; (2) prior published and unpublished geologic maps and reports, in particular the USDA National Resources Conservation Service Soil Survey (SSURGO) was used as a guide in key areas where deposit exposures were limited; (3) stereographic 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. These coordinates are different from the projected UTM-coordinate tic marks on the USGS topographic base map, which is in NAD27 (UTM; North American Datum 1927, Zone 13 North, meters).

Previous Work

The Hoovers Corner 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 east of the Hoovers Corner quadrangle, at a scale of 1:24,000. The Delta quadrangle (Morgan and others, 2008) and the Olathe NW quadrangle (Noe and others, 2008), which lie to the north and northeast of the Hoovers Corner quadrangle, respectively, were mapped by the CGS concurrently with this report.

Overview of Physiographic and Geologic Setting

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

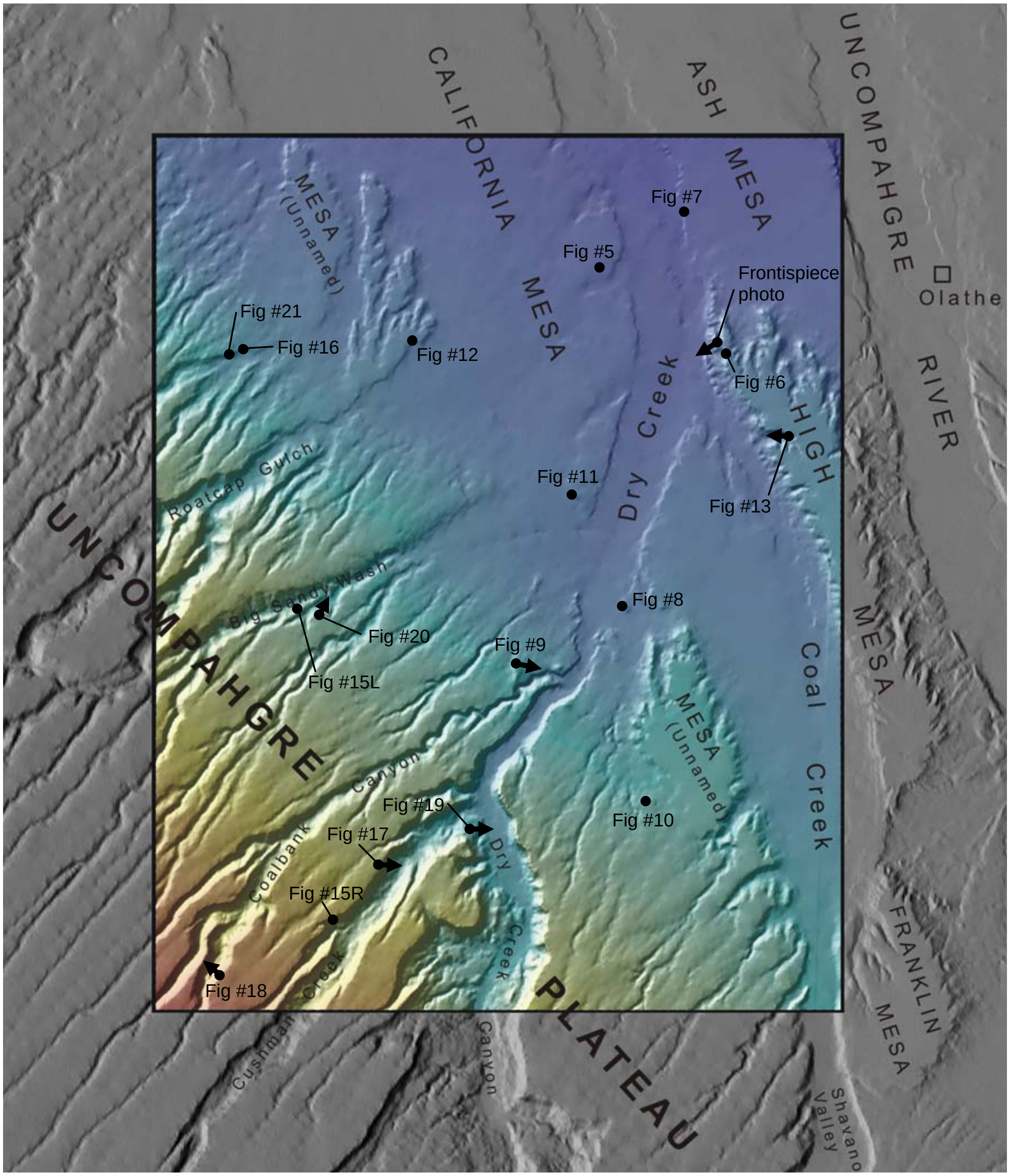

Figure 3. Hillshaded DEM of the Hoovers Corner quadrangle and surrounding region showing the location of major physiographic, geomorphic, and geologic features discussed in this text. Photo locations and view directions in this report are shown by points and arrows.

The Hoovers Corner quadrangle lies within the Canyonlands section of the Colorado Plateau physiographic province, an area characterized by deep canyons and monoclinal folds (Hunt, 1956; Foos, 2006). The Uncompahgre Uplift trends through the southwestern half of the mapped area. This uplift and the Gunnison Uplift centered at the Black Canyon of the Gunnison (see fig. 1), are Laramide orogenic structures. This more-recent vertical movement of faulted basement blocks has been superimposed on the eroded Precambrian roots of the late-Paleozoic ancestral Uncompahgre Mountains, as well as the package of Mesozoic rocks that were nonconformably deposited on its beveled surface. The Laramide movement has deformed these overlying Mesozoic rocks into gently dipping monoclinal folds that are well exposed in the southwestern half of the Hoovers Canyon quadrangle. The relatively uniform dip slope of the resistant Dakota Sandstone, incised with many side valleys that flow northeastward, rises to the southwest onto the Uncompahgre Plateau at a regional inclination of 3 degrees.

The bedrock exposed in the Hoovers Corner quadrangle records the transition from fluvial (terrestrial flood plains), through marginal marine, to predominantly marine conditions during Late Jurassic through Early to Late Cretaceous time. Variegated mudstones and channel sandstones of the Morrison Formation record the depositional history of wide flood plains and saline lakes while the Dakota and Burro Canyon Formations record swamp and near-coastal flood plain sedimentary environments as the epicontinental, Western Interior Seaway transgressed from the northeast to the west. These rocks are well exposed in the map-area canyons of the Uncompahgre Uplift. The Mancos Shale and its various subunits were deposited within the fully transgressed epicontinental 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 Hoovers Corner quadrangle the Mancos Shale is covered by extensive Quaternary deposits and is poorly exposed, except along the mesa edges.

Overview of Quaternary Geologic Setting

An understanding of the Quaternary geologic history begins with an introduction of the Neogene downcutting by the paleo Uncompahgre and Gunnison Rivers before the Uncompahgre Plateau existed as a topographic feature. This downcutting commenced shortly after 10 Ma, based on the age of the 10,000-foot elevation lava flows on Grand Mesa (Cole, 2007). Ancient volcanic-provenance outwash gravel (Sinnock, 1978; A. Aslan, Mesa State College, personal commun., 2007) also exist at similar elevations along what is now the divide of the Uncompahgre Uplift from Horsefly Peak (elev. 10,347 feet) to ridges above Columbine Pass (elev. 9,400 feet). Lateral migration occurred when the rivers cut through the easily eroded Mancos Shale and encountered the resistant Dakota Sandstone. River incision has been migrating northeastward, down the Dakota Sandstone dip slope ever since, from elevations of 10,000 feet to 6,000 feet. Hoovers Corner Quadrangle records the latest Quaternary episodes of this long-term incision and dip-slope migration.

The Quaternary geologic history of the Hoovers Corner quadrangle and vicinity is complex, controlled by:

1. the influx of three major sources of sediments,
2. stream incision,
3. abandonment of an earlier Uncompahgre River floodplain, and
4. northward migration of the confluence of Dry Creek and the Uncompahgre River through the Hoovers Corner and Delta quadrangles.

The three major sources of Quaternary alluvial deposits in the mapped area include the Uncompahgre River, Dry Creek, and wide alluvial fans. These fans were deposited as ephemeral streams flowed from many of the subparallel side canyons of the Uncompahgre Plateau onto the Uncompahgre River valley floor. Because of topographic inversion, the former river channels and alluvial fans with high gravel content now form the broadest terraces, colloquially called mesas. These mesas are underlain by Mancos Shale, which floors the Uncompahgre River valley.

The ancestral Uncompahgre River deposited the most widespread Quaternary units, which record middle to late Pleistocene stream levels during downcutting of the valley floor. Clasts of the Uncompahgre River sediments are mainly of volcanic and metasedimentary composition that eroded from the San Juan Mountains. The Uncompahgre River has six major geomorphic surfaces represented by prominent gravel-capped mesas (terraces) that are remnants of former glaciofluvial 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_{5b}, Qau_{5a}, $Qau_{4,}$ $Qau_{3,}$ and Qau_2. Only these five occur in the Hoovers Corner quadrangle since the modern flood plain (Qau_1) is off the map to the east. Mapping in the Hoovers Corner quadrangle has verified Sinnock's (1978) map of the Uncompahgre River valley terraces that indicate the middle Pleistocene courses of the Uncompahgre River incised Shavano Valley. This geomorphic circumstance is an exception to the northeastward migration of the river down the monoclinal dip slope. At Shavano Valley, it incised into the Plateau dip slope and eroded through the resistant Dakota and Burro Canyon sandstones into the Morrison Formation. Mapping by Hail (1986) and our geomorphologic analyses indicate that the incision into the Dakota dip slope at the location of Shavano Valley was likely fault controlled. Sinnock records two major terrace surfaces passed through Shavano Valley. However, our work reveals three major terrace surfaces: 1) the terrace gravels of Franklin Mesa and other unnamed mesas (Qau_{5b}) that lie against the Plateau dip slope, 2) High Mesa (Qau_{5a}), and 3)

California Mesa (Qau_4) (see figure 3). California Mesa represents the last flood plain of the Uncompahgre River when it last flowed through Shavano Valley. Subsequent stream capture and diversion of the Uncompahgre River to near its present course, east of Shavano Valley and the Qau_5 Franklin and High Mesas, did not occur until the late Pleistocene. At that time, Qau_3 terrace gravel, comprising present-day Ash Mesa, Spring Creek Mesa west of Montrose, and portions of North and East Mesas near Olathe were deposited. After the river abandonment, Shavano Valley became a wind gap. It is being aggraded with post-abandonment sediments and is currently occupied by the underfit stream, Coal Creek.

The second major source of Quaternary gravel is from the canyon of Dry Creek. The Dry Creek valley is a major south-north flowing drainage network on the Hoovers Corner quadrangle. Five geomorphic surfaces are mantled with Dry Creek alluvium. They share depositional and spatial relationship with the succession of Uncompahgre River alluvium. As erosion and river incisement lowered the valley floor, this spatial relationship records the northward migration of the confluence of the ancestral Dry Creek with the Uncompahgre River. Its middle Pleistocene location is at the mouth of Dry Creek canyon. The late Pleistocene location is at Ash Mesa, just below High Mesa, when the Uncompahgre River was diverted to the east side of Franklin and High Mesas. The present-day confluence is in the Delta quadrangle (Morgan and others, 2008). Clast lithologies of Dry Creek are also distinctly different from the Uncompahgre River deposits because their provenance is the Uncompahgre Plateau where Mesozoic sandstones predominate.

The third component of Quaternary deposition is broad alluvial fans that cover, and in some circumstances have eroded into, the ancient glaciofluvial terraces. These coalesced alluvial fans are composed of sediments derived from the Uncompahgre Plateau that record middle Pleistocene to Holocene flow down tributary streams that have cut the many shallow canyons into the Plateau. The two side canyons most responsible for these sediments are Roatcap Gulch and Big Sandy Wash.

Continued downcutting of the Uncompahgre River and Dry Creek has exposed the Mancos Shale below the Quaternary gravel cap. Modern mass-wasting deposits are common along the edges of the terraces. Gravelly colluvium can variably cover these slopes. Landslides commonly occur where near-surface weathered and weakened Mancos Shale has been saturated and is now unstable.

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 classifications 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 fill 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 Hoovers Corner 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 (uppermost Holocene)** — Riprap, engineered fill, agricultural fills, 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 also includes areas of construction, mine spoils, and quarrying operations where original deposits have been removed, replaced, or reworked. Larger canal and irrigation ditch embankments mapped in the quadrangle are included in this unit. This unit also includes certain fills that were placed to widen or increase the areas of irrigated farm fields. The average thickness of the unit is less than 20 feet. Other than engineered or structural fill, artificial fill may be subject to settlement, slumping, and erosion if not adequately compacted.

ALLUVIAL DEPOSITS

Clay, silt, sand, and pebbly gravel with cobbles and boulders deposited in stream channels, on flood plains, and in tributary drainages. More recent Holocene alluviums are finer grained and range from clayey silt to silty sand with gravel. Glaciofluvial terrace alluvial deposits are generally coarser and composed of well-rounded pebbles and cobbles with common boulders in a sandy gravel matrix that were deposited mostly during periods of enhanced stream power that coincided with Pleistocene glaciations. The glaciofluvial alluvium may contain surface veneers of variable-thickness fine-grained overbank deposits and loess. 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. For those alluvial deposits of the Uncompahgre River, the elevation difference was measured from the modern river bed in the Olathe quadrangle to the east. Thickness reported is the maximum exposed thickness of the unit.

Alluvial Deposits of the Uncompahgre River

The Uncompahgre River, which today runs through the Olathe quadrangle to the east of the mapped area, deposited middle to upper Pleistocene gravel in the Hoovers Corner quadrangle. There are four major terrace levels in addition to the modern, incised river channel (figure 4). Except for the lowest modern river level, these terraces are associated with Pleistocene glacial episodes (Sinnock, 1978). Sinnock's t_4 and t_3 terraces were deposited by the ancient Uncompahgre River when it passed through Shavano Valley, and corresponds with map units Qau_5 (Franklin Mesa and High Mesa) and Qau_4 (California Mesa). We have split the t_4 terrace of Sinnock (1978) into two subunits, Qau_{5b} and Qau_{5a} due to significant, 75- to 50-foot elevation differences in the longitudinal profiles of Franklin Mesa (and related unnamed mesas) compared to High Mesa. Sinnock's t_2 and t_1 terrace gravels were deposited when the Uncompahgre River was captured from its course in Shavano Valley and flowed east of Franklin and High Mesa. These lower t_2 and t_1 terrace units correspond with our Qau_3 (Ash Mesa) and Qau_2 (Holocene river valley) map units. The north to south, longitudinal profile of the earlier Pleistocene gravels steepened compared to the modern stream profile and those differences in elevations are noted in the unit descriptions.

The gravel-clast compositions within all of the Qau glaciofluvial deposits consist primarily of tuffaceous and porphyritic rhyolite, andesite, metaquartzite, silica-cemented sandstone, and lesser amounts of gneiss, granite, vein quartz, and limestone. These intermediate volcanics and resistant clasts are derived from the San Juan Mountains near

Ouray to the south and the Uncompahgre Plateau to the west and southwest. Where the terrace gravels are located near the dip slope of the Uncompahgre Uplift, gravel-clast composition has been influenced by the local influx of clasts derived from Dakota Sandstone, Burro Canyon Formation, and Morrison Formation sources on the Uncompahgre Plateau.

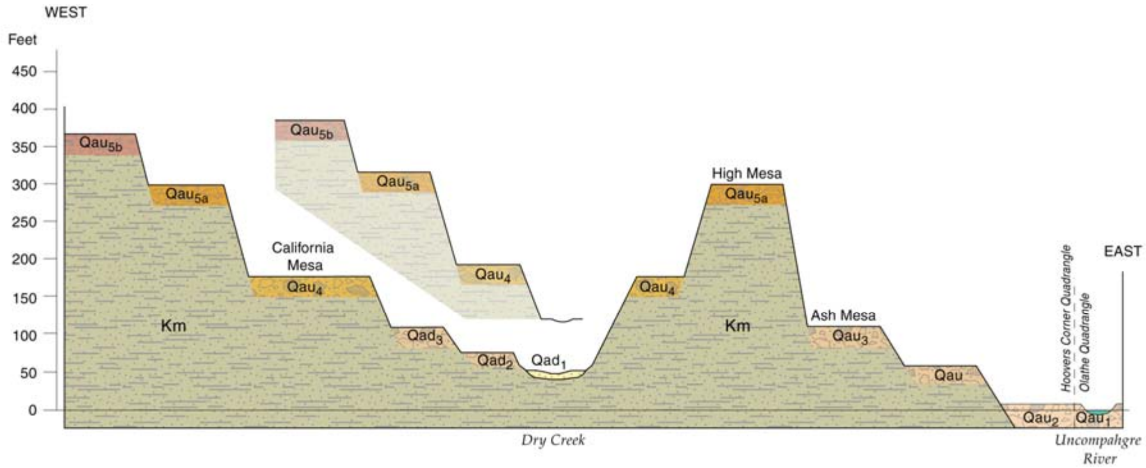

Figure 4. Diagrammatic profile of alluvial deposits associated with the Uncompahgre River and Dry Creek. From oldest to youngest these are: Qau_{5b}, Qau_{5a}, Qau_4, Qau_3, and Qau_2 (the current stream channel, Qau_1, is not shown). Qau is a local terrace remnant. Dry Creek alluvial deposits Qad_{5b}, Qad_{5a}, Qad_4, Qad_3, Qad_2, and Qad_1, are shown within or superimposed in the Dry Creek valley shown. See unit description for detailed information.

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 pebbly cobbly gravel with some boulders in stream terrace deposits above the modern flood plain of the Uncompahgre River valley. In the adjacent Olathe quadrangle, Morgan and others (2007) indicate that the Qau2 terrace surface is about 10 feet above the modern river channel. Clasts are subrounded to well rounded. 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. Only the narrow northeast corner of the Hoovers Corner quadrangle contains this deposit below the older Ash Mesa. A thin unmapped cover of colluvial clay, silt, and sand with mixed gravel- to cobble- sized clasts derived from erosion of the Mancos Shale and older terrace gravels of Ash Mesa mantle this unit on this map. Sinnock (1978) interpreted this terrace gravel deposit as being associated with the Pinedale glacial advance. In the adjacent Olathe and Delta quadrangles, this deposit forms a broad, flat terrace that is incised by younger streams and bordered by higher mesas. It is the primary regolith for agriculture in the Uncompahgre River valley. Only a small map area of this unit exists in the extreme northeast corner of the quadrangle. In the adjacent Olathe quadrangle, Morgan and others (2007) indicate that this unit can exceed 25 feet in thickness. The unit is a potential source of commercial sand and gravel.

Qau_3 **Alluvium three of the Uncompahgre River (upper Pleistocene)** — Gray to moderate-reddish-brown, poorly to moderately sorted, poorly to moderately consolidated glaciofluvial stream terrace deposits above the modern flood plain of the Uncompahgre River. The alluvium forms a broad gravel cap on Ash Mesa. Clasts are subrounded to well rounded; the dominant sediment is a pebbly to cobbly gravel in a coarse sand matrix with scattered boulders. Some boulders reach 3 feet in diameter. Soil profiles consist of A or Ap/Bk/2Btb/C horizons; the B horizons reach colors as red as 5YR 6/4 (light reddish brown). A Bt horizon that overlies the Bk horizon is only occasionally present in the soil profile and appears to have been formed in loess that was locally 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 B 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 height of 90 feet above current stream level at the north boundary of the quadrangle and 140 feet at the upgradient southern boundary. The maximum exposed thickness of the unit is 20 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 are susceptible to slope failure. The unit is a potential source of commercial sand and gravel.

Qau_4 **Alluvium four of the Uncompahgre River (upper middle Pleistocene) —** Gray to moderate-brown, moderately sorted, moderately consolidated, glaciofluvial terrace deposits above the modern flood plain of the Uncompahgre River. The alluvium forms a broad gravel cap on California Mesa and isolated erosional remnants on the western flank of High Mesa. Clasts are subrounded to well rounded and the dominant sediment is a pebbly to cobbly gravel with boulders in a coarse sand matrix. In some locations the base of this unit is weakly cemented. Some boulders reach 3 feet in diameter. Sinnock (1978) interpreted this terrace gravel deposit as being associated with a late Bull Lake glacial advance. The unit forms terraces that reach a maximum height of 150 feet above current stream level at the northern boundary, which rises to 190 feet above the modern Uncompahgre River where the gravel is first exposed inside Coal Creek valley near the mouth of Shavano Valley. The maximum exposed thickness of the unit locally exceeds 25 feet. The top of the deposit may contain up to 4 feet of variably deposited finer-grained overbank, sheetwash, and loess sediments with a well developed Stage II^{+} to III, Bk horizon and reddish Bt horizon (Figure 5). The unit generally forms a stable building surface, although the localized pockets of near-surface finer-grained sediments may be collapse-prone, and areas along the outer mesa edges that are susceptible to slope instability. The western and northern margin of the deposit on California Mesa is variably covered by the aggradation of more recent alluvial fans and alluvial

Figure 5. A foundation excavation on the Qau_4 terrace has exposed the fine-grained sediments that can overlie the gravels. Note the well-developed Bk/Bt soil horizons. The A horizon has been disturbed by previous agricultural use of this land. The Uncompahgre River gravels can be seen at the base of the excavation. [UTMX: 234916, UTMY: 4277430].

sediments of Coal Creek. The contact in those areas is approximately based on topography, clast lithology, and finer-grained sediment differences between the western San Juan Mountain sources of the Uncompahgre River gravels and Mesozoic sedimentary rocks of the Uncompahgre Plateau. The unit is a potential source of commercial sand and gravel.

Qau_{5a} **Alluvium five(a) of the Uncompahgre River (middle Pleistocene) —** Gray to light gray to brown, poorly to moderately sorted, moderately to very well consolidated silt, sand, pebble, cobble, and boulder gravel in glaciofluvial stream terrace deposits above the modern flood plain of the Uncompahgre River. 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. 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. Near the base of this unit at the contact with the underlying Mancos Shale, selective cementation by ground water has lithified the terrace gravel to a conglomerate (Figure 6). Sinnock (1978) interpreted this terrace gravel deposit as being

Figure 6. Close-up view of Qau_{5a} terrace gravel (High Mesa) overlying the Smoky Hill member of the Mancos Shale. Note cementation of the sandy matrix. Qau_{5b} units also contain this basal conglomeritic zone. [UTMX: 236645, UTMY: 4276190].

associated with early Bull Lake glaciation. The unit forms a major terrace called High Mesa that reaches a maximum height above current stream level of 265 feet at the north end and 325 feet at the south end of the mesa. Extrapolation of the longitudinal profile of this terrace appears to correlate with the elevation of an unnumbered mid-level Gunnison River (Qag) terrace surface near the confluence with the Gunnison River on the Delta quadrangle geologic map by Morgan and others (2008). The maximum exposed thickness of this unit occurs near the mouth of Shavano Valley in the extreme southeast corner of the quadrangle where 45 feet of gravel was measured at a landslide scarp. The unit generally forms a stable building surface, although areas along the outer mesa edges are susceptible to slope failure. Variable veneers of loess, less than 2 feet thick, may mantle this unit. The unit is a source of commercial sand and gravel.

Qau_{5b} **Alluvium five(b) of the Uncompahgre River (middle Pleistocene)** — Gray to brown, poorly to moderately sorted, moderately to very well consolidated silt, sand, pebble, cobble, and boulder gravel in glaciofluvial stream terrace deposits above the modern flood plain of the Uncompahgre River. 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. Soil development is virtually identical to Qau_{5a} with the exception of a deeper reddish hue, increased decomposition of phaneritic igneous clasts, and heavy desert varnish and shatter of clasts at the surface. As with Qau_{5a} gravel deposits, the base of this unit near the contact with the underlying Mancos Shale has also been selectively cemented to a conglomerate. Sinnock (1978) interpreted this terrace gravel as being indistinguishable from the Qau_{5a} deposit, which he associated with early Bull Lake glaciation. However, this unit forms terraces that reach a maximum height of 400 feet above current stream near the mouth of Shavano Valley and 320 feet at the northern boundary of the quadrangle, 75 to 50 feet higher than the Qau_{5a} unit. Along the ancestral Uncompahgre River course at the mouth of Shavano Valley there is a terrace-tread slope break in the Qau_{5b} unit with a 25-foot elevation difference. The maximum exposed thickness of the unit locally exceeds 40 feet. The unit is also mantled with a thin veneer of loess. Near where the terrace treads of unnamed mesas are uniform and unbroken against the Uncompahgre Plateau dip slope, remnant Holocene to middle Pleistocene-aged alluvial fans and colluvial slope wash deposits also mantle the unit. Many of the fine-grained slope wash sediments are too thin and discontinuous to be mapable units. The unit generally forms a stable building surface, although eroded areas along the outer mesa edges underlain by Mancos Shale are susceptible to slope failure. The low density sediments that mantle of the surface gravel of the unit may be prone to soil collapse and settlement. The unit is a 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, pebble, cobble, and boulder gravel in stream terrace deposits above the modern flood plain of the Uncompahgre River. The alluvium forms one small gravel-capped terrace remnant in the extreme northeastern corner of the quadrangle between, but separate from, the more widespread Qau_3 and Qau_2 surfaces. Clasts are subrounded to well rounded and the dominant sediment is a pebbly to cobbly gravel in a coarse sand matrix with scattered boulders. Variable thicknesses of unmapped colluvium and slope wash deposits, composed of gravely to sandy clay from the nearby flank of Ash Mesa, cover this terrace deposit that was mapped only in the northeast corner of the quadrangle. 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 susceptible to slope instability. The unit may be a potential source of commercial sand and gravel.

Alluvial Deposits of Dry Creek

Dry Creek, a tributary stream of the Uncompahgre River, contains five different alluvial deposits that were transported northward along the main stream channel. These units originated from Dry Creek, which drains a large basin and incised a 500-foot deep canyon into the northeastern flank of the Uncompahgre Plateau. These units can be correlated with the corresponding numbered Uncompahgre River map units.

Source area lithologies differentiate the Dry Creek alluvium from the adjacent alluvial deposits of the Uncompahgre River. Dry Creek gravel is predominantly (>85%) composed of buff-colored sandstone and gray chert pebble conglomerate derived from the Dakota Sandstone, Burro Canyon Formation, and Morrison Formation. It also contains some volcanic clasts reworked from older (early Pleistocene(?) to Neogene) glacial till and fluvial sediments discussed by Sinnock (1978), located upslope and south to southwest of the mapped area near Horsefly Peak and along the axis of the plateau towards Columbine Pass.

Holocene alluvium of Dry Creek, downstream from where the creek debouches from its canyon in the Uncompahgre Plateau, also contains reworked Uncompahgre River alluvial gravel that eroded from adjacent terrace remnants (mesas) located along the lower course of Dry Creek. The finer grained alluvium of the lower units is predominantly brown to tan silt and sand with little clay, also reflecting the sandstone source materials. The oldest of these deposits, Qad_{5b} and Qad_{5a}, occur above the mouth of Dry Creek Canyon and record the mid-Pleistocene confluence of Dry Creek and the Uncompahgre River near that location. At the northern boundary of the mapped area in Dry Creek valley, the plateau-provenance clasts indicative of Qad_3 gravel end where Uncompahgre River provenance clasts of Qau_3 (Ash Mesa) alluvium begin to predominate. There is evidence of limited scour of Qau_3 and deposition of Qad_3 above it (Figure 7) but there are no appreciable topographic differences that would suggest alluvial fan depositional processes. Figure 7 also reveals that Qad_3 is also a moderately to well-sorted riverine deposit with well rounded clasts, and lacks evidence of matrix supported, rapidly deposited, mud flows. We interpret the northward cessation of

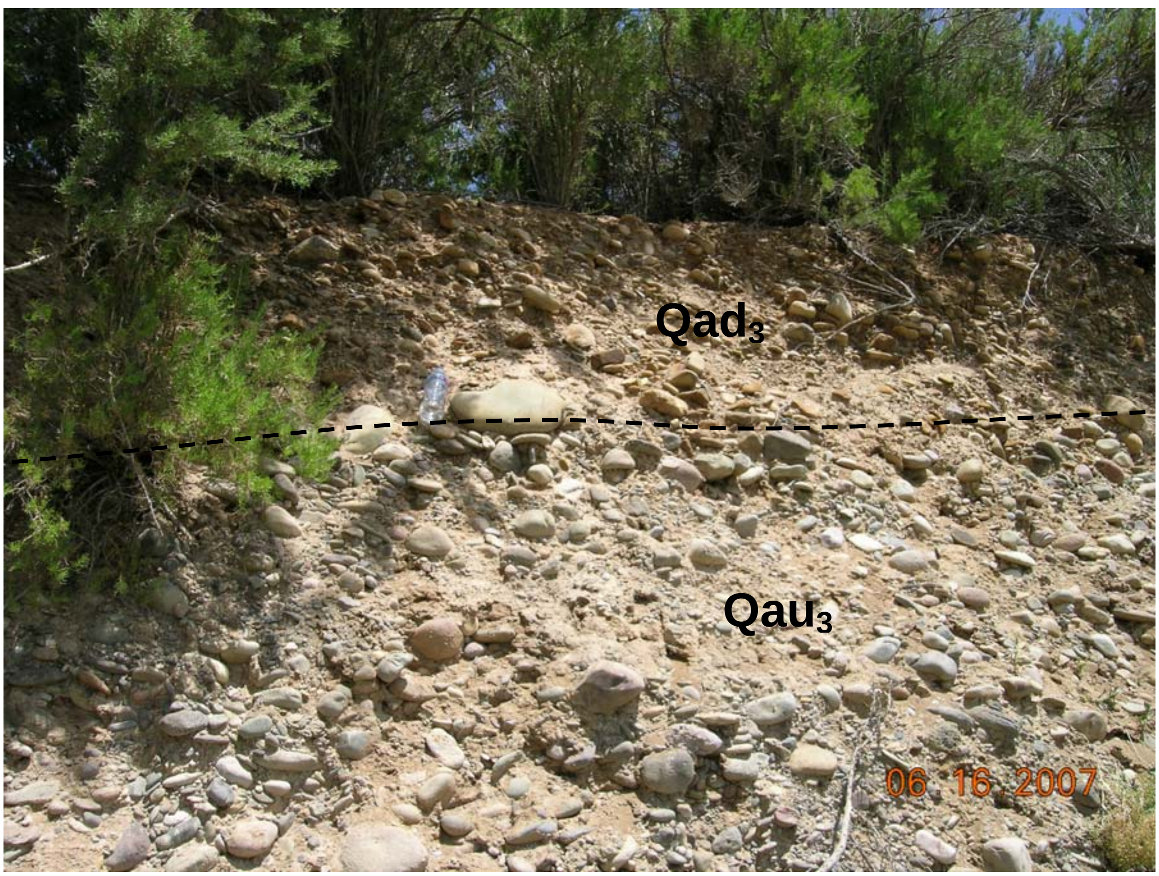

Figure 7. Exposed unconformable contact where the paleo Dry Creek had scoured the Qau_3 alluvium and deposited Qad_3 gravels over it along the western edge of Ash Mesa. Note the color change from the more uniform reddish-tan Dakota Sandstone clasts above to the more variable light gray to gray predominantly volcanic clasts of the Uncompahgre River gravel below. [UTMX: 236184.1, UTMY: 4278270.8].

Qad_3 clasts with a Plateau provenance on the Qau_3 terrace to represent the approximate location of the late Pleistocene paleoconfluence 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 glaciofluvial gravel from the main trunk of the Uncompahgre River. A similar relationship occurs near the present-day confluence of Dry Creek and the Uncompahgre River where Qad_2 deposits occur on, and grade into, Qau_2 alluvium (Morgan and others, 2008).

Qad_1 **Alluvium one of Dry Creek (Holocene)** — Dark-brown to brown to tan, poorly to moderately sorted, poorly to moderately consolidated sandy silt with thin beds of silty to sandy, pebbly to cobbly gravel in the currently active stream channel, flood plain, or in low stream-terrace deposits in Dry Creek Valley. Clasts are subrounded to well rounded. Soil development is absent. Clasts are predominantly sandstone with some reworked volcanic clasts that are coated by a discontinuous rind of $CaCO_3$, indicating that they were reworked from older Uncompahgre River deposits. The unit forms low terraces that reach a maximum height of 3 feet above current stream level. This unit is prone to flooding. Fine-grained portions of this unit may contain collapsible soil and may be susceptible to ground settlement.

Qad_2 **Alluvium two of Dry Creek (lower Holocene to upper Pleistocene)** — Tan to reddish tan to brown, poorly to moderately sorted, moderately consolidated, crudely stratified, 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. The sediments of this unit vary widely. Within Dry Creek Canyon, where the depositional energy was high, the deposit is typically silty to slightly gravelly sand with poorly sorted pebbly, cobbly, and bouldery layers that are indicative of flash flooding. Some of the larger cobble- to boulder-sized clasts are colluvial in nature (i.e., falling rocks from the canyon walls). Within Dry Creek Canyon, the sandstone, chert, and chert conglomerate clasts are subrounded to angular. Downstream of the canyon where quieter depositional environments existed, the unit is predominantly silt and sand with thin discontinuous layers of pebbly to cobbly gravel with a juvenile A horizon present that has a color of 7.5YR 2/6 (deep brown). In the lower creek course, there are scattered volcanic clasts that are coated by a discontinuous rind of $CaCO_3$, indicating that they were reworked from older Uncompahgre River deposits. The unit forms terraces that reach a maximum height of 12 feet above current stream level. The total thickness of the unit is unknown. Secondary disseminated blebs and stringers of gypsum are visible in unit exposures. Portions of this unit contain low density and potentially collapsible soil and could be susceptible to ground settlement.

Qad_3 **Alluvium three of Dry Creek (lower Holocene to upper Pleistocene)** — Orange-brown to tan-brown, moderately sorted, densely packed pebbles, cobbles, and scattered small boulders in a sandy gravel matrix. The clast-supported alluvium commonly forms steep-sided slopes where dissected by river erosion and later Qad_2 and Qad_1 deposition (Figure 7). The sandstone, chert, and chert conglomerate clasts are well rounded to subrounded to rarely subangular. Some Qad_3 sediments are reworked alluvial fan deposits that entered Dry Creek from ephemeral streams in the Plateau that crossed California Mesa. Soil profiles within the mapped area were not examined due to poor exposure, however, 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 Dry Creek stream level. The unit is a potential source of commercial sand and gravel.

Qad_4 **Alluvium four of Dry Creek (upper middle Pleistocene)** — Orange tan to orange-brown to buff, moderately sorted, densely packed pebbles, cobbles, and scattered boulders in a sandy gravel matrix. The clast-supported alluvium commonly forms small mesas near Dry Creek where the deposit has been dissected by river erosion and later Qad_3, Qad_2 and Qad_1 deposition. The sandstone, chert, and chert conglomerate clasts are well rounded to subangular with the larger boulders generally subangular (Figure 8). Approximately 15 percent of the clasts are reworked Uncompahgre River gravel. Soil profiles within the mapped area were not examined due to poor exposure; however, the deposit is stained reddish- to orange-tan (10YR 7/8). These reddish colors and an elevation very close to the Qau_4 surface suggest the deposit is of middle late Pleistocene age. The maximum exposed thickness of the unit locally exceeds 10 feet. The terrace-surface remnants this unit forms may reach a maximum height of 65 feet above the current Dry Creek stream level. The unit is a potential source of commercial sand and gravel.

Qad$_{5a}$ **Alluvium five(a) of Dry Creek (middle Pleistocene)** — Orange tan to orange-brown to buff, moderately sorted, densely packed pebbles, cobbles, and scattered boulders in a sandy gravel matrix. Clasts are well rounded to subangular with the larger boulders generally subangular. The clast-supported alluvium forms small mesas above the mouth of Dry Creek Canyon on the Dakota dip slope of the Uncompahgre Plateau monocline. Clast lithology is similar to Qad$_3$ and Qad$_4$ deposits but lacks reworked Uncompahgre River gravel and contains up to 10 percent light-purple volcanic clasts that are derived from lower Pleistocene glacial till near the Horsefly Peak area discussed by Sinnock (1978). Soil profiles within the mapped area were not examined due to poor exposure. Clasts exposed at the surface are heavily coated with desert varnish, many are shattered or pitted, contain thick weathering rinds, and the more phaneritic volcanic clasts are partially decomposed. The maximum thickness of this unit is 10 feet. Surfaces of this unit

Figure 8. Roadside exposure of small mesa capped with Qad$_4$ gravel. Note riverine pebbly to cobbly gravel is buff to orangebrown and overwhelmingly composed of sandstone clasts from the Uncompahgre Plateau. View is to the east. Note crude clast imbrication showing right to left stream flow. [UTMX: 235035, UTMY: 4272134]

are 150 feet above the present Dry Creek. The unit is a potential source of commercial sand and gravel.

Qad$_{5b}$ Alluvium five(b) of Dry Creek (middle Pleistocene) — Orange tan to orange-brown to buff, moderately sorted, densely packed pebbles, cobbles, and scattered boulders in a sandy gravel matrix. This unit is virtually identical to the Qad$_{5a}$ unit except that the surfaces of the terrace remnants are 30 to 50 feet higher in elevation and slightly higher on the plateau (Figure 9**).** The maximum unit thickness does not exceed 20 feet and the terrace surface is 200 feet above the current Dry Creek level. The unit is a potential source of commercial sand and gravel.

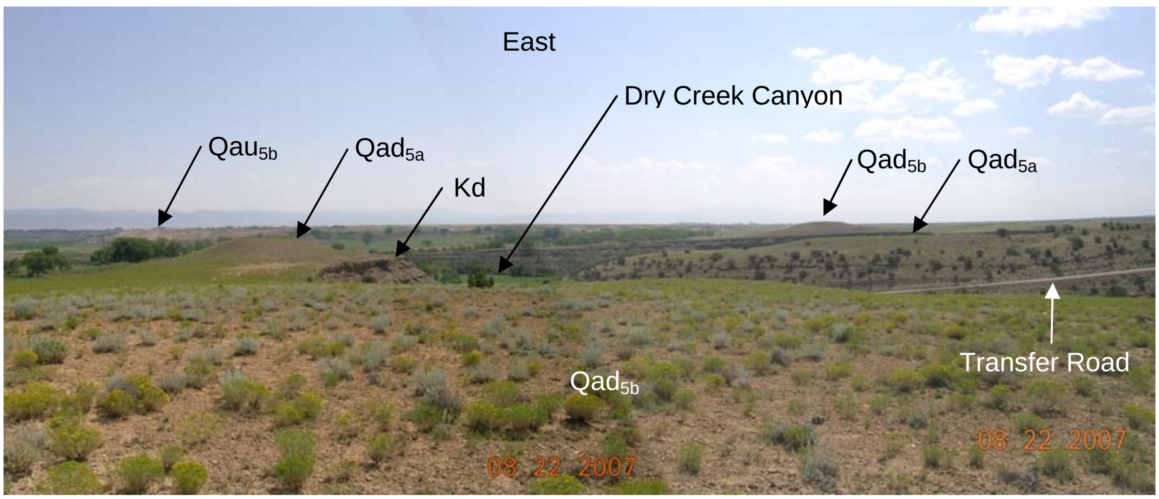

Figure 9. View east above the mouth of Dry Creek Canyon showing terrace remnants that lie on the Dakota Sandstone dip slope of the Plateau. Photo was taken from a Qad$_{5b}$ surface. The long mesa in middle background is a Qau$_{5b}$ terrace surface. The Gunnison uplift shows as the faint hills in the background. [UTMX: 233350, UTMY: 4271110]

Alluvial Deposits of Coal Creek

Coal Creek is an underfit tributary stream of Dry Creek that occupies the mid-Pleistocene paleovalley of the Uncompahgre River where it debouched from Shavano Valley. In the southern part of the map area, the two Coal Creek alluvial deposits have partially filled the valley and deposited finer-grained alluvium on top of older Uncompahgre River alluvium (Qau$_4$). These units are part of Sinnock's (1978) "post t$_3$ alluvium in Shavano Valley" that record the post-abandonment partial filling of the valley with reworked gravelly silt and sand alluvial-fan sediments eroded from the many Plateau side canyons. Coal Creek begins its incision into the Qau$_4$ gravel surface near Ida Road, about 3.5 miles above the confluence with Dry Creek. From this point to the confluence, Coal Creek alluvium is lower than the Qau_4 glaciofluvial terrace, the environment is more erosive in nature, and mesa morphology begins.

Source area lithologies are similar to the Dry Creek alluviums. The finer grained alluvium is predominantly brown to tan silt and sand with little clay. The alluvial gravel is predominantly (>85%) composed of buff-colored sandstone and gray chert pebble conglomerate from the Dakota Sandstone, Burro Canyon Formation, and Morrison Formation. Along the lower valley towards the confluence with Dry Creek the gravel fraction is predominantly reworked older Uncompahgre River alluvium from adjacent mesa edges.

$Qacc_1$ **Alluvium one of Coal Creek, (Holocene)** — Dark-brown to brown to tan, poorly to moderately sorted, poorly to moderately consolidated sandy silt with beds of sandy, pebbly to cobbly gravel in the currently active stream channel or in low stream-terrace or overbank deposits within the modern flood plain of the incised Coal Creek valley. Clasts are subrounded to well rounded. Soil development is absent but efflorescence occurs along the eroded banks. Clasts are sandstone with some volcanic clasts that are coated by a discontinuous rind of $CaCO_3$, indicating that they were reworked from older Uncompahgre River deposits (Qau_4 through Qau_5). The unit forms low terraces that reach a maximum height of 4 feet above current stream level. Maximum thickness is unknown. This unit is prone to flooding. Fine-grained portions of this unit may contain collapsible soil and be susceptible to ground settlement.

$Qacc_2$ **Alluvium two of Coal Creek (lower Holocene to upper Pleistocene)** — Tan to pinkish tan to brown, poorly to moderately sorted, poorly consolidated overbank, flash flood, alluvial fan, and stream-terrace deposits above the current stream channel within the modern flood plain of Coal Creek and Shavano Valley. The unit is predominantly weakly stratified silt and sand with thin discontinuous layers of gravelly sand. Secondary disseminated blebs and stringers of gypsum are visible. Visible primary macropores can be seen in the finer grained deposits. In the southern part of the mapped area, the unit contains multiple, weakly developed, brownish orange (5YR 5/8) and deep brown (7.5YR 2/6) buried B horizons that reflect the aggradational nature of the deposit. There is a juvenile A horizon present that has a color of 7.5YR 3/6 (strong brown). In the lower creek course, the deposit is thinner and there are scattered volcanic clasts that are coated by a discontinuous rind of $CaCO_3$, indicating that they were reworked from older Uncompahgre River deposits (Qau_4 through Qau_{5b}). The unit forms terraces that reach a maximum height of 15 feet above current stream level. Portions of this unit contain low density and potentially collapsible soil, and could be susceptible to ground settlement. Total thickness of this unit is unknown but extrapolating the longitudinal profile of the Qau_4 surface southwards suggests that the thickness does not exceed 25 feet at the southern map boundary.

Undifferentiated Alluvial Deposits

Qa **Alluvium, undifferentiated (Holocene)** — Dark brown to pinkish tan, poorly to moderated sorted, poorly consolidated, weakly stratified, silty to clayey sand with pebbly to cobbly gravel. The stream-channel and flood plain deposits are deposited along tributary valley floors of ephemeral, intermittent, and small perennial streams. Clast size and lithology vary depending on source areas. Coarser zones are derived from the Dakota Sandstone where alluvium is mapped from shallow-canyon drainageways that exit the Uncompahgre Plateau monocline. Finer-grained clayey deposits east of the Plateau are derived from Mancos Shale and reworked older alluvial deposits of the Uncompahgre River. This unit includes small terraces that reach a maximum height of 5 feet above modern stream level. Deposit thickness is variable, with thicknesses that range from less than a foot on the dip slope of Dakota Sandstone to up to 10 feet or more where the drainage stream has incised into Mancos Shale. Areas mapped as Qa may be prone to flooding, erosion, and sediment deposition. Portions of this unit may also contain low-density and soft soil, and could be susceptible to ground settlement.

Qgo **Old alluvial gravel, undifferentiated (middle Pleistocene)** — Dark brown to dark orange-brown, moderately sorted, well consolidated pebbly to cobbly gravel. This deposit is the oldest and highest alluvial gravel unit on the map. It is an erosional remnant of an ancient stream channel or alluvial fan deposit that flowed from the Uncompahgre Plateau and is preserved only where dip-slope erosion has been reduced by the abutment of Qau_{5b} terraces. The alluvium has been cemented to a conglomerate (Figure 10) that outcrops along two small rises on the Dakota Sandstone surface, above and approximately 25 feet higher than the Qau_{5b} alluvium on the edge of the Uncompahgre Plateau. Clasts are subangular to subrounded and the provenance is entirely Dakota Sandstone. The unit, where exposed, has been heavily stained by desert varnish.

Figure 10. Middle Pleistocene Qgo outcrop on the Uncompahgre Plateau. The oldest alluvial deposit found on the Hoovers Corner quadrangle is a cemented pebbly to cobbly gravel with clasts of Dakota Sandstone. Note the desert-varnish staining. [UTMX: 235300, UTMY: 4269053]

MUDFLOW-DOMINATED ALLUVIAL AND ALLUVIAL-FAN DEPOSITS

The second most common surficial deposits that cover broad areas within the Hoovers Corner quadrangle are associated with complex alluvial-valley-fill and alluvial-fan systems along tributary streams and in broad basins at the foot of the Plateau monocline. In these systems, channelized to laterally unconstrained mud and gravel debris flows have been the dominant depositional processes. Depending on the energy of deposition, these widespread, Holocene to upper Pleistocene deposits can range from fine-grained mudflow-dominated sandy to silty clay, to clast-supported pebbly to cobbly gravel more typical of riverine environments. Most of the source material is derived from sandstone within the Cretaceous Dakota, Burro Canyon, and Morrison formations that have washed down small canyons in the Uncompahgre Plateau. Smaller fans have been deposited from the many gullies that have incised the high mesas. These latter deposits reflect erosion from the terrace gravels and the underlying Mancos Shale. They form a darker, more clayey deposit with dispersed reworked Uncompahgre River gravel.

Qf **Alluvial-fan deposits (Holocene)** — Tan to light-brown, poorly sorted, poorly consolidated, sandy silt with dispersed gravel that ranges to a much coarser gravelly to cobbly sand with scattered boulders when deposited in alluvial fans at the mouths of ephemeral steams in small canyons of the Uncompahgre Plateau. The deposits can have a fan-shaped morphology but generally have coalesced and aggraded the valley floor to very low surface gradients, less than 1° at the broad well-defined fans of Roatcap Gulch and Big Sandy Wash. The sharply angular to subrounded clasts are derived from bedrock in the plateau canyons and the boulders can exceed 5 feet in diameter near the mouth of the larger ephemeral streams. Water-well drill logs indicate that this deposit may exceed 50 feet in thickness in the larger fans on California Mesa. Other alluvial fan deposits, sourced from gullies in the high mesas, are smaller and compositionally different since they are derived from the Mancos Shale and the mesa terrace-gravel cap. Sediments are deposited primarily as fine-grained alluvium with occasional input from muddy debris flows and hyperconcentrated flows. The deposits consist of gray brown to yellow gray, silty to sandy clay with dispersed gravel with occasional stringers and lenses of locally reworked gravel in a clayey matrix. Deposits may locally exceed 20 feet in thickness. Areas mapped as alluvial fans may be subject to future flash floods and debris flow events. The deposits may contain zones of low density and/or high-porosity and may be susceptible to soil collapse and ground settlement.

Qfo **Old alluvial-fan deposits (upper to middle Pleistocene)** — Tan to orange tan to light reddish brown, unsorted, moderately consolidated, sandy silt with dispersed gravel that can range to a much coarser gravelly to cobbly sand with scattered boulders. Through erosion and topographic inversion, only remnants of these deposits occur at higher elevation than the younger Qf deposits. Clast composition and shape vary depending on source areas, ranging from rounded to well-rounded gravel of the Uncompahgre River to more local, sharply angular to rounded clasts from Dry Creek and other plateau streams. Some are coated by a discontinuous rind of $CaCO_3$, indicating that they were reworked from older Uncompahgre River and Dry Creek deposits. Rapid mud deposition is indicated by the unsorted nature of the deposits with clasts generally dispersed and supported within a finer-grained matrix. Soil development also varies but some of the older deposits have developed a carbonate Stage III Bk horizon (Figure 11). The unit thickness may locally exceed 20 feet in thickness.

Figure 11. Roadside exposure of a Qfo deposit on California Mesa near the mouth of Dry Creek Canyon. At this location the deposit is an unsorted mix of reworked older Uncompahgre River and Dry Creek gravels dispersed in a silty to sandy matrix. The small ledge on the slope marked by the arrow is the location of a Bk soil horizon near the top of the unit that is more resistant to erosion. [UTMX: 234304, UTMY: 4273887].

Qafo Old alluvial and alluvial-fan deposits (upper to middle Pleistocene) — Buff to light-gray to yellow-gray, moderately well to poorly sorted, moderately to well consolidated, stratified silt, sand, gravel, and rare cobbles deposited in old coalescing alluvial fans and channels that were shed from the Uncompahgre Plateau onto existing Uncompahgre River terrace surfaces and through channels in California Mesa onto Dry Creek valley terraces. The rounded to subangular clasts are composed of sandstone, chert, and chert conglomerate. The typical sediments were deposited as silty to gravelly sand, which is interlayered with clast-supported sandy gravel with occasional cobbles. This unit was separated from the Qf and Qfo units because it shows more evidence of riverine deposition, which is reflected by better rounding of the clasts, better sorting and stratification, and a denser packing of the gravel. The individual layers in the unit record episodic and dynamically differing depositional events as alluvium aggraded over existing Uncompahgre River and Dry Creek terrace surfaces (Figure 12). Soil development reflects the aggrading nature of the deposit with buried Bt and Bk soil horizons and oxidized/red-stained C horizons that typically demarcate the individual sediment layers in the deposit. In younger units, selective $CaCO_3$ cementation by ground 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 animal burrowing. Older units may have basal zones that have been cemented to a conglomerate. Maximum thickness of the unit is approximately 30 feet. The unit may be a potential source of sand and gravel.

Figure 12. Silage-pit excavation exposing 17 feet of Qafo sediment overlying middle Pleistocene Uncompahgre River terrace gravel (Qau_{5b}). Contact is shown by dashed line. Inset photo is an example of the Qafo unit cemented to a conglomerate. Note green pen on boulder for scale [UTMX: 231940, UTMY: 4276378, insert photo UTMX: 231401, UTMY: 4275789]

ALLUVIAL/COLLUVIAL AND MASS-WASTING DEPOSITS

Earth materials that were transported downslope primarily by gravity and limited alluvial processes. These deposits have not experienced the sorting or extensive transport 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.

Qc **Colluvial deposits (Holocene)** — Heterogeneous gray to brown gray deposits consisting of unsorted and unstratified clay, silt, and sand, with dispersed gravel. The sediment was typically deposited as sheetwash located along steeper mesa slopes where it thinly veneers the underlying Mancos Shale. The unit is typically composed of silty clay and weathered shale fragments, but also contains dispersed, rounded, cobbly to pebbly gravel that is derived from terrace gravel deposits at the mesa edge. Unit may include areas of accelerated creep. Unit thickness averages about 5 feet but may include areas much thinner or where weathered bedrock is at or near surface. Other colluvial deposits in the canyon of Dry Creek are on steeper slopes and more rocky in nature, becoming talus. Colluvium derived from Mancos Shale may contain swelling clay. Steeper colluvial slopes may be potentially unstable. Rocky talus-type colluvium in the Dry Creek canyon may be prone to settlement and rockfall hazards from the cliffs above.

Qac **Alluvial and colluvial deposits, undifferentiated (Holocene)** —Poorly sorted, poorly consolidated, sheetwash, hillside colluvium, overbank, and flash flood alluvial deposits that cannot be mapped separately. Within narrow valleys and tributary canyons of the Uncompahgre Plateau, the unit is predominantly weakly stratified, tan to grayish yellow to light brown, gravelly to cobbly silt and sand with thin discontinuous beds of sandy to silty gravel. The sharply angular to subrounded clasts are of local origin; sandstone, conglomerate, and chert derived from the Dakota Sandstone, Burro Canyon, and Morrison formations. Soil development is generally absent but there may be a juvenile A horizon present that has a color of 7.5YR 3/6 (strong brown). The unit forms thin terrace treads and valley-side slopes that extend to where bedrock is exposed. Thickness is variable but generally doesn't exceed 15 feet above current stream level. Along scoured and gullied ephemeral streams, bedrock is commonly exposed on the stream floor. Other, dissimilar Qac deposits are found along the lower slopes of High Mesa. These deposits are composed of dark gray to brown gray, gravelly-silty clay to gravel in a clay matrix that are derived from the Mancos Shale and the terrace gravel at the mesa edge.

Portions of this unit can contain low density and potentially collapsible soil, and could be susceptible to ground settlement.

Qaco **Old alluvial and colluvial deposits, undifferentiated (upper Pleistocene)** — Poorly sorted, moderately consolidated, mixed alluvial fan, sheetwash, and colluvium reworked from older alluvial fan deposits. The unit is a nonstratified, reddish tan to reddish brown, matrix-supported gravelly silt and sand with dispersed pebbles and cobbles. The angular to subrounded clasts are of local origin; sandstone, conglomerate, and chert derived from the Dakota Sandstone, Burro Canyon, and Morrison formations. Soil profiles are poorly exposed but surface soils have a characteristic reddish hue (10R 4/10 – dark reddish orange). The unit forms flatter sloped surfaces adjacent to old alluvial fans, and on eroded ancient landslides on the Morrison Formation in Dry Creek Canyon where the clay content is higher. Thickness is highly variable and likely does not exceed 7 to 8 feet. Portions of this unit can contain low density and potentially collapsible soil, and could be susceptible to ground settlement.

Qco **Old colluvial deposits (upper Pleistocene)** — Heterogeneous gray to brown gray deposits consisting of clast-supported pebbly to cobbly gravel in an unsorted sandy clay matrix. These older colluvial deposits, concentrated with reworked gravel, were typically laid on the lower slopes of High Mesa by sheetwash, limited alluvial, and possibly landsliding processes. Further erosion has winnowed the finer-grained constituents and caused the gravels to become clast-supported to create an armored layer at the surface. This deposit is more resistant to weathering than the underlying Mancos Shale and where it exists, has formed either relict faceted slopes or mounds along the lower slopes of High Mesa. Some Qco units may include ancient, small landslide deposits if gravel has also been concentrated to create an armored layer and diagnostic landslide morphology has been obscured by subsequent erosion.

Qls **Landslide deposits (Holocene to upper Pleistocene)** — Landslide deposits are found along the steeper slopes below the edge of the many gravel-capped mesas where weathered Mancos Shale is exposed and within the plateau canyons on the canyon walls where weak mudstones of the Morrison Formation have failed.

The landslide deposits along the mesa edges consist of chaotic, unsorted and unstratified, unconsolidated, highly weathered and disturbed Mancos Shale fragments, derived clay, and transported and reworked terrace gravel. Gravel becomes incorporated into the slide mass where scarps form in the gravel deposit above and the underlying shale begins to mobilize and incorporate the surface gravel. The dark gray to gray unit includes rotational, translational, and complex earthflow mass movements. In most places, these landslides show obvious geomorphic expression that disrupts the profile of the mesa slopes (Figure 13). 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, fissures, terracettes, tension cracks, pressure ridges at the toe of the mobilized mass, and lenticular pods or mounds of gravels that have been transported downslope from the original terrace elevation. Soil profiles were not developed on any of the examined deposits; however, based on morphology, the relative ages of the landslides are highly variable with many currently active. Vegetation may be thick due to the amount of water seeping into and running off of the deposits (See frontispiece). Thickness of landslide deposits in Mancos Shale may locally exceed 20 feet.

The landslide deposits within the Plateau canyons consist of chaotic, unsorted and unstratified, unconsolidated rubble that cover the canyon sides where they have been incised deeply into the Uncompahgre Plateau. Broken blocks of Dakota, Burro Canyon, and Morrison sandstone, ranging to the size of trucks, lie within clay-seamed rocky debris that slumped down the steep canyon walls when weak mudstones beds of the underlying Morrison Formation failed (see figure 17 in the bedrock section of this report). Sympathetic, rotated, intermediary landslide blocks indicate the retrogressive rotational nature of many of the landslide deposits. The relative ages of the landslides are highly variable, most are ancient but some are currently active. On the slope south of the Transfer Station in Cushman Creek, deep crevices of an incipient scarp have formed in Morrison shale immediately below the Burro Canyon-Dakota cliffs. Much older landslide deposits are incised by later weathering and erosion and colluvial surfaces have formed. Dry Creek Valley opens to as much as a mile width near the southern edge of the quadrangle. It is floored with hills and valleys of in-place Morrison Formation. Almost all of the hills are capped with relict landslide debris. Landslides in the Morrison Formation on the walls of Dry Creek Canyon can be up to 300 feet thick.

All landslide deposits should be considered potentially unstable. The deposits derived from Mancos Shale and shales and mudstones of the Morrison Formation also contain expansive clay. See the “Geologic Hazards” section for a discussion of landslides within the mapped area.

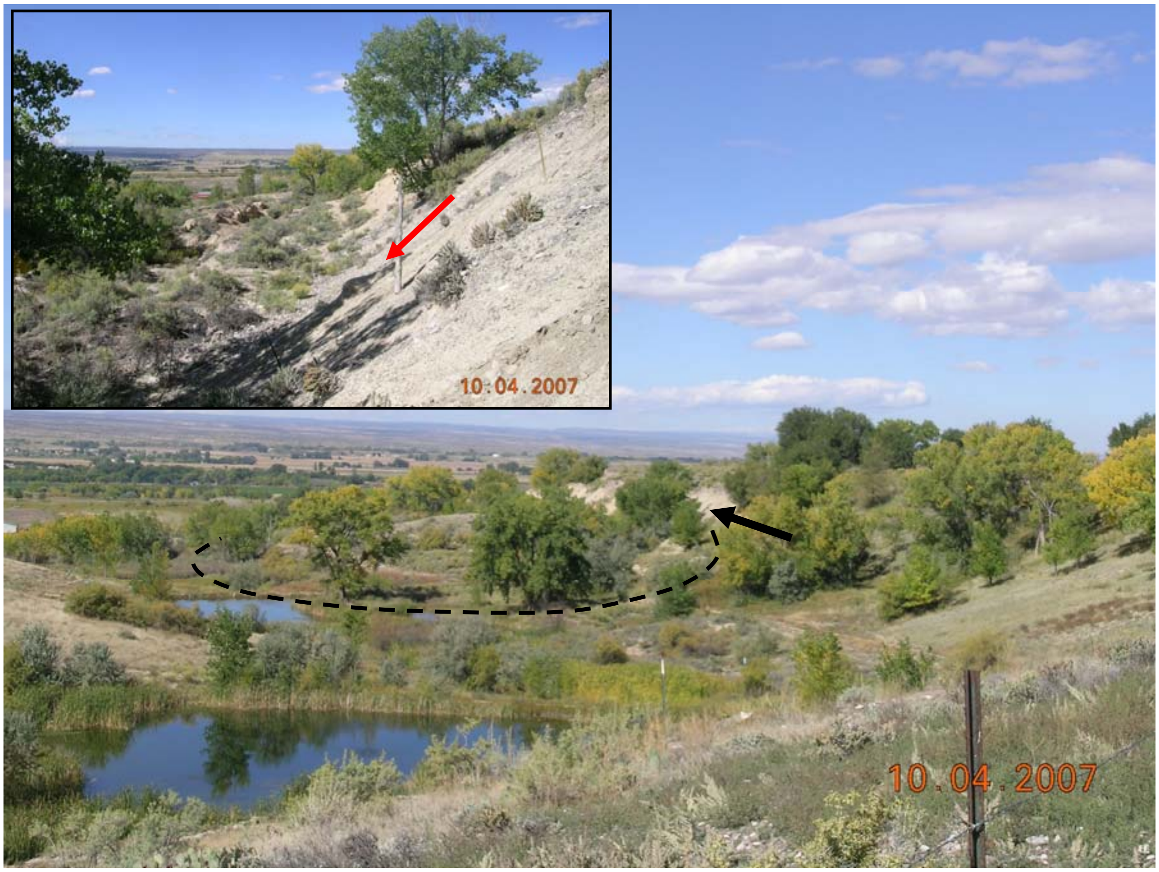

Figure 13. Typical landslide setting along the western slope of High Mesa. Recent landslide is shown by dashed line. The black arrow shows the direction the inset photo was taken along the head scarp of the landslide. Light gray ground exposed at the scarp is the Smoky Hill member of the Mancos Shale. Intact, cemented Uncompahgre terrace gravel can be seen in upper right of insert photo. Also on the inset photo, note broken ground at the bench, which is the top of the rotational block that slid down the scarp face in the direction shown by the red arrow. Far background is the Uncompahgre Plateau. [UTMS 237543, UTMY 4274749]

EOLIAN DEPOSITS (not shown on map) (middle to late Pleistocene)

Most of the high Dakota Sandstone dip slope that surfaces the Uncompahgre Uplift in this region is in turn mantled by thin deposits of pale orange to brownish orange, fine grained, unconsolidated eolian sand and loess. These deposits are probably middle to late Pleistocene in age. The highly variable and discontinuous deposits are generally less than three feet thick, and are not delineated on the map. On the Uncompahgre Plateau, the eolian deposits are commonly reworked as sheetwash and contain regolithic chips of sandstone. For erosion control many of the areas with a thin loess mantle have been plowed into broad shallow furrows perpendicular to the slope dip direction. Pleistocene loess also is sporadically deposited on the Pleistocene terrace gravel and where preserved, contains well developed Bt/BK horizons and a pronounced reddish hue.

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BEDROCK UNITS

The bedrock geology within the Hoovers Corner quadrangle consists of the more resistant Dakota Sandstone, Burro Canyon, and Morrison formations that are exposed on the northeastward-dipping Uncompahgre Plateau monocline, and the Mancos Shale that underlines the broad Uncompahgre River Valley. In this area, these bedrock units record the Jurassic to Late Cretaceous transition from a terrestrial to shallow marine environment. These units have been previously mapped at this location on the Moab 1° X 2° geologic map (Williams, 1964) and the Delta 15-minute geologic map (Marshall, 1959). On the basis of field observations, we distinguished the Dakota Sandstone from the Burro Canyon Formation, separated the Brushy Basin and Sand Wash Members of the Morrison Formation, and 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), the Colorado National Monument (Scott and others, 2001) and Book Cliffs (Hettinger and Kirschbaum, 2002) near Grand Junction, and the Salt Anticline region on the west side of the Uncompahgre Plateau (Stokes and Phoenix, 1948, and Cater, 1970).

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 Hoovers Corner quadrangle is shown in Figure 14. The biostratigraphy is based on fossil collections made by the authors, as well as fossil collections made by previous workers (Merewether and others, 2006; Morgan and others, 2007; Noe and others 2007) from nearby sites that may be physically traced into the Hoovers Corner quadrangle. The Mancos Shale is poorly exposed along colluvium-covered mesa slopes on Hoovers Corner so more detailed lithologic descriptions can be gained from the nearby Olathe and Delta quadrangles mapped by Morgan and others (2007, 2008) and the Olathe NW quadrangle mapped by Noe and others (2008).

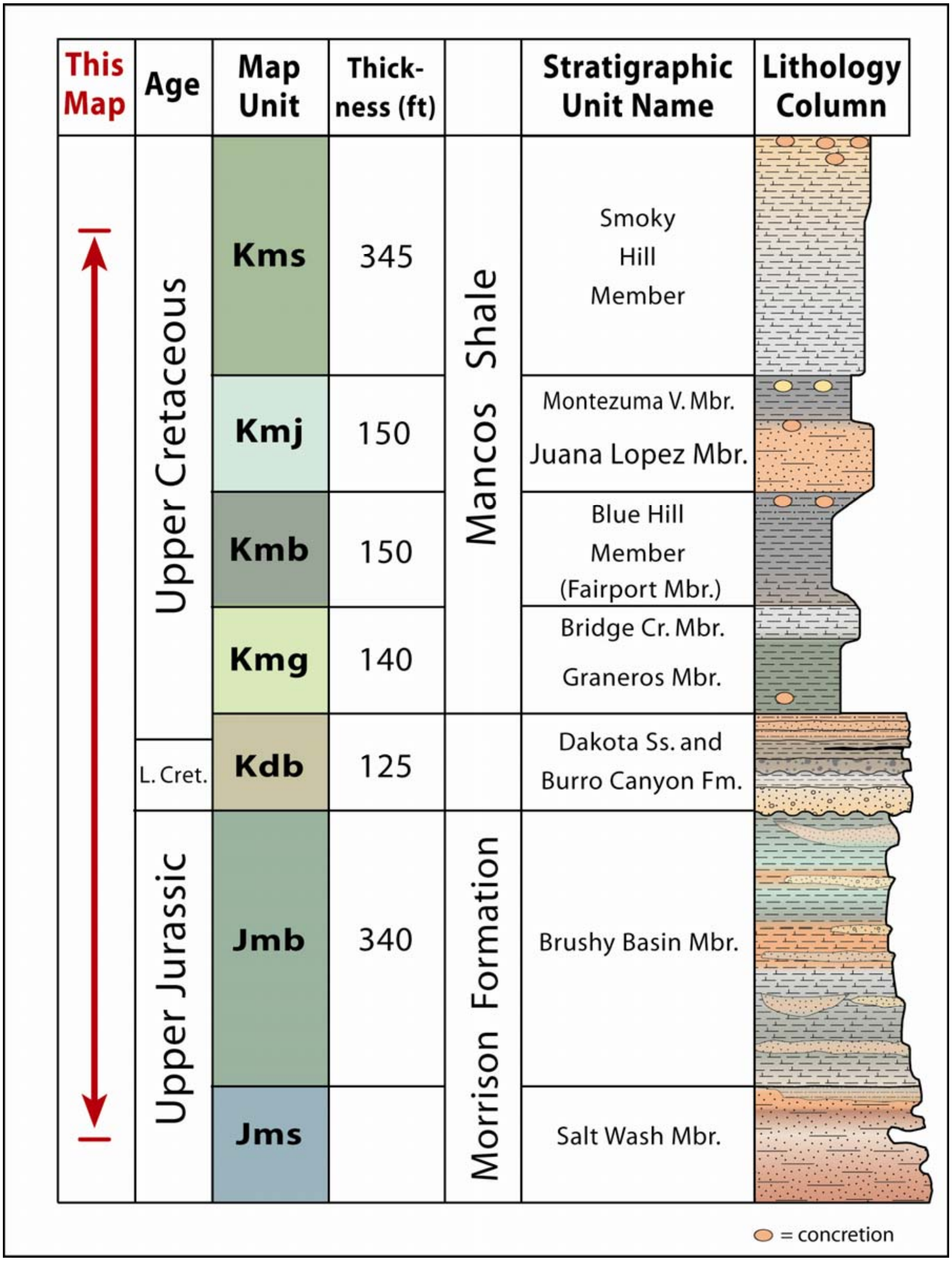

Figure 14. Simplified stratigraphic column of the bedrock units that exist within the Hoovers Corner quadrangle.

Mancos Shale (Upper Cretaceous)

Surface exposures of the Mancos Shale were poor on the Hoovers Corner quadrangle because of the widespread cover of Quaternary terrace gravels and alluvial fans. Exposures on the steeper terrace slopes were limited, commonly covered by variable colluvium and landslide deposits. In some cases, access to property was not given or the owner could not be located. Except where exposures were favorable on the western flank of High Mesa, some estimation of contacts between the varied members was made. Detailed description of the shale units have been taken, in part, from Morgan and others (2008).

Kms **Smoky Hill Member of the Mancos Shale** — Dark gray to tan, slightly calcareous to calcareous silty marine shale. The base of the unit contains light gray to tan shale and silty to shaly limestone beds with very light gray, limonite stained shale partings. The basal limestones weather to a tan to yellow tan color and have a subblocky to subspheroidal appearance in outcrop. The unit becomes moderately fossiliferous, consisting of dark gray, slightly calcareous, subfissile to platy shale with abundant plant debris, shell fragments, and fish scales concentrated along bedding planes. Multiple bentonite beds, some up to 6 inches thick, are located throughout the bottom half of the unit. The upper part of the unit exposed in the map area consists of interbedded blocky to subplaty calcareous shale beds that, where exposed, weather in a rounded subblocky manner. Seams and fracture fills 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 basal shaly to silty limestone is likely equivalent to the Fort Hays limestone member of the Niobrara.

The upper contact of the Smoky Hill Member does not occur in the mapped area. The lower contact with the Montezuma Valley Member, which was only approximately 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).

The Smoky Hill Member may be prone to instability in areas having ground-water discharge and seepage. The unit contains moderately to highly expansive clays, especially in the lower and middle, shaly, bentonitic part of the section.

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

Kmj **Juana Lopez and Montezuma Valley Members of the Mancos Shale, undivided** — Brown to orange-brown to dark gray, calcarenitic, and calcareous marine shale. On the basis of field observations, the Juana Lopez is divided into two parts. The lower part 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 (Anderson, 2007 and B. Ball, USGS, personal commun., 2006). The lower unit forms distinctive orange-brown ledges where exposed on the west flank of High Mesa in the mapped area. The upper unit is gray, slightly fissile, silty, moderately to non-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). Fossils collected within this unit include: *Lopha lugubris* (oyster), *Prionocyclus macombi* (ammonite), *Prionocyclus sp.* (ammonite), *Inoceramus sp.* (bivalve), *Mytiloides sp.* (bivalve), *Baculites sp*., and *Scaphites sp.* The exposed thickness of the unit is approximately 150 feet. The Juana Lopez Member is mostly non-expansive, whereas the Montezuma Valley Member contains moderately expansive clays.

Kmb **Blue Hill and Fairport Members of the Mancos Shale, undivided** — Olive-green to dark-gray, glauconitic, 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, irregular-shaped concretions that cross bedding planes, 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). Fossils are generally scarce but a fossil-bearing zone of fissile shale was located in the middle part of the unit that contained small *Prionocyclus sp.* (ammonite) specimens. 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 residue decrease to the base of the unit. The exposed thickness of the unit is approximately 150 feet.

Kmg **Graneros and Bridge Creek Limestone Members of the Mancos Shale, undivided** — Soft, dark-gray to olive-gray to tan-gray, slightly calcareous, nonfissle silty shale that commonly weathers to small platy chips. Most of the unit has distinct bedding planes that may be coated by gypsum crystals. The lower unit contains disk-shaped iron-stained concretions and thin bentonite beds. Thin (1-inch) sandstone beds occur near the conformable Dakota Sandstone contact. Discontinuous, 8-inch-thick limestone beds occur in the middle of the unit. The lighter gray upper 25 feet of the unit consists of interbedded limestone, calcareous shale, and marlstone of 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.

Kd **Dakota Sandstone (Upper to Lower (?) Cretaceous)** — Buff to orange-brown, well indurated, moderately to well-sorted, fine to coarse grained sandstone, gray black to gray shale, minor coal, and conglomerate. The Dakota Sandstone, usually around 80 to 100 feet thick, unconformably overlies the Burro Canyon Formation. It consists of a lower cliff-forming sandstone section with a basal conglomerate; overlain by a slope-forming unit of noncalcareous shale, carbonaceous shale, and thin sandstone beds with thin coal seams; then sequences of thin shales and cliff-forming coarsening-upward sandstone beds; and an upper thin unit of thinly bedded sandstone and shale. It conformably transitions to the overlying Graneros member of the Mancos Shale. On the Uncompahgre Plateau monoocline, the uppermost thin interbedded sandstone and shale unit has been stripped away, or reduced to regolith, and the uppermost cliff-forming sandstone beds form the dip slope. The transition from the shale interval with the coal seams to the upper cliff-forming sandstone strata marks the upward limit of plant fragments in the Dakota Sandstone (Stokes and Phoenix, 1948). These rocks represent the lower to upper Cretaceous time of marine trangression when depositional environments transitioned from continental fluvial, flood plains, and swamps to marginal marine, wave-influenced deltaic, to off-shore marine (Scott and others, 2001, Serradji and Kamola, 2007).

Lowest in the Dakota Sandstone stratigraphic sections is a chert pebble conglomerate that varies in thickness from 1-2 inches to almost 8 feet; however, it is very commonly 6 inches to 2 feet thick (Figure 15). The basal unconformable contact is irregular, filling scours in the underlying Burro Canyon Formation. It is typically clast supported gravel, which are well rounded chert that are mostly dark gray or black, with lesser amounts of white, red, and dark yellow colors. Green clasts are found where the rock is altered. Composition is 70% gray chert, 8% black chert, 7% white chert, and 5% brown, yellow and red chert. At many locations, it is strongly silica cemented, which causes it to break across the chert pebbles. There are areas, notably Big Sandy Wash and the south fork of Roatcap Gulch, where it is weakly cemented, and the horizon is marked by abundant chert pebbles in a crumbly calcareous matrix. Chert clasts are most commonly about an inch across, but pebbles as large as 3 inches in diameter can be found. The clast provenance is suggested by Young (1973) to be the Sevier orogenic belt in Utah.

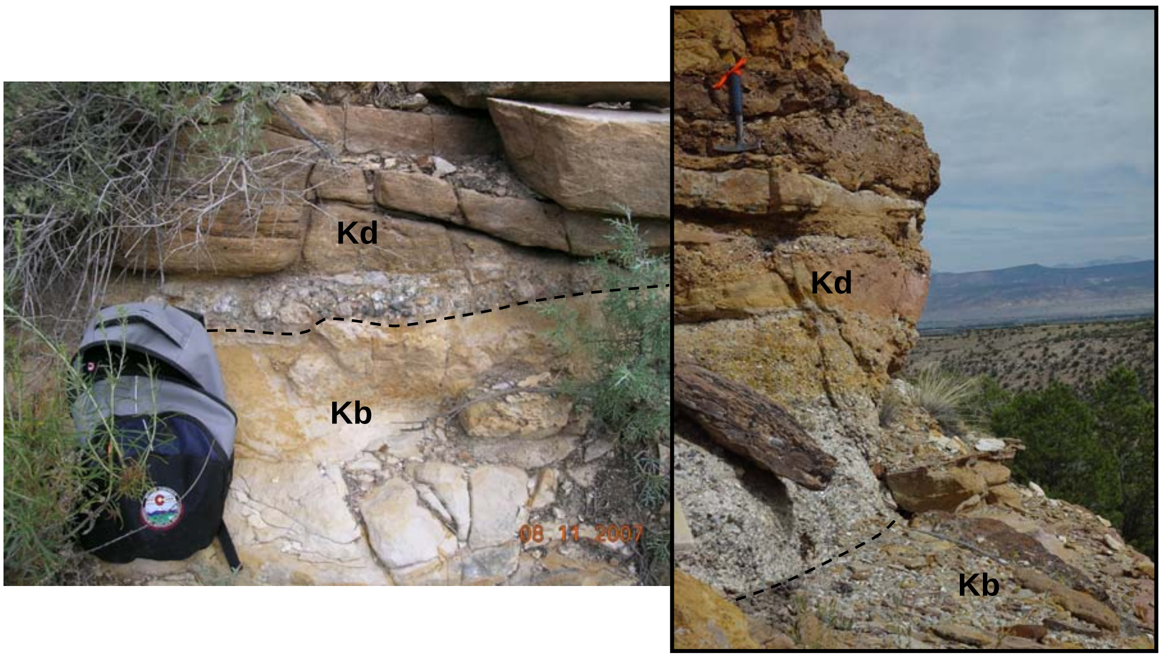

Figure 15. These two photos illustrate the variation in the Kd basal chert conglomerate. The left photo at Big Sandy Wash shows a basal conglomerate with a thickness of 6 inches [UTMX: 230157, UTMY: 4272417]. Right photo at the northwest cliff line of Cushman Creek [UTMX: 230199, UTMY: 4267289] shows a basal thickness of almost 5 feet. Right photo background is the Uncompahgre River Valley, the Gunnison Uplift, and the peaks of the West Elk Mountains.

The conglomerate layer either grades upward into or is overlain by a light olive gray to pale tan to orangebrown, trough cross-bedded, non- to slightly calcareous, medium to fine grained sandstone a few feet to 10 feet thick. Pebbles may be present as far as 8 feet up into this sandstone subunit. One-inch diameter limonitic concretion voids are widely scattered (less than 1%) through the sandstone.

Above the sandstone is a 30- to 50-foot thick section of interbedded shale, siltstone, carbonaceous shale, minor coal, and sandstone. This subunit has been referred to as the Middle Carbonaceous Shale Member by Eakins (1986).   This shale subunit is medium gray to gray black and non- to slightly-calcareous, which weathers light gray to gray in outcrop. The subunit is interbedded with thin, light gray, fine grained, non- to slightly-calcareous sandstone that weathers medium brown in outcrop. Individual shale beds range from a few inches to 30 feet in thickness. The uppermost shale of this unit becomes increasingly dark and increasingly carbonaceous. Thin coal seams in the carbonaceous shale have been prospected for coal with limited production. In the thinly interbedded sandstone beds, which are from 2-3 inches to 5 feet thick, scattered limonite concretions, roughly 1-inch in diameter, are common, as are ripple marked and bioturbated surfaces, and occasional impressions of fossilized leave fragments. Almost all sandstone beds are horizontally bedded, breaking into thin flaggy pieces. Limonite is common, coating fractures in both sandstone and shale, with minor black staining on deeply weathered sandstone surfaces.

The main cliff-forming unit of the Dakota Sandstone is a 20- to 40-foot-thick layer of interbedded, well sorted, buff to light gray, calcareous, fine-grained sandstone and minor gray calcareous shale. This resistant unit outlines the upper edges of the canyons. Bioturbation, fossilized plant fragments, and platy pieces of petrified wood were found in several locations. Fossil dinosaur bones were also found in this unit (Figure 16). Symmetrical ripple marks and burrows (typically

Figure 16. Fossilized dinosaur bone impressions in medium-grained Kd sandstone in stone quarry. Original fossilized bone material is shown by arrows. [UTMX: 228829, UTMY: 4276270].

Thalassinoides) are present on bedding planes of some sandstone beds. There are occasional areas with raindrop imprints. The sandstone weathers medium brown to yellow brown, and often has limonite coating fractures. Black manganese stain is common on deeply weathered surfaces. This sandstone forms the dip slope of this area of the Uncompahgre Plateau. Large, lenticular, cross-bedded sandstone channels occur at different levels in the Dakota Formation. One can be seen forming the canyon rim a hundred yards east of the Transfer Road cutoff in the canyon of Dry Creek and along Cushman Creek (Figure 17). These channels contain fine to medium grained, well-sorted quartz sand, often with widely scattered 1-inch concretion voids.

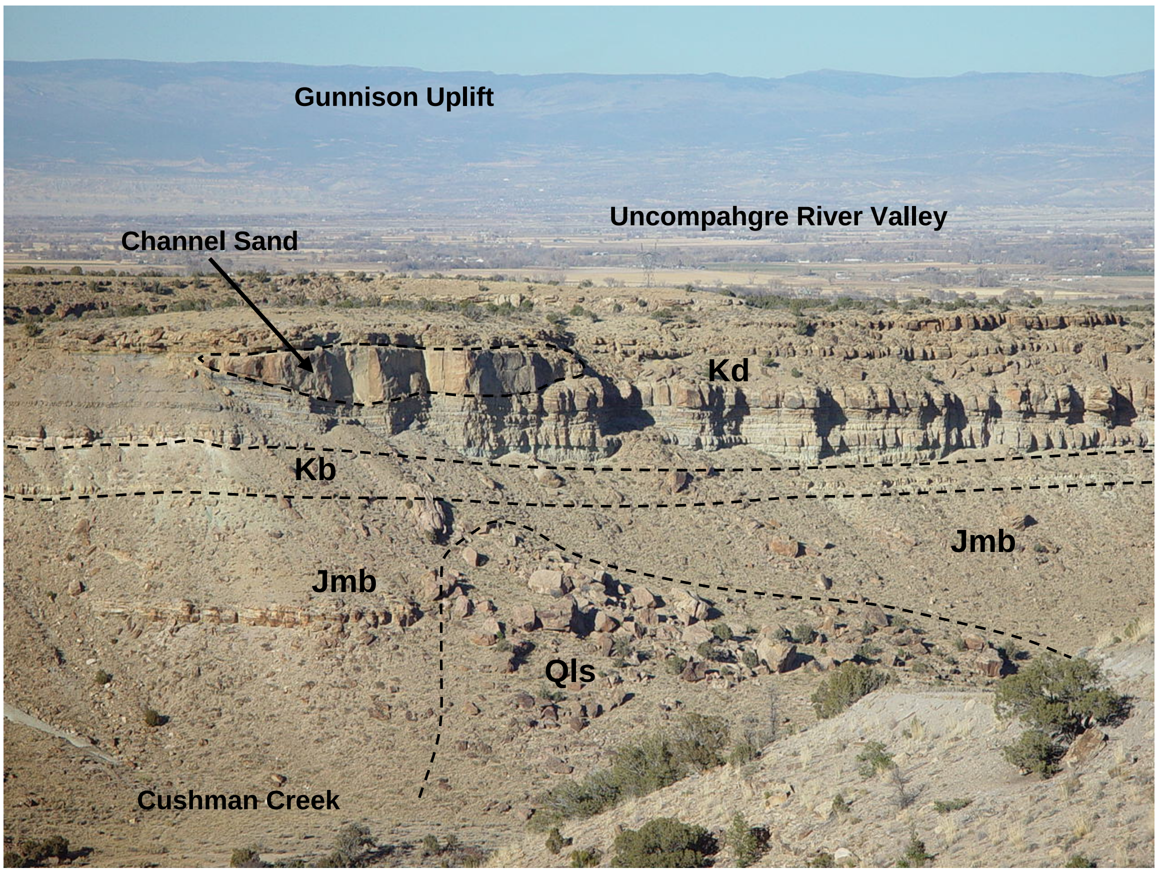

Figure 17. View of cliff line at Cushman Creek that reveals a large channel sandstone unit in the Dakota Sandstone. View is about 30° oblique from the dip direction, toward the Uncompahgre Valley and the Gunnison Uplift. [UTMX: 231829, UTMY: 4268034]

In the Hoovers Corner quadrangle where exposures exist, the conformable contact with the overlying Graneros Member of the Mancos Shale is marked by a 5- to 20-foot transitional zone in which thin beds (1 to 2 inches) of fine to medium grained sandstone occurs within gray, poor to well indurated, silty shale that contains terrestrial plant fossils. It is the absence of these thin sandstone beds that we have used to define the base of the Graneros Shale. On the dip slope of the Plateau, this upper transition unit has been reduced by erosion to a regolith of thin sandstone chips that is mixed with loess and reworked loessal sheetwash above the more resistant, thicker sandstone beds that define the canyon rims.

Kb **Burro Canyon Formation (Lower Cretaceous) —** The Burro Canyon Formation was first named by Stokes and Phoenix (1948) with its type section in Burro Canyon in San Miguel County, Colorado, southwest of the Uncompahgre Uplift. At its type location, it is 150 to 260 feet thick. Within the mapped area it is 12 to 60 feet thick, with an average thickness of around 30 feet. It consists of a lower, commonly cliff-forming, white conglomeratic sandstone and an upper slope-forming greenish yellow siltstone. The Burro Canyon Formation is continental in origin; conglomeratic sandstone beds at its base were deposited by braided streams flowing eastward from the Sevier Highland in central Utah and the overlying mudstones were laid down in flood plains and lakes (Cole, 1987).

The unconformable base of the Burro Canyon Formation is uneven and is marked by a persistent white to light tan, friable, clast-supported calcareous conglomerate that ranges from approximately 2-3 inches to up to 10 feet thick. Clasts are well rounded and usually less than one inch across, although larger pebble-sized clasts are common. Clasts are composed of light to medium gray chert and white mudstone with lesser amounts of white and red-brown chert, tan and gray siltstone and limestone, and petrified wood. Occasional limonitic and bright green chert clasts are found in altered areas. Clasts are 58% chert (over half is gray with lesser amounts of white, black, brown, yellow, and red), 30% white cherty mudstone, 9% gray siltstone and limestone, and 3% tan siltstone. Some of the gray chert and white cherty mudstone pebbles are petrified wood. As pebble size increases, the easily fractured white cherty mudstone dwindles to around 10% of clasts. The conglomerate grades up into a white to light tan, 10- to 50-foot-thick trough-cross bedded, friable, calcareous, poorly sorted, sandstone with common pebble layers and lag gravels. This sandstone forms a steep, rounded and sometimes cliffy slope. The sandstone bed and the underlying conglomerate bed form a white band on the sides of the canyons, easily discerned on the ground and on air photos (Figure 18).

Overlying the lower cliff forming sandstone and conglomerate, below the unconformable contact with the overlying Dakota Sandstone, is commonly a light to bright yellow-green to gray-green, slightly calcareous, shale that is up to 20 feet thick. Its distinct green color helps to locate the top of the formation because shales in the overlying Dakota Formation are always various shades of gray. Locally, scour at the Kd unconformity during Dakota Sandstone deposition resulted in erosion and removal of the green shale (Figure 15). Except for small pieces of petrified wood, fossils were not found in the Burro Canyon Formation in the Hoovers Corner quadrangle.

The base of the Burro Canyon Formation has been placed stratigraphically in different locations by different authors. Stokes and Phoenix (1948) originally placed it at the base of the lowest conglomeratic sandstone above the variegated mudstone of the Brushy Basin member of the Morrison Formation.

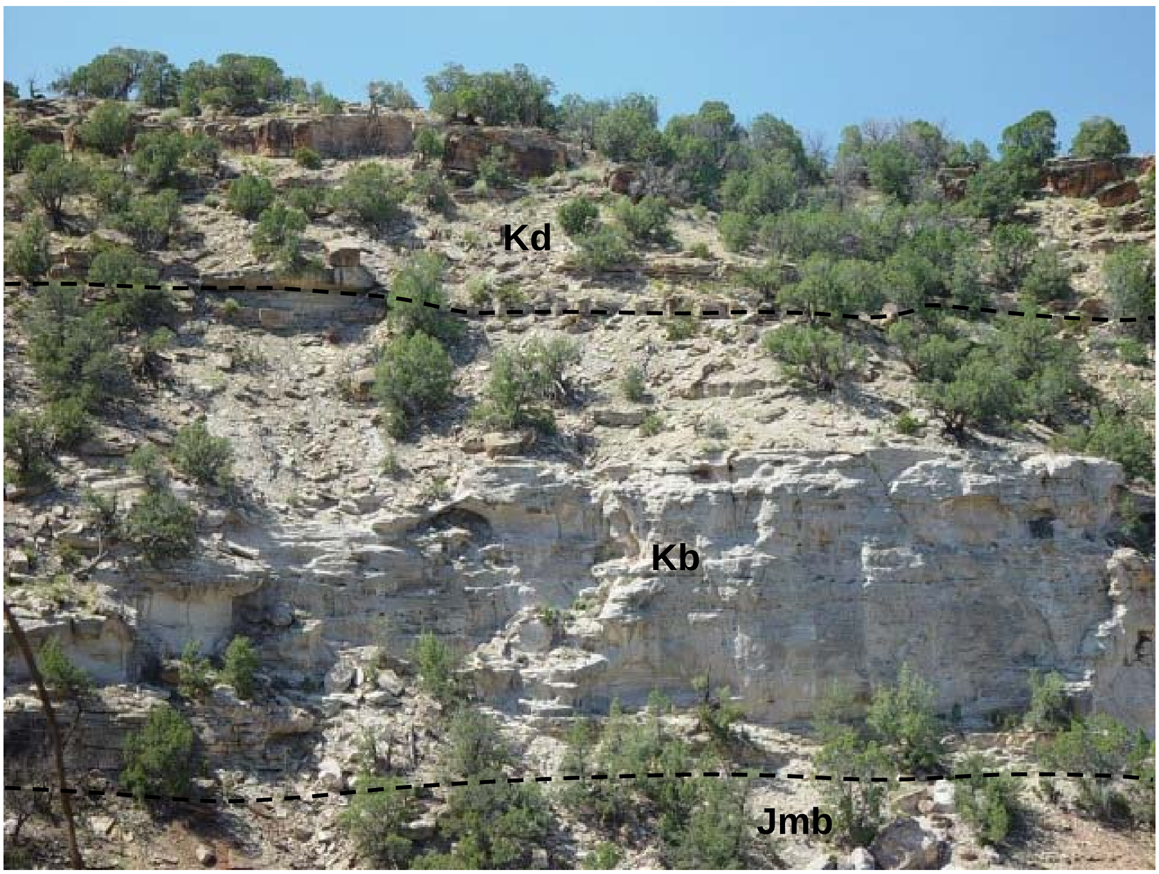

Figure 18. Typical outcrop of Burro Canyon Formation and contact with overlying Dakota Sandstone. Underlying Morrison Formation can be discerned by the reddish mudstone slope at bottom of photo. [UTMX 228167, UTMY 4266515].

In the Salt Anticline Region in southwestern Colorado, Cater (1970) did not find a continuous erosion surface at the base of the Burro Canyon Formation. Instead, the two formations interfinger and are conformable. He noted that local lenticular conglomeratic sandstones occurred below siltstone layers at the base of the Burro Canyon Formation, and that these siltstones were indistinguishable from those in the Brushy Basin Member of the Morrison Formation. Mapping the contact at the base of the lowest lenticular conglomeratic sandstones would have resulted in a contact that crossed bedding horizons. Cater (1970) projected the contact from the base of one lenticular conglomeratic sandstone through a mudstone sequence to the base of another conglomeratic sandstone so the contact remained in virtually the same stratigraphic position.

At Dinosaur National Monument, the persistent Buckhorn Conglomerate Member forms the base of the Lower Cretaceous Cedar Mountain Formation, of equivalent age to the Burro Canyon Formation (Berman and others, 1980). Below it, the upper Morrison Formation contains numerous lenticular conglomeratic fluviatile sandstone channels (Hansen and others, l983). One of these sandstones contains Jurassic dinosaur fossils. It would seem likely then that similar channels in the Hoovers Corner quadrangle could be Jurassic. In Colorado National Monument, the base of the Burro Canyon is defined by Stokes (1952) as the bottom of the lowest thick sandstone or conglomerate bed above the mudstone of the Brushy Basin Member of the Morrison Formation.

In the Hoovers Corner quadrangle, a very persistent clast-supported conglomerate unit separates the Burro Canyon Formation from underlying Morrison Formation shales. The contact is “at the base of the continuous conglomeratic sandstone above the variegated mudstone of the Brushy Basin member of the Morrison Formation” as described by Stokes in 1952. Here, as elsewhere, lenses of poorly sorted channel sediments, similar lithologically to the Burro Canyon beds, are found within the Morrison shales, separated from the Burro Canyon conglomerate by at least several feet, but as many as 120 feet of greenish yellow and red shale (Figure 19).

The Dakota Sandstone and Burro Canyon Formation are shown as undivided Kdb on the cross section (plate 2).

Morrison Formation (Upper Jurassic)

The Morrison Formation is exposed on the Hoovers Corner Quadrangle within canyons that have been incised into the Uncompahgre Plateau. The canyons with the best exposures include Dry Creek, Cushman Creek, Coalbank Creek, Big Sandy Wash, and Roatcap Gulch. Total thickness of the Morrison Formation was reported as 540 feet at the Colorado National Monument (Scott and others, 2001). The Morrison Formation includes three members: the Bushy Basin Member, the Salt Wash Member, and the Tidwell Member.

Only the Bushy Basin and the upper Salt Wash members are exposed in the map area. On the cross section (Plate 2) the Tidwell Member has been included with the Salt Wash Member.

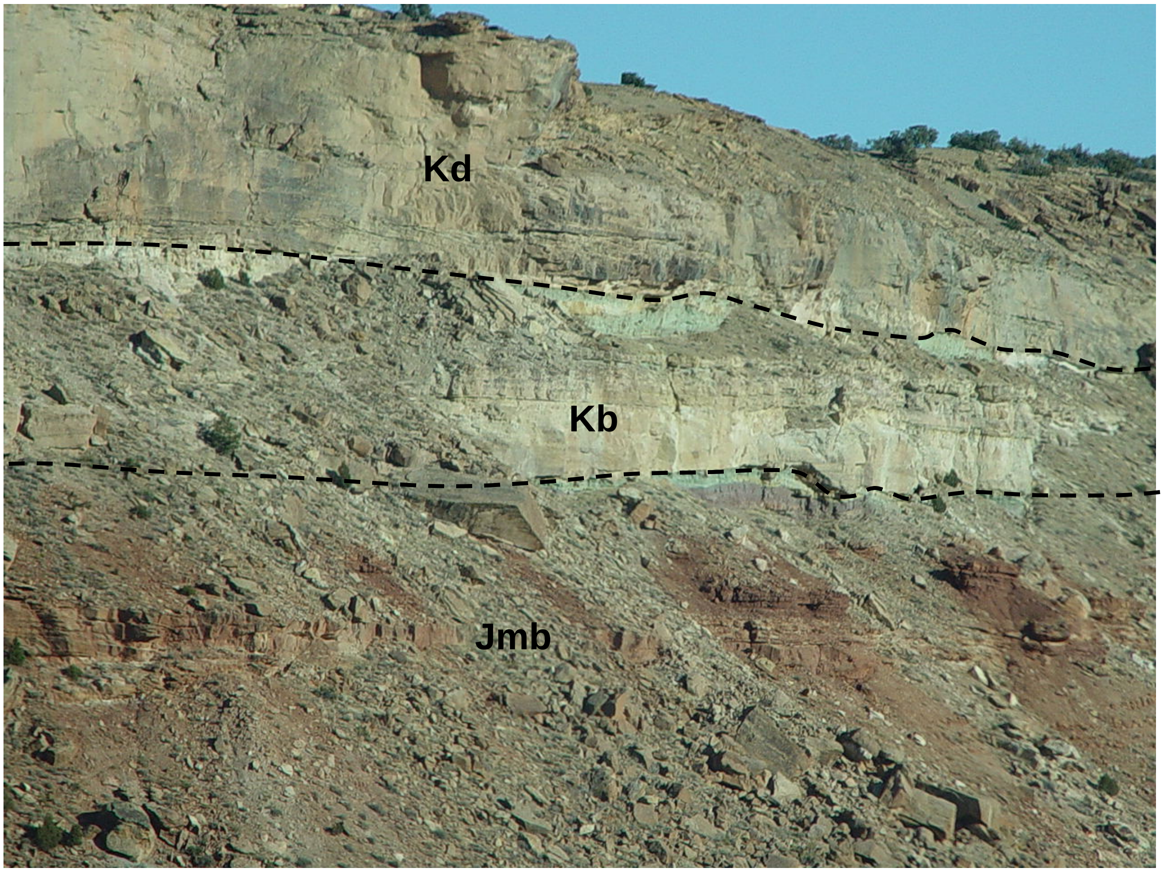

Figure 19. Unconformities in the Dry Creek canyon, marked by discontinuous greenish gray mudstone overlain by conglomerate layers, separate the Dakota Sandstone (Kd) from the Burro Canyon Formation (Kb), and the latter from the Brushy Basin Member of the Morrison Formation (Jmb). Note the variability in formational contacts compared to Figures 15, 17, and 18. Kd is more massive here and the unconformities more pronounced. Note reddish brown-stained channel sandstone in Jmb roughly 10 feet below its upper contact. These channel sands are common in the area and can be thick and tan in color, easily mistaken for Kd or Kb beds when they occur near the Kb contact. [UTMX: 233243, UTMY: 4268498].

Jmb **Brushy Basin Member of the Morrison Formation** — The Brushy Basin Member makes up the upper half of the Morrison Formation. It is a 340-foot thick, slope-forming, varicolored, soft, partly bentonitic mudstone with minor sandstone beds and lenticular sandstone channels that are more common near its top. The Brushy Basin lithologic units formed from terrestrial sediments that accumulated in mud flat, saline lake, and flood plain environments (Blakey, 2007). The mudstones may contain abundant bentonite, a swelling-clay rock constituent that is derived from diagenetic alteration of weathered volcanic ash that fell from Late Jurassic volcanoes of the

Nevadan Orogeny in present-day California and southwest Arizona (Scott and others, 2001; Young, 1987). The canyon of Dry Creek, near the south edge of Hoovers Corner quadrangle, is the only location on the quadrangle where the entire thickness of the Brushy Basin Member is exposed. Even then, the upper third of it is partly obscured by colluvium and ancient landslide deposits.

The lower 150 feet of the Brushy Basin Member consists of mostly light yellow-green, red, and dark purple calcareous bentonitic claystone, siltstone, shale, and sandy shale, with thin (usually only a few inches but can be up to 2.5 feet thick) horizontal dark gray to green well sorted fine-grained sandstone beds, which are often sharply jointed. One 6.5-foot massive, pale yellow-green, fine-grained sandstone lens occurs 24 feet from the base. Bentonite gives weathered outcrops a popcorn-like texture throughout this section. The top 60 feet of this section is light to medium grayish orange, and contains small discontinuous pods of calcareous sandstone and limestone with jasper-filled cracks.

The upper 190 feet of the Brushy Basin Member does not contain swelling clays. It remains soft and weathers to steep rounded slopes. It is predominantly a pale yellow-green, calcareous sandy siltstone and mudstone with several light red bands, grading upward into similar but non calcareous layers. Several light gray to tan, fine grained, rounded and limonitic-weathered, horizontally bedded calcareous sandstone layers a few feet thick are interbedded with the siltstone and mudstone. Channel sandstone deposits become common toward the top of this section. They are composed of trough-cross-bedded, poorly to moderately sorted, calcareous sandstone with occasional chert pebbles. Over most of the quadrangle, the upper 2 to 6 feet of the Brushy Basin Member is a distinctive non-calcareous to calcareous, non bentonitic, pale to bright yellow-green shale. The top several inches often contains rip-up clasts of the green shale.

Mudstones of the Bushy Basin member are susceptible to mass wasting. Steeper slopes should be considered susceptible to slope instability. Large landslide complexes typically mantle the canyonsides where the formation is exposed. Mudstones and the soils derived from the Bushy Basin Member should be considered potentially expansive.

Jms **Salt Wash Member of the Morrison Formation** — Along the center-south margin of the Hoovers Corner quadrangle, the upper 84 feet of the Salt Wash Member outcrop below old landslide deposits near the floor of Dry Creek canyon. No other side canyons cut deep enough to reveal the base of the overlying Brushy Basin Member in the map area. The arkosic sandstones and mudstones of the Salt Wash Member were formed in aggradational braided fluvial systems that created the extensive Jurassic floodplains when sediments were carried northeastward from Nevadan orogenic highlands in present-day southwest Arizona and south-central Utah (Young, 1987; Blakey, 2007)).

This exposed part of the Salt Wash Member consists of interbedded light gray-green to pale tan calcareous sandstone and red to pale yellow-green shale and sandy mudstone. The thin, soft, usually calcareous, shale beds contain bentonite and swelling clays on weathered surfaces form a crumbly popcorn-like texture. Beds are typically less that 1 inch to up to 12 inches thick and may be laminated. Sandstone layers are poorly to moderately cemented and range from less than 1 inch to 4 feet thick. They are composed of medium-grained well-sorted quartz and altered feldspar (around 10%) sand, with occasional zones of more angular and coarser grains (grit). Soft-sediment deformation is common. Interbedded sandstone and mudstone beds contain "pinch and swell" structures. Trough and planar-tabular cross bedding is common in sandstones beds over 1 foot thick. Bioturbation, sometimes with tubular trace fossils, is common in the top 1 to 3 inches of the beds.

In slope exposures, the weathered red mudstone tends to tint the interbedded sandstone beds the same color. In fresh exposures the banded appearance of the interbedded, alternating gray and red beds is more apparent. Soft, friable, and easily weathered by moving water, piping erosion can created voids and small collapse features along rills and gullies.

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

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

Tc Chinle Formation (Triassic) — Shown on cross-section only.

The Chinle Formation is mapped by Marshall (1959) in Roubideau Creek canyon (figure 1) and logged in the subsurface at the oil well, Stephens #1 (location is shown on the resource map on page 56). The Chinle was not deposited in the Black Canyon area (Hansen, 1971, 1987). Oil well subsurface information indicates the Chinle pinches out in the vicinity of the Hoovers Corner and Olathe quadrangle boundary. The location on the cross section where the Triassic Chinle Formation terminates is approximated.

Pc Precambrian Rocks — Shown on cross-section only.

STRUCTURAL GEOLOGY

The monoclinal dip slope where the resistant Dakota Sandstone is exposed in the southwest half of the Hoovers Corner quadrangle is the physiographic manifestation of the eastern limb of the Uncompahgre Uplift (Figure 3). The Uncompahgre Uplift is a Pennsylvanian structure that rejuvenated during the Laramide Orogeny. Laramide southwest-northeast compressive stress caused the lifting of plateau rocks thousands of feet along preexisting basement faults. On the northeast flank of the Uplift, this resulted in gentle folding and shallow easterly dips of the Cretaceous rocks in the map area (Marshall, 1959; Tweto, 1977; and Stone, 1977). The Dakota Sandstone monocline strikes approximately N60W and dips 3 degrees to the northeast, rising 1,300 feet in elevation from California Mesa (the late Pleistocene paleo-valley floor where the Qau_4 terrace was deposited) to the highest point on the quadrangle map. This gentle dip and general strike of beds are reflected over much of the map; however the main dip-slope monoclinal structure, in turn, contains shallow, ripple-like anticlinal and synclinal folds that plunge in the same approximate direction and declination of the dip slope. Localized rock attitudes may range from being near horizontal to dips up to 10 degrees. These subtle structures have not been individually mapped but the synclines of these “ripple” folds appear to have controlled the development of some of the drainage streams that have incised the subparallel side canyons into the Dakota Sandstone dip slope.

One structure that has visibly deformed the plateau homocline is a paired monocline and syncline along Big Sandy Wash that also plunges in the approximate regional dip direction. This structure has been mapped as a fault by Marshall (1959), Williams (1964), Sinnock (1978), and Lettis and others (1996). It is included in the Late Cenozoic fault and fold database of Colorado (Widmann and others, 2002) where it is referred to as the Monitor Creek fault (Q18). Lettis and others (1996) report that despite the lack of definitive evidence of Quaternary offset, the most recent movement is considered to have occurred during the Quaternary. Minor fault displacement and offset of about 10 feet does occur just outside of the map boundary along a notch in the canyon side of East Fork Roatcap Gulch (SE¼SW¼, Sec. 32, T50N, R11W). However, our mapping reveals that a monoclinal flexure and synclinal fold is responsible for the 120 feet of net downward displacement in the regional dip, measured from the top of the Dakota Sandstone (Figure 20), and this displacement is opposite of the throw of the fault. This flexure in the regional dip extends down into the California Mesa valley and across Dry and Coal Creeks to where it was also identified in deformation and downward displacement of the Juana Lopez member of Mancos Shale that is exposed along the western flank of High Mesa. There is no evidence of displacement of the overlying gravels (Qau_4 or Qau_{5a}) so any movement along this structure at the valley floor predates middle Pleistocene age.

Alteration in the form of abundant limonite and silicification of the basal conglomerate is fairly common in the Dakota Sandstone. The Burro Canyon Formation is very white, often bleached. Along Cushman Creek and upper Coalbank Canyon there are roll-fronts in the Burro Canyon where conglomeratic sandstones are cemented with black hematite next to bleached, limonitic areas. Southwest of the transfer station on the north bank of Cushman Creek is an area where the Burro Canyon Formation is tinted green as a result of propylitic alteration. This alteration is probably Laramide in age (R. Livaccari, Mesa State College, personal commun., 2007). The flow of mineral-laden fluids along faults in Precambrian rocks during the time of uplift preferentially spread into the very porous, poorly cemented Burro Canyon sandstones.

Figure 20. Monoclinal flexure from the background ridge to a syncline in the Dakota Sandstone at Big Sandy Wash has resulted in a regional elevation offset of 120 feet in the Plateau dip slope along the trend of this structure. This paired monocline and syncline are shown on the Plate 1 map and the cross section on Plate 2. Coal prospect adits (location shown by arrow and shown in inset photo of figure 21) occur at the syncline axis near stream level [UYMX: 230434, UTMY: 4272476].

GEOLOGIC HAZARDS

Bedrock structure, hydrogeology, topography, surface drainage, lithology, soil development, and clay mineralogy are important controls on the development of geologically hazardous areas within the Hoovers Corner quadrangle. In this section of the Authors' Notes, the term "soil" is used in the geotechnical or civil engineering sense as to describe an unconsolidated geologic material or nonlithified sediment. Landslides within the Mancos Shale affect most of the mesa edges where residential development is increasing. Flash floods, mudflows, and hydrocompactive (collapsible) and swelling soils are also impacting residential and commercial structures throughout the Uncompahgre River valley. Other significant and potentially damaging hazards in the mapped area include corrosive and erodible soils, and earthquakes. Receiving increased water-quality attention of late is the impairment of the Uncompahgre River related to selenium concentrations.

Landslides

In the Quaternary Period, the Mancos Shale has been subaerially exposed and weathered prior to the deposition of different levels of alluvial terrace gravel. The gravel cap is more resistant to weathering than the weaker shale below thus resulting in the formation of mesas. Landslides are prevalent on the steeper 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 reworked gravelly alluvium. The slope failures are mainly rotational and translational slides where failure typically occurs within the heavily weathered, fractured, and weakened shale (Figure 13 and frontispiece). Accelerated ground creep and earth flows may also occur if slopes become fully saturated. Ground water infiltrates through the permeable gravel that caps the mesas and perches on the more impermeable shale. The ground water flows laterally to the flank of the mesa where springs and ground seeps occur. Major unlined irrigation canals also cut into weakened and weathered shale and contribute seasonal water to the steeper mesa slopes. Water slowly seeps into the shale causing further weakening of the bedrock by additional weathering, increased pore pressure, and/or dissolution of gypsum fracture filling. Pore pressure and 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. The Uncompahgre Valley Water Users Association has periodic problems with landslides that affect their canal system.

Occurrences of landslides within the quadrangle follow the morphology of mesa edges, and appear independent of geologic structure. Landslides are accelerated by agricultural practices in the Uncompahgre Valley (White and Morgan, 2007). Additional runoff and infiltration from farmland irrigation further "lubricates" fractures and increases the pore pressure of the weathered bedrock, which reduces the inherent stability of the slope. All landslides and similar terrain where they form should be considered susceptible to future ground movements.

Landslide areas are subject to future movement during episodes of heavy rain or snowfall, or when critical weathering thresholds that weaken clay minerals in the shale are met, or may be reactivated by human-made disturbances such as cutting of slopes for roads, quarries, housing developments, periodic canal operations, irrigation systems, and septic systems. Poor irrigation practices commonly initiate new landslides or remobilize older landslide deposits. In addition to potential for further reactivations, landslide deposits are prone to lateral creep movements and settlement when disturbed, loaded, or wetted during development. Landslides in the Morrison Formation in the mapped area do not present hazards to development because they lie within public lands administered by the Bureau of Land Management.

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 hydraulically incorporates additional materials. 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 flash floods can form at any point along a drainage bottom, including on the sides of valleys (Qac). They are the result of torrential rainfall or very rapid snowmelt runoff, where sediment supply is abundant and easily mobilized (Selby, 1993).

Much of the base of the Uncompahgre Plateau dip slope consists of mud-dominated alluvium and alluvial fan deposits (Qf). Debris floods from Roatcap Gulch have historically flowed almost 3 miles over the broad alluvial fan to the Hoover Corner intersection, flooding events that caused the construction of a flood control dam at the mouth of the gulch (Mrs. Martha Brack, local ranch owner, and Dennis Miller, BLM, personal commun., 2007). Holocene to upper Pleistocene deposits extend to the Dry Creek valley. These sediments were derived mostly from the rocks exposed on the Uplift and were deposited as mud and gravel debris flows from the narrow canyons of the local drainage basins that extend up onto the Plateau. The mouths of all the ephemeral streams that outlet the narrow canyons in the

Plateau dip slope should be considered at risk of potential debris flooding. Small, localized debris flows can also occur in gullied areas in mesas with mapped landslides (Qls). Landslides can cause failures of the valley's irrigation canals along the steeper mesa slopes that also result in debris and mud flows to course down slopes. Residents living within or in close proximity to these areas and their associated drainageways should be aware of the possibility of large precipitation events triggering future debris flows, which may inundate these areas with dangerous amounts of water and sediment.

Rockfall

Rockfall deposits are included in landslide (Qls), colluvium deposits (Qc), and alluvium and colluvium (Qac) deposits in the Hoovers Corner quadrangle. Most rockfall occurs below the cliff lines of the many canyons that have incised into the Uncompahgre Plateau dip slope. Minor rockfall also occurs along the mesa edges where loose cobbles and boulders overlie unconsolidated Mancos Shale. Large precipitation events, freeze-thaw processes, and undercutting of shale where interbedded with sandstone may trigger rockfall. Cliff lines and runout areas along the sides and floors of canyons incised into the plateau that are rimmed by Dakota Sandstone should be considered rockfall hazard zones.

Earthquakes

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. That same earthquake today, modeled with the Federal Emergency Management Agency's risk assessment software program (Hazus), resulted in a simulated economic loss of 27.2 million dollars (White and others, in prep.).

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 mudstones of the Morrison Formation, as well as derived soils, may undergo volumetric swelling when wetted due to the presence of smectite, an expansive clay mineral. Smectite is prevalent in reworked and altered volcanic ash (i.e., bentonite) found in Jurassic terrestrial mudstones and marine shales of Cretaceous age in the North American mid-continent. Upon wetting, these clay minerals, which are relatively dry under the natural semi-arid climate conditions of the area, draw water into their crystalline matrices and expand to accommodate the added water molecules (Noe, 2007). The expansion of clays results in ground heaving and potential damage to structure foundations, paved roads, concrete flatwork, and underground utility pipes.

In the Hoovers Corner quadrangle, the Graneros and Smoky Hill Members of the Mancos Shale (Kmg and Kms) and mudstones in the Morrison Formation contain clay-rich zones that may be prone to swelling in near-surface bedrock. Derived soils of the Mancos Shale on the valley floor, particularly the alluvial fan (Qf), landslides (Qls), alluvium (Qa), and colluvium (Qc) deposits, may contain pockets or zones of swelling clays. Derivative maps of the NRCS Soil Survey (SSURGO) of the Montrose-Delta area indicate that the Mancos Shale and surficial deposits derived from the Mancos have a moderate (3-6) to high (6-9) linear extensibility. Linear extensibility is a measure of a soil's shrink-swell behavior; "moderate" refers to 18-35% mixed or smectitic clays and "high" is >35% mixed or smectitic clays (Natural Resources Conservation Service, 2008). The detection of swelling soil conditions is best accomplished on a site-specific basis. This involves the drilling of exploratory boreholes, 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 may be used to assess the plasticity and swell potential of the samples.

Collapsible Soils and Bedrock

Surficial deposits derived from the bedrock units in the Hoovers Corner quadrangle can be especially prone to hydrocompaction. In these dry and low-density 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 soil densification and collapse often results in ground settlement. Collapse typically occurs in matrix-supported deposits where clay- and silt-sized particles dominate the matrix. Rapidly-deposited Alluvial fan (Qf), Holocene valley fill (Qac) and the fine-grained Holocene alluviums of Dry Creek and Coal Creek, and colluvial sheetwash (Qc) deposits in the

Hoovers Corner quadrangle should be considered potentially susceptible to the occurrences of collapsible soil.

Both the Mancos Shale and surficial units derived from the Mancos Shale may also be prone to settlement where it is in a highly weathered state. Within the weathered zone of the Mancos Shale, 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 future wetting, subsequent dissolution of the gypsum can create micro-pipes and subsurface voids that may cause the weathered claystone to collapse or recompress when loaded (White and Greenman, 2008).

Damage such as cracking of foundations and other structural problems can be caused by ground settlement, 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 collapse potential of bearing soils for development. Knowing the thickness of the collapse-prone soil is also important.

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 clay soils and weathered bedrock may slightly swell upon wetting but quickly settle or collapse upon further incremental loading. Such conditions need to be assessed by professional engineering geologists or geotechnical engineers and taken into account during the engineering 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 (National Resources Conservation Service, 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. Some of the highest are the eolian residual soils on the plateau dip slope. There, the BLM has plowed a series of shallow parallel furrows and berms to capture rainfall, reduce runoff, and control erosion.

There is a close correlation between 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. 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 (National Resources Conservation Service, 2008).

Wind erosion may 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.

Corrosive Soils

The Mancos Shale and sediments derived from the Mancos Shale typically have high salt and sulfate content and should be considered potentially corrosive. Corrosive soils may damage typical concrete and buried unprotected metal. Areas mapped as Mancos Shale and surficial soil units derived from Mancos Shale are prone to high rates of corrosiveness for steel and concrete. The NRCS soil survey also indicates that the thin residual/loessal soils (which have not been mapped) that discontinuously mantle the lower dip slope of the plateau, are also potentially corrosive. 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-grades in Mancos-derived soils, as well as protective coatings for buried metalworks.

MINERAL RESOURCES

Sand and gravel are presently the most economically significant mineral resources in the Hoovers Corner quadrangle because of the areal extent of the gravel-capped mesas. Many active and inactive aggregate quarries are located in the mapped area. Dimension and landscaping stone resources also exists where sandstone outcrops on the Dakota Sandstone dip slope. There are stone quarries on the few private land holdings on the dip slope where sandstone has been historically mined for landscaping stone and facing stone. Thin subbituminous coal seams and coaly shale occur in the Dakota Sandstone, and many coal prospects and small-scale historical production for private use early in the last century have been mapped (Figure 21). Eakins (1986) describes these coal beds as occurring in the Middle Carbonaceous Shale Member of the Dakota Sandstone where swamp conditions existed in a low-lying Cretaceous structure called the Montrose Sag. Eakins (1986) reported small production from two small coal mines in the Montrose West quadrangle south of the mapped area in the 1920s and 1930s. The coal seams are about 6 to 18 inches thick, in up to 4 feet of coaly shale in the mapped area. They are not economically viable as a mineral fuel resource.

From 1931 through 1979, six 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, last accessed March 18, 2009).

Excellent potential exists for the development of additional sand and gravel operations in the significant alluvial terrace deposits of the Uncompahgre River in the mapped area. Other lower quality aggregate resources occur in the gravels of the Dry Creek alluviums and some of the old, better sorted, riverine alluvial fan deposits. Figure 22 shows the locations of potential quality stone and gravel resources, as well as active and abandoned gravel pits, abandoned coal mines and prospects, and abandoned oil and gas wells within the quadrangle.

Figure 21. Small coal strip mine in middle shale unit of the Dakota Sandstone. Inset photo above shows another shallow prospect adit in Big Sandy Wash. Location of inset photo is shown by arrow in Figure 20. [UTMX: 228867, UTMY: 4276258]

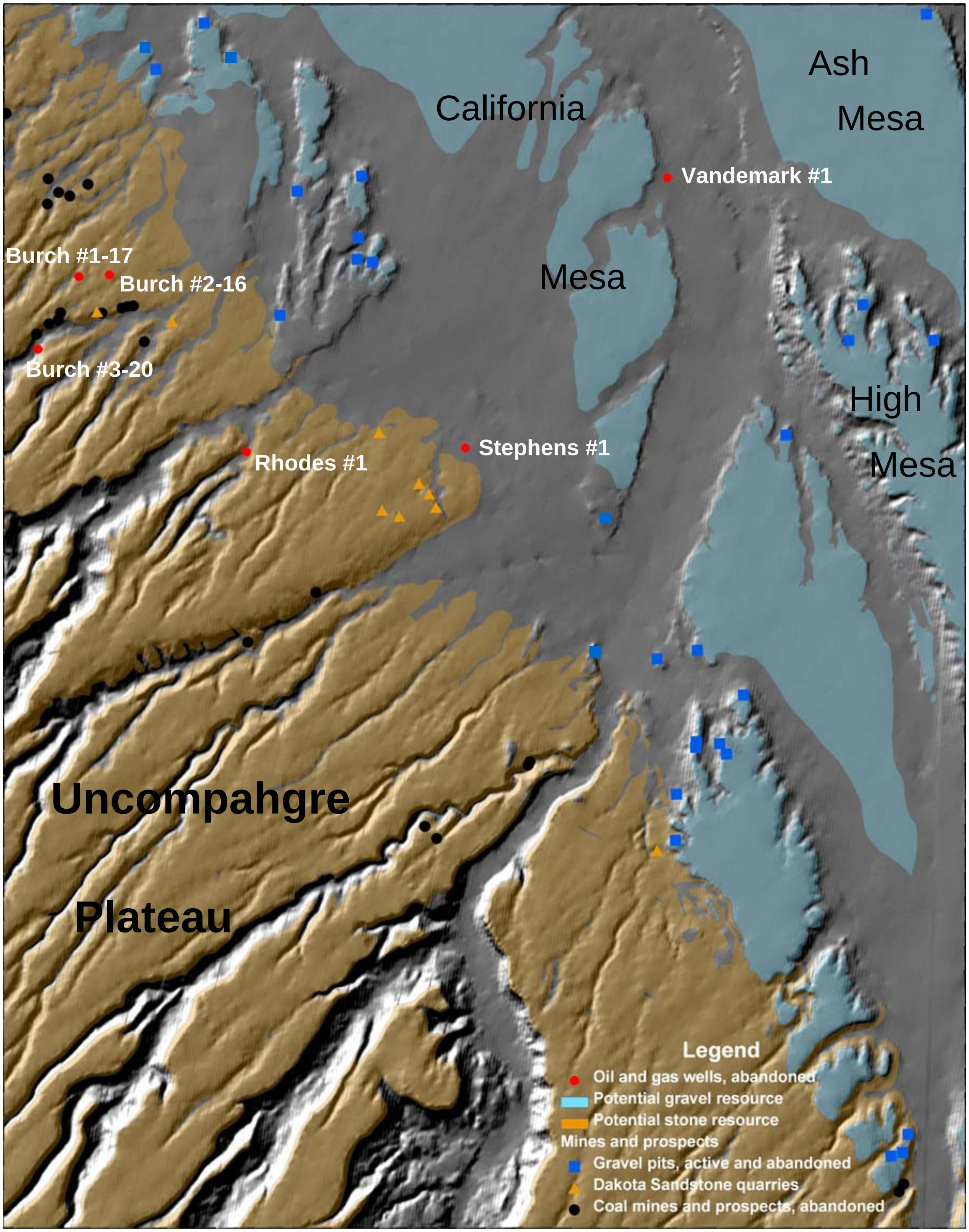

Figure 22. Resource map of the Hoovers Corner quadrangle showing locations of quality gravel resources, stone resources, historic coal mines and prospects, active and inactive gravel pits, and abandoned oil and gas wells.

GROUND-WATER RESOURCES

The primary source of domestic drinking water within the Hoovers Corner quadrangle comes from the Gunnison River (M. Catlin, Uncompahgre Valley Water Users Association, personal commun., 2007). The water is transported to the local communities via the 5.8 mile-long Gunnison Tunnel that diverts water from the Gunnison River in the Black Canyon of the Gunnison. The water is stored in a number of reservoirs: the Taylor Park Reservoir located approximately 60 miles east of Delta in the Sawatch Range, Blue Mesa Reservoir, and Morrow Point and Crystal Reservoirs in the Black Canyon. A complex system of canals, diversion dams, and treatment plants makes the water available for domestic and agricultural use. Other important sources of domestic drinking water are from alluvial and bedrock wells.

Depending on the location in the map area, ground water can be found in three hydrogeologic units:

1) consolidated bedrock aquifers found in the Dakota/Burro Canyon sandstones,
2) consolidated bedrock aquifers found in sandstone of the Morrison Formation, or
3) 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

Ground-water for domestic use comes from the Quaternary alluvial deposits associated with the Uncompahgre River, Dry Creek, and Coal Creek, and the thicker alluvial fan deposits. These alluvial aquifers are part of the Gunnison River basin, which extends west from the Continental Divide to Grand Junction and north from the San Juan Mountains south of Ouray (Topper and others, 2003). Most of the lower alluvial deposits (mapped with numbered 1 and 2 subscripts) 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, especially the higher alluviums that cap the mesas.

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 range from 11 to 50 feet. Well yields vary from 8 to 50 gallons per minute (GPM) but 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).

Bedrock Aquifers

Where ground-water from alluvial aquifers is not feasible or available, permitted water wells on the Hoovers Corner quadrangle utilize aquifers in the sandstone beds of the Morrison Formation and the Dakota Sandstone (combined with the Burro Canyon Formation). Bedrock aquifer wells range from 100 to over 710 feet in depth. The Dakota and Burro Canyon sandstones are the primary bedrock aquifer in the mapped area for both domestic and livestock uses. Regionally, sandstone bodies in the lower part of Mancos Shale are also used for domestic water, but to a limited extent (Meeks, 1950). In the southern part of the mapped area, and in Shavano Valley, the Morrison Formation is a common domestic water target (Meeks, 1950).

The porosity of the Dakota and Burro Canyon sandstone beds is highly variable and is not published for the Hoovers Corner area. On the basis of surface outcrops, the potential thickness of the Dakota/Burro Canyon Sandstone aquifer ranges from about 120 to 160 feet in the mapped area. The aquifer may be confined to partially confined, and artesian wells occur in some locations. An abandoned oil and gas well, Burch #2-16 shown on figure 22, produces water at the ground surface that is the source for a ranch stock pond.

Water-level data for the Dakota/Burro Canyon 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/Burro Canyon aquifer can be expected to vary considerably depending on location and elevation; values listed in the DWR permit database are between 100 and 500 feet below the surface.

Well yields from the Dakota aquifer within the quadrangle typically range from 2 to 24 GPM and average 7 GPM. Ground water from the Dakota/Burro Canyon sandstone aquifer is considered “tributary” and directly connected to surface water (Hobbs, 2004). Thus, this groundwater is subject to the State of Colorado surface water appropriations system.

According to Meeks (1950) water from the Dakota/Burro Canyon 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 and is typically better near the recharge zone on the east flank of the Uncompahgre Uplift (Meeks, 1950). In general, water quality of the Dakota/Burro Canyon aquifer in the area is adequate for domestic use. Meeks’ (1950) local study reported total dissolved solids (TDS) values ranging from approximately 210 to 4,200 mg/L and averaging 1,845 mg/L. More regional in scope, Apodaca (1998) report TDS values in the Dakota/Burro Canyon aquifer ranging from 114 to 2,300 mg/L and averaging 331 mg/L.

Individual well data from deeper wells (up to 710 feet) producing water from the Morrison Formation sandstone beds indicate a production rate range from 2 to 10 gpm. Meeks (1950) did not include water quality tests for the Morrison Formation. Apodaca (1998) report TDS values in the Morrison Formation groundwater in the Upper Colorado River Basin to range from 244 to 908 mg/L and average 350 mg/L.

Mancos Shale is the bedrock that underlies most of the irrigated farmlands in the mapped area and irrigated return flows return to the Uncompahgre River by way of Dry Creek. The Uncompahgre River from the town of Montrose to the confluence with the Gunnison River is listed as “Selenium Impaired Stream Segments” meaning that the waters “do not or do not expect to meet applicable water quality standards” (Gunnison Basin Selenium Task Force, 2008). Elevated selenium levels have been shown to be harmful to fish and aquatic birds. 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 units, most of the residences in Hoovers Corner have tapped into domestic water mains.

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., 1998, Analysis of ground-water-quality data of the upper Colorado River basin, water years 1972-92: U.S. Geological Survey Water-Resources Investigations Report 97-4240.

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.

Berman, A.E., Poleschook, D., Jr., and Dimelow, T.E., 1980, Jurassic and Cretaceous Systems of Colorado, *in* Kent, H.C., and Porter, K.W., eds., Colorado Geology: Rocky Mountain Association of Geologists, Denver, CO, p. 111-128.

Blakey, R., 2007, Paleogeographic evolution of the passive-margin to active-margin transition, Early Mesozoic, Western North America, Northern Arizona University, http://jan.ucc.nau.edu/~rcb7/, last accessed March 18, 2009.

Cater, F.W., 1970, Geology of the Salt Anticline Region in Southwestern Colorado: U.S. Geological Survey Professional Paper 637.

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.

Cole, R.D., 1987, Cretaceous Rocks of the Dinosaur Triangle, p 21-35 *in* Averett, W. R., Paleontology and Geology of the Dinosaur Triangle, Guidebook for 1987 Field Trip: Museum of Western Colorado, Grand Junction, Colorado.

Cole, R.D., 2007, The Grand Mesa basalt field, Western Colorado [abstract]: Geological Society of America Abstracts with Programs, v. 39, No. 6, p. 307.

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.

Eakins, W., 1986, Coal resources of the Dakota Sandstone, southwestern Colorado: Colorado Geological Survey Open File Report 86-1, 77 p., 5 plates, scale 1:50,000.

Foos, A., 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, last accessed March 18, 2009.

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.

Gunnison Basin Selenium Task Force, 2008, http://www.seleniumtaskforce.org/, last accessed March 18, 2009.

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.

Hansen, W. R., Rowley, P. D., and Carrara, P. E., 1983, Geologic Map of Dinosaur National Monument and Vicinity, Utah and Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-1407, scale 1:50,000.

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.

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/Default.aspx?tabid=270, last accessed March 18, 2009.

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.

Machette, M.N, 1985. Calcic soils of the southwestern United States. *In*: D.L. Weide (ed.) Soils and Quaternary geology of the southwestern United States. Geological Society of America Special Paper 203, pp. 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, last accessed March 18, 2009.

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., 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.

Morgan, M.L., Noe, D.C., White, J.L., and Townley, S.M., 2008, Geologic map of the Delta quadrangle, Montrose and Delta Counties, Colorado: Colorado Geological Survey Open-File Report OF-08-02, scale 24,000.

National Resources Conservation Service, 2008, On-line soil survey data for Montrose County available at: http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx, last accessed March 18, 2009.

Noe, D.C., 2007, A guide to swelling soils for Colorado homebuyers and homeowners, 2nd ed.: Colorado Geological Survey Special Publication 43, 52 p.

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.

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.

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., 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.

Scott, R.B., Harding, A.E., Hood, W.C., Cole, R.D., Livaccari, R.F., Johnson, J.B., Shroba, R.R., and Dickerson, R.P., 2001, Geologic Map of Colorado National Monument and Adjacent Areas, Mesa County, Colorado: U.S. Geological Survey Geologic Investigation Series I-2740, http://pubs.usgs.gov/imap/i-2740/, last accessed March 18, 2009.

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

Serradji, H. and Kamola, D., 2007, Depositional environment and sequence stratigraphy of the Dakota Sandstone (Lower Cretaceous) in the Ridgway Area, SW Colorado, American Association of Petroleum Geologists Annual Convention, Long Beach, California, April 1-4, 2007, Poster (website adapted from poster available at http://www.searchanddiscovery.net/documents/2007/07097serradji/index.htm, last accessed on March 18, 2009.

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.

Stokes, W. L., 1952, Lower Cretaceous in Colorado Plateau: Am. Assoc. Petroleum Geologists Bull., v. 36, no. 9, p. 1766-1776.

Stokes, W.L., and Phoenix, D. A., 1948, Geology of the Egnar-Gypsum Valley area, San Miguel and Montrose Counties, Colorado: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 93.

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.

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

White, J.L., and Greenman, C., 2008, Collapsible Soils in Colorado: Colorado Geological Survey Engineering Geology Bulletin 14, 108 p., 1 map plate, scale 1:1,000,000.

White, J.L., Wait, T.C., and Morgan, M.L., in prep., Geologic hazards mapping project of the Uncompahgre River valley area, Montrose County, Colorado: Colorado Geological Survey Open-File Report OF-09-1, 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/Default.aspx?tabid=270, last accessed March 18, 2009.

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 1:250,000.

Young, R.G., 1973, Depositional Environments of basal Cretaceous rocks of the Colorado Plateau *in* Fassett, J.E., ed., Cretaceous and Tertiary rocks of the southern Colorado Plateau, Four Corners Geological Society Memoir, p. 10-27.

Young, R. G., 1987, Triassic and Jurassic Rocks in the Dinosaur Triangle, *in* Averett, W. R., (ed.), Paleontology and Geology of the Dinosaur Triangle, Guidebook for 1987 Field Trip: Museum of Western Colorado, Grand Junction, Colorado, p. 5-20.

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

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

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.