OPEN-FILE REPORT 07-02

Authors' Notes

Geologic Map of the Montrose East Quadrangle, Montrose County, Colorado

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Geologic Map of the Montrose East Quadrangle, Montrose County, Colorado

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

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View to northwest from "Chicken Wing Mesa" toward Montrose, showing the Uncompahgre River valley (upper left), the elongate mesas of the gravel-capped "Mesa Staircase" (upper right), and badlands terrain eroded into the Upper Cretaceous Smoky Hill Member of the Mancos Shale (foreground). [UTM83 256162, 4253023]

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FOREWORD

The purpose of Colorado Geological Survey Open File Report 07-02, *Geologic Map of the Montrose East Quadrangle, Montrose County, Colorado* is to map and describe the geologic setting, mineral and ground-water resources, and geologic hazards of this 7.5-minute quadrangle located to the southeast of Montrose in western Colorado. Staff geologists David C. Noe and Matthew L. Morgan and summer volunteer geologist Stephen M. Keller completed the field work on this project during the spring of 2006. David Noe was the principal mapper and author for this report, using maps and field notes generated by all three investigators. Paul Hanson (University of Nebraska-Lincoln) provided summaries of optical dating results for two Quaternary-age gravel units. Some surficial and bedrock unit descriptions were coordinated between this area and the Olathe quadrangle (Morgan and others, 2007).

This mapping project was funded jointly by the U.S. Geological Survey (USGS) and the Colorado Geological Survey (CGS). USGS funds were received under STATEMAP award number 06HQAG0045. STATEMAP is a component of the National Cooperative Geologic Mapping Program, which is authorized by the National Geologic Mapping Act of 1997. The CGS matching funds were drawn from the Colorado Department of Natural Resources Severance Tax Operational Funds, which are obtained from the Severance Tax paid on the production of natural gas, oil, coal, and metals in Colorado.

Vince Matthews
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We are appreciative of local geological and geotechnical information that was provided by Jon White (CGS); Laurie Hauptmann, Shane Duckworth, and Tim Brethauer (Buckhorn Geotech); Dennis Lambert, Daniel Lambert, and Bill Hardy (Lambert and Associates); and Norm Johnston (Geotechnical Engineering Group). Dick Grauch, Bill Cobban, Dave Sawyer, Bridget Ball, and Al Merewether (USGS), and Alan Watchman (Urraca Archaeological Services) aided tremendously in our interpretations of the Mancos stratigraphy. In particular, Bill Cobban provided identification of the fossils that we collected. Merewether and others (2006) wrote an open-file report at our request that described previous USGS stratigraphic sections and fossil localities in the Uncompahgre River valley area. Lambert and Associates generously allowed us the use of a drilling rig and crew for the day to investigate subsurface deposits beneath the Qau_2 alluvial terrace. Laurie Hauptmann provided the narrative for the “Iron Mike” artesian water well. Andres Aslan (Mesa State College) helped us interpret the area’s Quaternary geomorphology and field-verified the presence of Bostwick-Shinn Park alluvial deposits at the crest of “Chicken Wing” mesa. Paul Hanson (University of Nebraska-Lincoln) provided us with summaries of optical dating results for Quaternary gravel units Qg_1 and Qg_2, which are included in this text.

Dave and Matt wish to thank Steve Keller for doing yeoman volunteer work during several weeks of the mapping campaign. In addition, we would like to thank Felicie Williams and Nancy Lamm (independent geologists) for their volunteer assistance in the field, and Neil Hauser (graduate student, University of Colorado–Denver), Allen Stork (Western State University), and John Keller (CGS) for helping with the identification of lithic clasts and artifacts.

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INTRODUCTION

The Montrose East 7.5-minute quadrangle is located in Montrose County, Colorado, in the valley of the Uncompahgre River (figure 1). The town of Montrose (2000 census population of 12,344) is located in the northwestern part of the quadrangle, at the junction of U.S. Highways 50 and 550. The highest elevation in the quadrangle is a hilltop in the southeastern part of the quadrangle, in the NE 1/4 of Section 9, T. 48 N., R. 8 W. (elevation 7,347 feet). The lowest point (elevation 5,760 feet) is located near the northwestern corner, in the SE 1/4 of Section 22, T. 49 N., R. 9 W., where Cedar Creek exits the quadrangle.

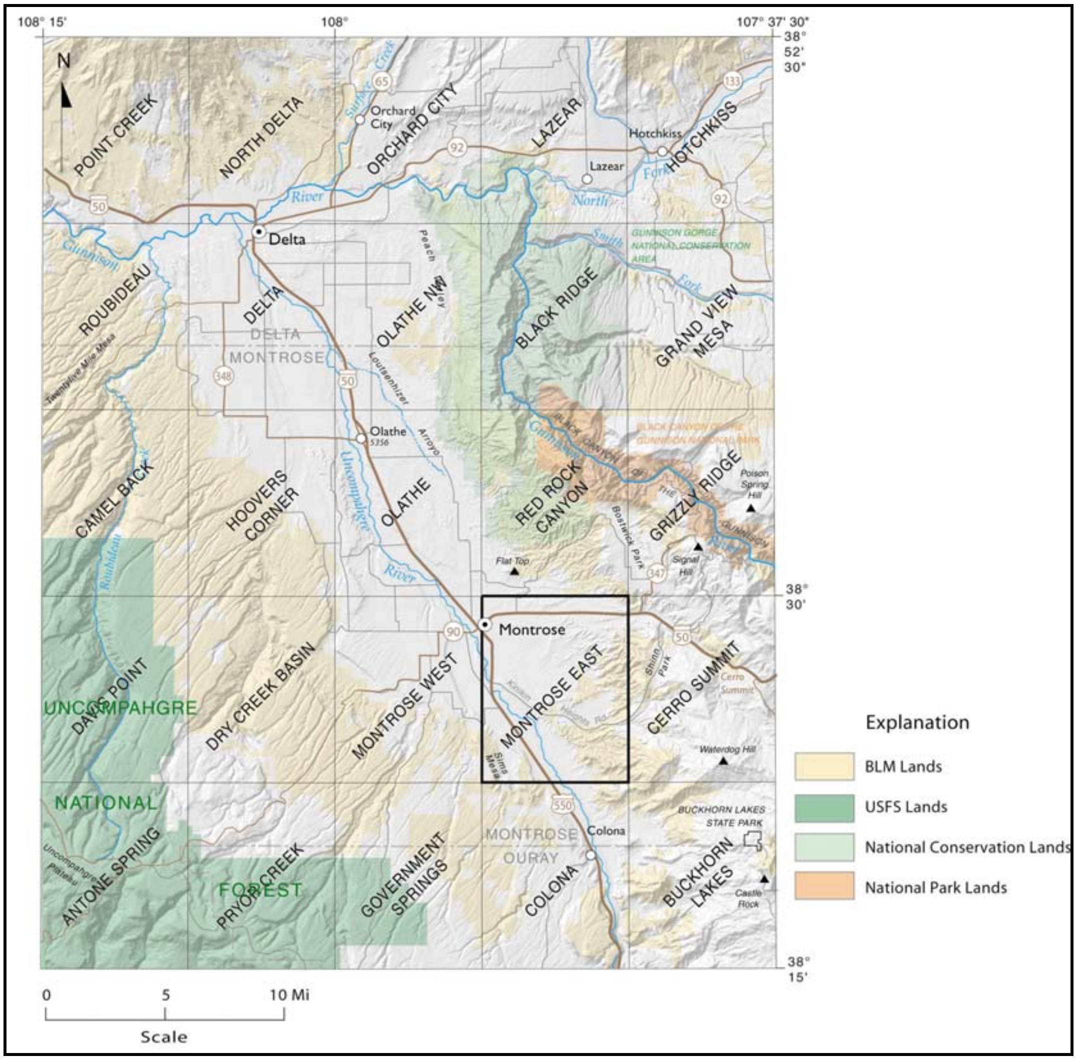

Figure 1. Location of the Montrose East quadrangle (shown in bold black outline) in relation to the valley of the Uncompahgre River. Land ownership within the quadrangle consists of private and BLM lands.

Geologic mapping of the Montrose 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 7.5-minute-quadrangle geologic mapping in the surrounding area, including eight older maps that have been published by the USGS.

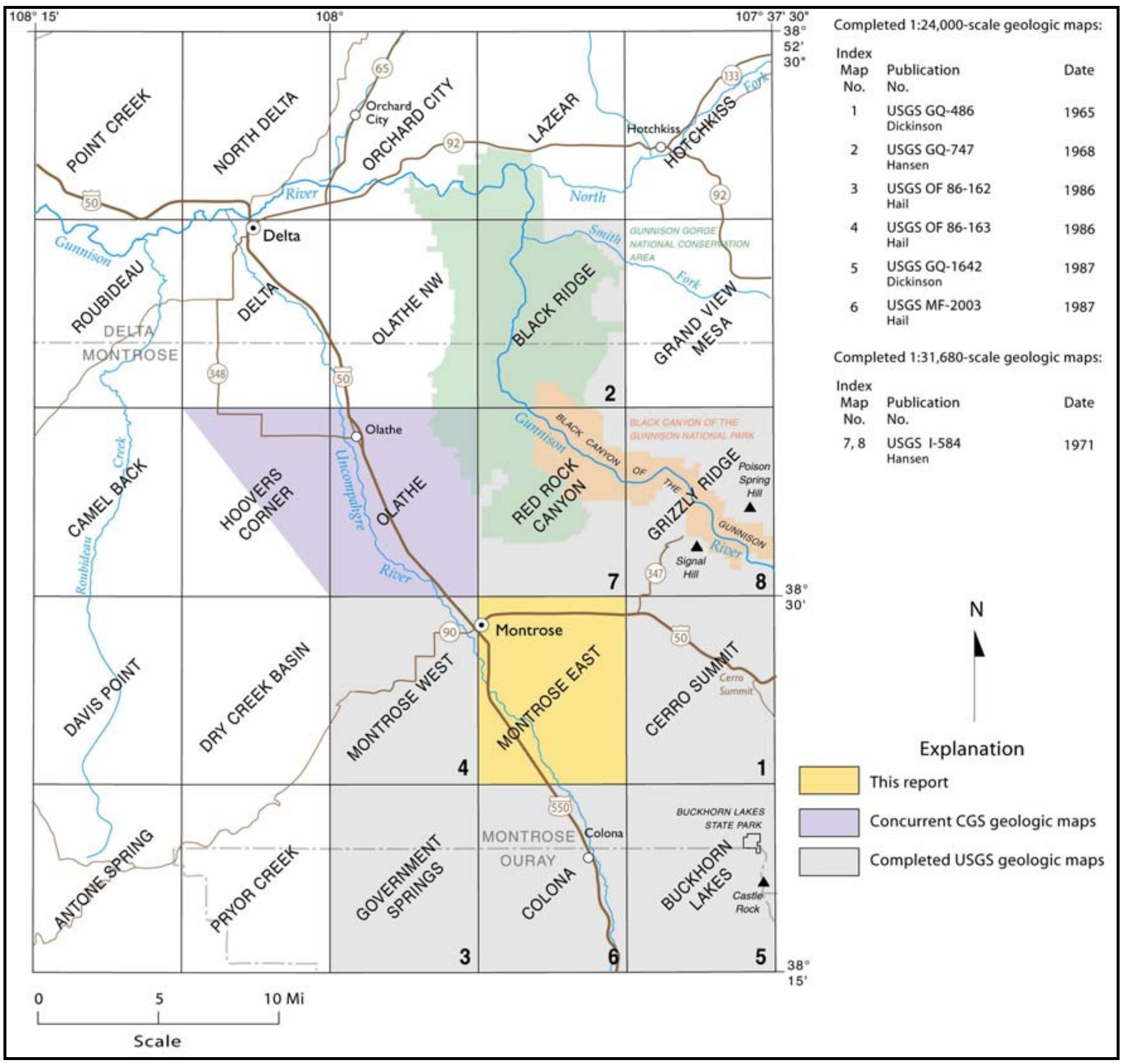

Figure 2. Index map of published, 7.5-minute quadrangle (1:24,000-scale) and other similar-scale geologic maps in the Montrose-Delta area.

The geologic interpretations shown on the map were based on the following sources: (1) CGS field investigations conducted from April to June 2006; (2) prior published and unpublished geologic maps and reports; (3) interpretation of remote sensing data including black and white 1:20,000-scale Agricultural Stabilization and Conservation Service (ASCS) aerial photography flown in 1966, a 10-meter digital elevation model (DEM), and a 1-meter resolution National Agricultural Imagery Program (NAIP) digital orthophoto taken in 2005.

Bedrock geology and surficial deposits were mapped in the field on aerial photographs. Key geologic sites and photograph locations were recorded in the field using a portable GPS receiver, using Universal Transverse Mercator (UTM; North American Datum 1983, Zone 13) coordinates. After fieldwork was completed, the annotated aerial photos were scanned, georeferenced, and imported into Leica Photogrammetry Suite, where they were photogrammetrically corrected and rendered in 3D. Line work for the map was traced directly from the scanned field photos using ERDAS Imagine Stereo Analyst for ArcView and exported as ESRI GIS shapefiles.

PREVIOUS WORK

The Montrose East quadrangle has not previously been mapped at 1:24,000 scale. The area is included in a regional, medium-scale geologic map of the Montrose 1x2-degree sheet (Tweto and others, 1976) 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 aquifers along the Uncompahgre River valley and its margins.

The U.S. Geological Survey published 1:24,000-scale geologic maps for most of the areas that surround the Montrose East quadrangle. These include the Cerro Summit quadrangle to the east (Dickinson, 1965), Buckhorn Lakes quadrangle to the southeast (Dickinson, 1987), Colona quadrangle to the south (Hail, 1987), Government Springs quadrangle to the southwest (Hail, 1986a), and Montrose West quadrangle to the west (Hail, 1986b). The latter three maps were published as reconnaissance geologic maps. In addition, Hansen (1971) produced a series of joined geologic maps for the Black Canyon of the Gunnison area (at a “near-quadrangle scale” of 1:31,680), including the Red Rock Canyon quadrangle to the north and the Grizzly Ridge quadrangle to the northeast.

CGS mapped the Olathe quadrangle (Morgan and others, 2007), which lies to the northwest of the Montrose East quadrangle, concurrently during 2006.

OVERVIEW OF GEOLOGIC SETTING AND FINDINGS

Figure 3 shows major, named physiographic and geomorphic features from the Montrose East quadrangle and adjacent areas. Few named features appear on the USGS topographic base maps. To aid in the discussions herein, we use some informal names to designate areas or features of specific interest. These names reflect local usage where possible, and are signified by quotation marks in the text.

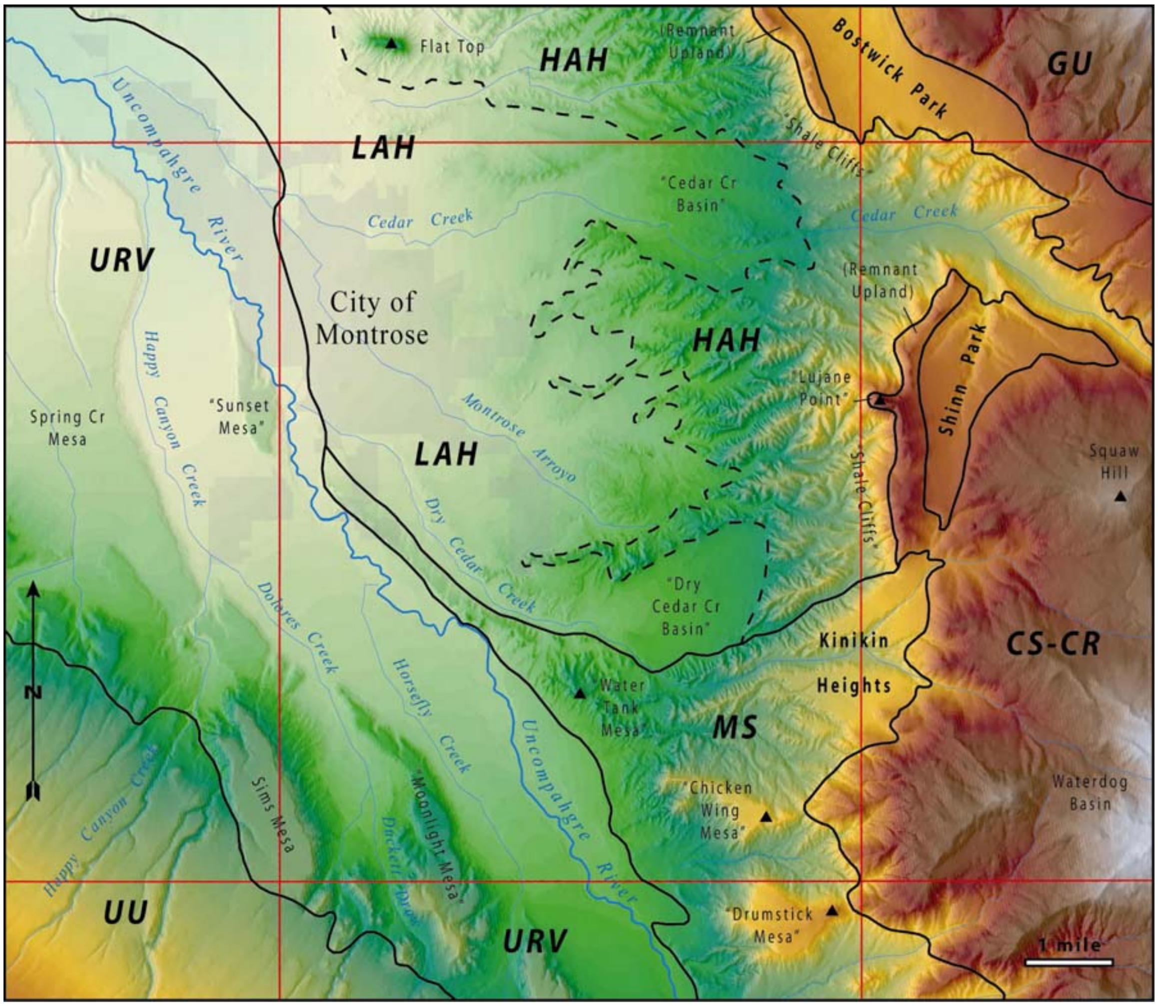

Figure 3. Shaded-relief map of the Montrose East quadrangle and nearby areas, showing major named and informally named physiographic and geomorphic features mentioned in the report. Geomorphic areas are demarcated by black lines and include the Uncompahgre uplift (UU), Uncompahgre River Valley and associated alluvial terraces (URV), “Mesa Staircase” (MS), “Low Adobe Hills” (LAH), “High Adobe Hills” (HAH), Gunnison uplift (GU), and the Cerro Summit-Cimarron Ridge highlands (CS-CR).

Major geomorphic features include the Uncompahgre uplift to the southwest, the Cerro Summit-Cimarron Ridge highlands to the east and southeast, and the Gunnison (also known as the Black Canyon) uplift to the northeast of the quadrangle. The Uncompahgre River valley, consisting of the modern river flood plain and various gravel-capped mesas that mark its former courses, cuts across the southwestern part of the area. Flanking this valley on its northeastern side is a narrow sweep of multi-leveled, gravel-capped mesas. This “Mesa Staircase” rises to the east and abuts the Cerro Summit-Cimarron Ridge highlands.

Badlands topography of the “Adobe Hills” (or “the Adobes”) typifies the northern two-thirds of the quadrangle. This area consists of a high part, containing moderately steep shale ridges and hills with deeply incised valleys, and a low part with broad basins and low shale hills. Two relict paleovalleys, Shinn Park and Bostwick Park, lie just to the east and northeast, about midway up the flanks of the Cerro-Cimarron highlands and Gunnison uplift. Remnants of the former valley walls now form ridgelines that separate these elevated parks from the topographically lower badlands to the west. The western edge of these ridges forms a wall of “shale cliffs” that mark the uphill terminus of the “Adobe Hills.”

The Montrose East quadrangle lies within the Canyonlands Section of the Colorado Plateau physiographic province, an area characterized by widespread flat-topped mesas, deep canyons, and monoclinal folds (Hunt, 1956). Vertical basement-block movements during the Cretaceous-Paleocene Laramine orogeny (Stone, 1977; Tweto, 1977) and possibly during the late Cenozoic (Cater, 1966; Steven, 2002) created the uplifts that surround this area. The rise of the Uncompahgre uplift to the west of the quadrangle resulted in folding and gentle northeasterly tilting of Mesozoic sedimentary rocks. Similarly, uplift along the western margin of the Gunnison uplift created gently to steeply dipping bedding and local monoclinal folding in Mesozoic formations to the north. The Montrose syncline is a small, broad fold that marks the axis of the asymmetrical sedimentary basin between the Uncompahgre and Gunnison uplifts. It trends roughly from northwest to southeast through the northeastern part of the quadrangle.

The bedrock exposed in the quadrangle records the transition from marginal marine to predominantly marine conditions during early to late Cretaceous time. The Dakota Sandstone was deposited along the shoreline during the rise and advance of the epicontinental Western Interior Seaway. The overlying Mancos Shale and its various subunits were deposited within the 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). We subdivide the Mancos Shale into seven stratigraphic units and ten members based on lithofacies associations and biostratigraphy (that is, fossils of marine bivalves and ammonites). In outcrop, the Mancos Shale typically forms badlands-style topography — the result of water and wind eroding the soft shale and carving it into gentle hills and valleys. This style of erosion is best observed in the “High Adobe Hills” area in the eastern half of the quadrangle.

Several levels of Quaternary-age gravel deposits are found in the quadrangle. The deposits include both alluvial and debris-flow origins. Some were deposited by the modern and ancestral Uncompahgre River and other paleoriver systems as they flowed northward out of the San Juan Mountains and migrated over the landscape. These deposits cap several of the larger mesas in the area, including Sims Mesa, “Sunset Mesa,” “Moonlight Mesa,” “Chicken Wing Mesa,” and “Drumstick Mesa.” Other gravel deposits originated as debris flows in fans and tributary paleochannels derived primarily from erosion of the Mancos Shale, Tertiary volcanic rocks, and upland-gravel deposits of Tertiary and Quaternary age. We identified and mapped four levels of terrace gravels associated with the ancestral Uncompahgre River and two levels of terrace gravels associated with ancestral Cedar Creek. In addition, we identified and mapped four levels of upland gravels. These gravels were deposited in large alluvial fan complexes, laterally constricted tributary streams and basins, or within the former valley of the Bostwick Park-Shinn Park trunk stream system (Dickinson, 1965; Hansen, 1971).

Because of topographic inversion, the former channels now comprise broad terraces and/or ridge-capping boulder-gravel veneers that are underlain by Mancos Shale. The inverted topography arises from long-term incision by the Uncompahgre and Gunnison Rivers and their tributaries that commenced during the late Pliocene, approximately 2.5 million years ago (Hansen, 1987). Each level represents a period of downcutting and aggradation. We recognize evidence for numerous instances of stream piracy within the quadrangle since middle Pleistocene time. In most cases, this involved the breaching of a shale-walled stream valley by an adjacent, headward-eroding arroyo at a lower topographic elevation. Upon breaching, the stream was partially abandoned and incised to its new base level, leaving its former deposits high and dry.

The processes that formed this landscape were most active during the Pleistocene, during high-moisture periods related to glacial and interglacial climatic cycles. These same processes are operating today at reduced rates because of the present dry climate. The many tributary arroyos that occupy the “Mesa Staircase” and “Adobe Hills” areas are incising into mud-dominated alluvial and debris-flow deposits that partially fill the modern valleys. The valley-fill deposits are rich in gypsum. Dissolution of the gypsum by meteoric waters and/or lowering of the water table creates many car-sized caverns and other soil piping features along the arroyo margins. Gravel- and boulder-bearing mudflows occur below some of the steeper headwalls of drainages. Landslides are common along the edges of the alluvial terraces where slope failure occurs along fractures or bedding planes of the Mancos Shale.

DESCRIPTION OF MAP UNITS

The following section contains descriptions of surficial and bedrock units identified on the geologic map. The surficial units are organized by the dominant process of deposition (human-made, alluvial, eolian, and mass-wasting deposits) and age, with the younger units preceding older units within each category. Similarly, the bedrock units are organized by age. Geologic time divisions and nomenclature used in this report are shown in Table 1.

The following conventions are used for describing the surficial deposits and bedrock outcrops. Clast sizes are based on the modified Wentworth grain-size scale (Wentworth, 1922) using a chart from the American Geological Institute (Ingram, 1989). Colors of materials are determined by comparison to Munsell rock and soil color charts (Geological Society of America, 1991; GretagMacbeth, 2000). The stages of calcic soil development are from the classification of Machette (1985).

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

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

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

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

Era	Period		Series/Epoch	Age (Ma)
PALEOZOIC	Permian		upper/late	260.4 ± 0.7
			middle	270.6 ± 0.7
			lower/early	299.0 ± 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

SURFICIAL DEPOSITS

The surficial deposits in the Montrose East quadrangle are Quaternary (Pleistocene and Holocene) in age. The deposits shown on the map are generally more than 5 feet thick but may be thinner locally. Residuum, colluvium, sheetwash deposits, and artificial fills of limited extent were not mapped. Certain contacts between surficial units may be gradational, and mapped units locally may include deposits of other types.

Relative age assignments for the Pleistocene and Holocene deposits (lower, middle, upper) reported herein 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. We attempted to age-date two upland gravels (Qg1 and Qg2) and the alluvial mudflow-and-fan (Qamf) deposits. 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 6 to 8 miles to the south of the mapped area, near the town of Ridgway).

HUMAN-MADE DEPOSITS

af **Artificial fill (upper Holocene)** — Rip-rap, engineered fill, and refuse placed during construction of roads, railroads, buildings, dams, canals and ditches, and landfills. Generally consists of unsorted silt, sand, clay, and rock fragments. This unit may also include areas of construction and quarrying operations where original deposits have been removed, replaced, or reworked. The predominant artificial-fill deposits in the Montrose East quadrangle are associated with embankments along numerous water canals and major irrigation ditches. Numerous properties in the Montrose area have been built upon pads of engineered fill; only the largest and most easily discernable fill areas were mapped. The average thickness of the unit is less than 20 feet. Artificial fill may be subject to settlement and erosion if not adequately compacted.

ALLUVIAL DEPOSITS

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

Alluvial Deposits of the Uncompahgre River

The Uncompahgre River, which runs through the southwestern part of the mapped area, has four major terrace levels in addition to the Holocene flood plain associated with the modern, incised river valley (figure 4). These terraces and their capping gravel deposits are associated with Pleistocene glacial episodes (Sinnock, 1978). The gravel-clast compositions within these deposits consist primarily of metaquartzite, tuffaceous and porphyritic rhyolite, andesite and intermediate volcanics, and lesser amounts of gneiss, granite, vein quartz, limestone, and silica-cemented sandstone. These resistant clasts are derived from the western San Juan Mountains near Ouray to the south, Cimarron Ridge to the southeast, and the Uncompahgre Plateau to the southwest.

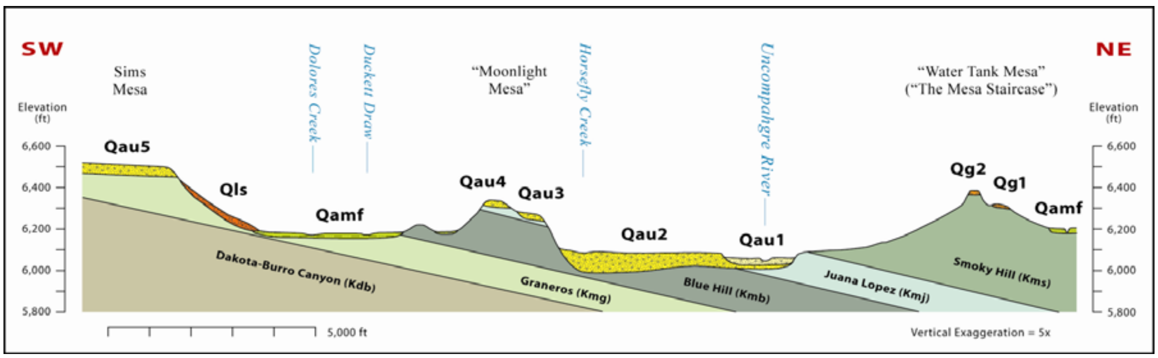

Figure 4. Diagrammatic profile of the five levels of alluvial deposits associated with the Uncompahgre River in the southwestern part of the Montrose East quadrangle. From oldest to youngest these are: Qau_5, Qau_4, Qau_3, and Qau_2 (on elevated alluvial terraces), and Qau_1 (the modern river valley and flood plain).

Qau_1 **Alluvium one of the Uncompahgre River (upper to lower Holocene)** — Reddish-brown, poorly to moderately sorted, moderately consolidated clay, silt, sand, pebble, and cobble gravel in the currently active stream channel, or in low stream terrace deposits above the current stream level within the modern flood plain of the incised Uncompahgre River valley. The alluvium commonly forms steep-sided walls where dissected by river erosion. Clasts are subrounded to well rounded. The dominant sediment is pebble-cobble gravel with a coarse sand matrix. Boulders up to 2 feet in diameter are present, but uncommon. Soil development is absent; however, a few of the clasts are coated by a discontinuous rind of $CaCO_3$, indicating that they were reworked from older deposits. The deposit occasionally includes organic-rich layers interbedded with clay, silt, and sand lenses. The unit may form low terraces that reach a maximum height of 8 feet above current stream level. These terraces fine upward, with localized, thin deposits of eolian or overbank sand and silt in the upper few feet. A second, younger group of lower terraces with heights of up to 3 feet have formed since 1987, when the river flows were first regulated by the Ridgway Dam, located several miles upstream. Since then, the braided flood plain has filled in and the stream has mostly coalesced into a single channel. The present-day river valley deviates away from the next-oldest paleovalley (associated with Qau_2, below) and now follows a different course through the City of Montrose. It appears that during the middle Holocene, a tributary to Dry Cedar Creek eroded headward, captured the river near the southeastern point of "Sunset Mesa," and diverted it around the eastern side of the mesa. Maximum exposed thickness of the unit locally exceeds 12 feet; the thickness below current stream level is not known. The unit is a potential source of commercial sand and gravel.

Qau_2 **Alluvium two of the Uncompahgre River (lower Holocene to upper Pleistocene)** — Pale-red to reddish-brown, poorly to moderately sorted, moderately consolidated clay, silt, sand, pebble, cobble, and boulder gravel, with belts of clayey silt along the outer edges, in stream terrace deposits above the modern flood plain of the Uncompahgre River valley. The deposit fines upward and may contain eolian and overbank sand, silt, and clay lenses within the uppermost 3 feet. This is the most widespread alluvium in the quadrangle and forms a broad, flat valley that is incised into by the modern river valley and is bordered by higher mesas, mostly to the west of the river. It is the primary regolith for agriculture in the Uncompahgre River valley. The alluvium forms continuous and steep-sided, cut-bank walls where it has been dissected by the modern river valley. Clasts are subrounded to well rounded. The dominant sediment is pebble-cobble gravel with a coarse sand matrix. Small to medium boulders of up to 2 feet in diameter are common within some strata. Occasional lenses of cross-stratified, coarse sand are interbedded with the gravels. Soil development is weak and is often masked by seepage and mineral precipitates from crop irrigation. Juvenile A, Bt, and Bk horizons are locally present, especially in the uppermost silt deposits. A few of the clasts within the deposit are coated by a discontinuous rind of $CaCO_3$, which indicates that they were reworked from older deposits. Sinnock (1978) interpreted this terrace gravel deposit as being associated with the Pinedale glacial advance. Lenses or tabular deposits of eolian or overbank sand and silt, possibly dating to early Holocene age, are present within the upper 2 feet of the deposit.

The unit forms terraces that reach a maximum height of 25 feet above current stream level near Uncompahgre, decreasing in the downstream direction to 20 feet near its intersection with the southeastern edge of "Sunset Mesa." Maximum exposed thickness of the unit locally exceeds 20 feet, and deposits of greater than 120 feet have been encountered in drill holes in the adjacent Montrose West quadrangle (D. Lambert, Lambert and Associates, oral communication, 2006). A second, less continuous terrace riser of up to 5 feet in height occurs between Uncompahgre and Riverside Schools. Three exploration test holes drilled into the unit by Lambert and Associates and CGS in August 2006, along US-550 south of Montrose near the Uncompahgre Memorial Gardens, encountered interbedded gravel and clay deposits to depths ranging from 21.5 to greater than 89 feet (figure 5). The thickest gravels occur along the southwestern side of the paleovalley in Borehole 1, underlying an 18-foot thick deposit of silty clay. The actual lateral continuity of gravels and the depth distribution of the shale/alluvium contact between the test holes are not known.

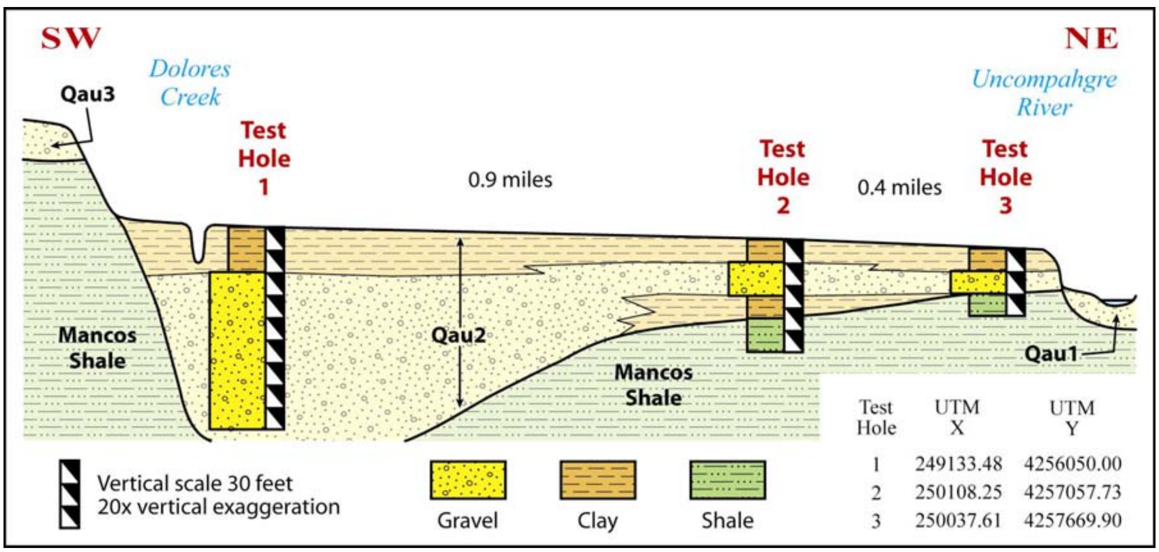

Figure 5. Schematic cross-section of the Qau_2 alluvial paleovalley south of Montrose, showing associated subsurface gravel and clay deposits as interpreted from three test holes drilled by Lambert and Associates for CGS in support of this mapping project.

The outer edges of the unit along the older mesas consist of mixtures of clay, silt, and sand derived from erosion of the Mancos Shale, transported colluvial material from older gravel deposits, alluvial mudflow deposits originating from local colluvium or sheetwash from the flanking mesas, alluvial mudflow deposits along tributary streams (Horsefly and Dolores Creeks) that enter and flow for several miles along the western edge of the valley, or main-stream overbank flow. Although the main river terrace has been abandoned, Holocene deposition has continued to occur along these tributary streams. The unit generally forms a stable building surface, but there may be localized pockets of collapse-prone sediment, especially along the outermost edges where fine-grained sediments predominate. Swelling clays may be present within the surficial clay deposits. Unit Qau_1 is inset into unit Qau_2 and a prominent terrace scarp separates these units. Areas along the edge of the Qau_1-Qau_2 cut bank may be prone to localized landsliding. This unit is a potential source of commercial sand and gravel.

Qau_3 **Alluvium three of the Uncompahgre River (upper Pleistocene)** — Pale-red to reddish-brown, very poorly to poorly 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 valley. The alluvium commonly forms a gravel cap on isolated mesas, including the lowest terrace level on “Moonlight Mesa” (Secs. 21 and 22, T. 48 N., R. 9 W.) and Sims Mesa (Sec. 17, T. 48 N., R. 9 W.), and is the only terrace level on “Sunset Mesa,” located in the Montrose West quadrangle just to the west of the mapped area. Clasts are subrounded to well rounded. The dominant sediment is bouldery, pebble-cobble gravel with a coarse sand matrix. Small to very large boulders up to 10 feet in diameter, which include rounded quartzite and Dakota Sandstone boulders, are common within this deposit (figure 6). The poor sorting and large clast sizes indicate that this unit was deposited, at least in part, by large-magnitude, torrential flooding of glacial outwash. The soil profile includes poorly developed A and Bt horizons. A partially developed Bk horizon lies within the uppermost 2 to 3 feet, featuring $CaCO_3$ rinds around the bottoms of the gravel clasts (Stage II calcic soil) and localized pockets of Stage III calcic soil dispersed within the soil matrix. Sinnock (1978) interpreted this terrace gravel deposit as being associated with the Pinedale glacial advance. The unit may form terraces that reach a maximum height of 225 feet above current stream level. Maximum exposed thickness of the unit locally exceeds 20 feet, and its base is erosional and shows local channeling. The unit generally forms a stable building surface. There may be localized pockets of collapse-prone sediment, and areas along the outer mesa edges may be prone to landsliding. It is a potential source of commercial sand and gravel.

Qau_4 Alluvium four of the Uncompahgre River (upper middle Pleistocene) — Pale-red to reddish-brown, poorly to moderately sorted, moderately consolidated silt, sand, pebble,

Figure 6. Large boulders of massive to cross-bedded quartzite from alluvial deposit Qau_3, which have been stacked into a row in a gravel pit atop “Sunset Mesa,” just to the west of the mapped area [UTM83 249074, 4260230].

cobble, and boulder gravel in stream terrace deposits above the modern flood plain of the Uncompahgre River valley. The alluvium commonly forms a gravel cap on isolated mesas, mainly to the west of the quadrangle; the only exposure in the mapped area is the intermediate terrace level on “Moonlight Mesa” sec. 27, T. 48 N., R. 9 W.). Clasts are subrounded to well rounded. The dominant sediment is pebble-cobble gravel with a coarse sand matrix. Small to medium boulders of up to 2 feet in diameter are common. The soil profile includes poorly to moderately developed A, Bt, and Bk horizons within the upper 2 to 3 feet, featuring continuous $CaCO_3$ rinds around the gravel clasts (Stage II calcic soil). Sinnock (1978) interpreted this terrace gravel as being associated with the Bull Lake glacial advance. The unit forms terraces that reach a maximum height of 300 feet above current stream level. Its maximum exposed thickness locally exceeds 12 feet. The unit generally forms a stable building surface, although there may be localized pockets of collapse-prone sediment. Areas along the outer mesa edges may be prone to landsliding. It is a potential source of commercial sand and gravel.

Qau_5 **Alluvium five of the Uncompahgre River (middle Pleistocene)** — Pale-red to reddish-brown, poorly to moderately sorted, moderately consolidated silt, sand, pebble, cobble, and boulder gravel in stream terrace deposits above the modern flood plain of the Uncompahgre River valley. The alluvium commonly forms a gravel cap on large and small mesas in the vicinity of the southwestern corner of the quadrangle; these include Sims Mesa (Secs. 20 and 28 to 33, T. 48 N., R. 9 W.), the highest terrace level on "Moonlight Mesa" immediately to the south of the quadrangle, and two nearby, remnant mesas (Secs. 33 and 34, T. 48 N., R. 9 W.). Clasts are subrounded to well rounded. The dominant sediment is bouldery, pebble-cobble gravel with a coarse sand matrix. Boulders up to 2 feet in diameter are relatively common within this deposit, and boulders up to 4 feet in diameter are present but rare. The soil profile includes poorly developed A and Bt horizons and a well developed Bk horizon within the upper 3 to 5 feet, featuring continuous $CaCO_3$ rinds around the gravel clasts (Stage II calcic soil). Sinnock (1978) interpreted this terrace gravel as being associated with the Bull Lake glacial advance. The unit forms terraces that reach a maximum height of 475 feet above current stream level. Its maximum exposed thickness locally exceeds 40 feet. The unit generally forms a stable building surface, although there may be localized pockets of collapse-prone sediment, and areas along the outer mesa edges may be prone to landsliding. It is a potential source of commercial sand and gravel.

Alluvial Deposits of Cedar Creek

Three alluvial gravel deposits are associated with Cedar Creek, which flows from east to west across the northern part of the Montrose East quadrangle. The two older deposits are terrace gravels associated with Pleistocene glacial episodes. The youngest deposit is associated with the modern flood plain of Cedar Creek. These deposits record the breaching and entrainment of older gravels from the Shinn Park-Bostwick Park paleovalley system (Dickinson, 1965; Hansen, 1971), as well as from Precambrian rocks in the emergent Gunnison uplift and Tertiary alluvial fan gravels in the Cerro Summit area to the east of the quadrangle, during the establishment of the present Cedar Creek drainage system. The gravel-clast compositions within these deposits consist primarily of metaquartzite, andesite, and tuffaceous and porphyritic rhyolite from the San Juan Mountains and Cimarron Ridge, and lesser amounts of granite, pegmatite, and black gneiss and schist from the Gunnison uplift.

Qac_1 **Alluvium one of Cedar Creek (upper to lower Holocene)** — Grayish-orange to reddish-brown, interstratified silt and gravel. The silt is sandy to clayey and is poorly stratified. The gravel consists of moderately sorted, rounded pebbles and occasional cobbles in a sand to silt matrix, and ranges from clast supported to matrix supported.

Soil development is weak to absent. We interpret this unit to be deposited by alternating alluvial and mudflow episodes. Some of the individual gravel lenses are alluvial in origin, whereas others are from gravelly mudflows.

This unit contains what appears to be an abandoned paleovalley reach that follows a different course than the modern Cedar Creek. The older stream reach is recognizable as a gently west-sloping terrace surface that contains 20 to 30 percent pebble-and-cobble gravel in plowed fields and construction grading areas. From the Fairview area along U.S. Highway 50, it essentially follows the old railroad grade into the city of Montrose and meets with Montrose Arroyo. The present-day stream departs the paleovalley in the NW 1/4, Section 25, T. 49 N., R. 9 W. and follows a more northerly course to the Uncompahgre River. The newer stream reach contains only fine-grained sediments, and its deposits are indistinguishable from the "Qamf – alluvial mudflows and fans" unit that is described in a later section.

It was difficult to designate a mappable Qac_1 unit for the Cedar Creek flood plain between Fairview and Montrose (where the edges of the deposit are not constrained by Mancos Shale hills) based on local physiology and geomorphology. This is because (1) much of this surface is irrigated and plowed farmland, and exposures are rare to absent; (2) there are no elevation differences between the Cedar Creek deposits and flanking mudflow valley-fill deposits; and (3) the two deposits are closely related, genetically, in terms of depositional processes. As a result, the lateral boundaries between the two units cannot be readily discerned. We mapped the approximate location of the Qac_1 unit based on the visible occurrence of scattered pebbles and cobbles at the ground surface. The deposit could not be identified with any certainty within the city of Montrose where residential development has occurred.

This unit appears to be equivalent to the modern stream valley and lowest-level terraces of the Uncompahgre River (Qau_1), described previously. Maximum exposed thickness of the unit locally exceeds 8 feet (not including an unknown thickness below current stream level). Near Montrose Hospital, gravel that is possibly associated with this unit was encountered in a drill hole at a depth of 30 feet (N. Johnston, Geotechnical Engineering Group, oral communication, 2006). The unit's stability as a building surface is variable because of layer-by-layer grain-size variations and high silt content. It may contain localized pockets to broad areas of collapse-prone sediment, and areas along the edge of the stream cut banks may be prone to landsliding. Overall, it is a marginal source of commercial sand and gravel due to its limited extent and potentially limited thickness of the gravel lenses.

Qac_2 **Alluvium two of Cedar Creek (lower Holocene to upper Pleistocene)** — Pale-red to reddish-brown, poorly to moderately sorted, moderately consolidated silt, sand, pebble, cobble, and boulder gravel, in stream terrace deposits to the south of the modern flood plain of the Cedar Creek valley. The deposit is found only in Sections 27-28-29, T. 49 N., R. 8 W. Clasts are subrounded to well rounded. The dominant sediment is clast-supported, pebble-cobble gravel with a coarse sand matrix. Small to large boulders of up to 4 feet in diameter are present, but rare. Soil development is very weak to absent, and juvenile A-, Bt-, and Bk-horizons are locally present. A few of the clasts within the deposit are coated by a discontinuous rind of $CaCO_3$, which indicates that they were reworked from older deposits. We interpret this terrace gravel deposit as being associated with the Pinedale glacial advance, and it is probably equivalent to the "Qau_2" unit described previously. The unit forms terraces that reach a maximum height of 20 feet above current stream level. Maximum exposed thickness of the unit locally exceeds 15 feet. The unit generally forms a stable building surface, although there may be localized pockets of collapse-prone sediment, and areas along the outer mesa edges may be prone to landsliding. It is a potential source of commercial sand and gravel.

Qac_3 **Alluvium three of Cedar Creek (upper Pleistocene)** — Pale-red to reddish-brown, poorly to moderately sorted, moderately consolidated silt, sand, pebble, cobble, and boulder gravel, in stream terrace deposits to the south of the modern flood plain of the Cedar Creek valley. The deposit is found only in Sections 27-28-29, T. 49 N., R. 8 W. The terrace surface is used for irrigated agriculture. Unlike the other terraces in the mapped area, which are generally flat topped, its upper surface is inclined away from the creek valley. Clasts are subrounded to well rounded. The dominant sediment is clast-supported pebble-cobble gravel with a coarse sand matrix. Small to large boulders of up to 4 feet in diameter are present, but rare. Soil development is weak to absent, and in places is masked by mineral precipitates from crop irrigation and seepage. A few of the clasts within the deposit are coated by a discontinuous rind of $CaCO_3$, which indicates that they were reworked from older deposits. We interpret this terrace gravel deposit as being associated with the Bull Lake glacial advance, and it is probably equivalent to the "Qau_3" unit described previously. The unit forms terraces that reach a maximum height of 80 feet above current stream level. Maximum exposed thickness of the unit locally exceeds 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 may be prone to landsliding. It is a potential source of commercial sand and gravel.

Mudflow-Dominated Alluvial and Alluvial-Fan Deposits

The most common surficial deposits within the map area are associated with complex alluvial-valley-fill and alluvial-fan systems along tributary streams and in broad basins. The dominant depositional processes are channelized to laterally unconstrained mudflows or mud-and-gravel debris flows. These widespread deposits are primarily mudflow dominated and gravel poor, with most of the source material being derived from the Mancos Shale.

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

Qamf **Alluvial mudflow-and-fan valley-fill deposits (upper to lower Holocene)** — Grayish-orange-pink to grayish-orange, well to occasionally poorly sorted, poorly consolidated, clayey to sandy silt deposited in valley-head and valley-side alluvial fans, tributary-stream valleys, and coalescing fans in broad basins (figure 7). The deposits comprise a complex system of deposits that extend for several miles along numerous tributary-stream reaches. The largest basin underlies the city of Montrose east of the Uncompahgre River and contains a number of low-gradient, coalescing fans. Some of the tributary-stream systems (for example, Dry Cedar Creek and Cedar Creek; figure 3) have intermediate basins along their courses. Muddy debris flows primarily deposit these arroyo- and basin-filling sediments, with occasional input from sheetwash, and normal and hyper-concentrated floodwater flows.

The deposits consist of poorly defined silt layers, typically less than an inch to a few inches thick, which record individual mudflow depositional events (figure 8). Some

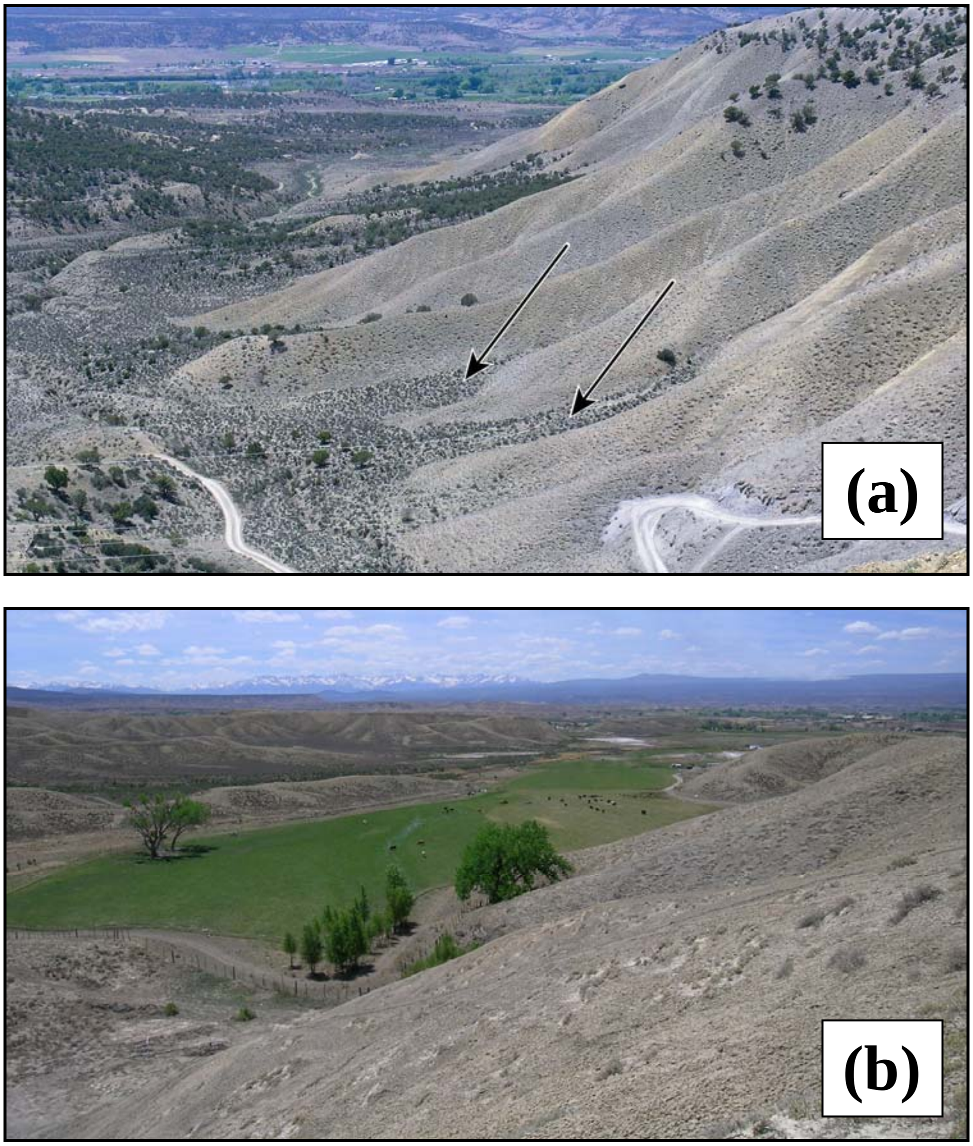

Figure 7. Geomorphology of alluvial mudflow deposits (Qamf). (a) Valley-side alluvial fans (arrows) separated by spur ridges of Mancos Shale along the southern side of “Chicken Wing Mesa” [UTM83 258884, 4252197]. (b) Irrigated tributary stream valley partially filled with mudflow deposits, in the “High Adobe Hills” area [UTM83 256264, 4262358].

layers show incipient soil development that was curtailed by burial during subsequent events. There are occasional stringers and lenses of locally reworked gravel from older deposits on flanking, gravel-capped mesas. Modern mudflow depositional processes are actively occurring in some headwater areas (figure 9). Flash flooding results in the deposition of low-gradient mud fans containing occasional, mud-encrusted cobbles and small boulders. Fresh deposits may contain abundant, rounded shale clasts

Figure 8. Horizontally laminated clayey to sandy silt beds in Qamf, exposed in a basement excavation near downtown Montrose [UTM83 249706, 4262534]. These deposits show abundant macropores, sulfate accumulation along rootlets, and slightly organic paleosol horizons. These are interpreted to be distal mudflow deposits.

ranging from granule to cobble size; these clasts slake apart and disaggregate during subsequent drying and wetting, and are either buried by new sediment or are easily removed by flowing surface water from rainstorms or irrigation. Near the base of the highland areas in the eastern part of the quadrangle, modern mudflows have transported boulders up to 10 feet long, depositing them as concentrated masses or boulder bars in arroyo constrictions, against trees, and in areas where the stream broadens and flattens. The downstream deposits, along valley reaches and in the broad basins, are primarily composed of mud (clayey silt). An exception to this is the pebbly silt deposit within the abandoned paleovalley of Cedar Creek (described above as unit Qac_1).

Qamf deposits may exceed 5 feet in thickness in valley-head and valley-side areas and may exceed 25 feet in thickness along the valley reaches and in the basins. The tributary stream and basin systems are best developed within the “High Adobe Hills” area of the quadrangle. The filling of the intermediate and terminal basins has resulted in the near burial of low hills and ridges of Mancos Shale, especially within the “Low Adobe Hills” area; it may be necessary to use drilled boreholes to determine the depth to

Figure 9. Recent mudflow deposit (Qamf) in the headwaters of an arroyo in the "High Adobe Hills" area. (a) Dispersed mud and mud-covered gravel clasts. (b) Intermixed, rounded clasts of hard igneous-rock gravels and soft shale. The shale clasts are beginning to crack and slake as they dry out. They disaggregate and take on the appearance of a mud matrix upon further weathering. [UTM83 259183, 4264226]

bedrock in these areas. Near the Montrose Hospital (S. 3rd Street and Junction Street), 30 feet of mudflow deposits overlie older stream-gravel deposits, while two blocks to the south, shale bedrock was encountered at a depth of 3 feet (N. Johnston, Geotechnical Engineering Group, oral communication, 2006).

Morgan and others (2007) reported a conventional age of 9.81±60 ^{14}C ka (11.30-11.17 ka, 2-sigma 95-percent probability) from a bulk sample recovered near the base of a Qamf deposit in Loutsenhizer Arroyo, in the Olathe quadrangle. The onset of Qamf deposition roughly coincides with the end of the Younger Dryas, a prolonged cold period that lasted from 12.7 to 11.5 ka. We interpret that increased runoff from melting snow and ice during the earliest Holocene eroded and transported mud derived from the Mancos Shale, resulting in large and extensive debris/mudflows. Although extensive incision of the badlands has been ongoing since before Pleistocene time, much of the topography that is seen today in the mapped area was created during the Holocene.

Renewed stream erosion during the latest Holocene has dissected many of the tributary-stream mudflow deposits and coalescing fans, resulting in narrow arroyos that are 8 to 10 feet deep along the valley bottoms in most areas. In particular, an arroyo system between mesas in the far southeastern corner of the mapped area (sec. 29, T. 48 N., R. 8 W.) has been incised to a depth of 40 feet, through 20 feet of mudflow deposits and 20 feet of the underlying Mancos Shale.

Areas mapped as Qamf may be subject to future flash floods and debris flow events, especially in non-incised, valley-head and valley-side areas and within the deeply dissected modern arroyo channels. The deposits may be prone to significant collapse, hydrocompaction, or slope failure when wetted or loaded. Qamf deposits have been used for agriculture as cropland and pasturage, especially in the “Low Adobe Hills” area, east of Montrose. Typically, irrigation is required, and because the deposits are sulfate-rich, the quality of these lands for agriculture is relatively poor.

Mixed Debris-Flow and Alluvial-Gravel Deposits

There are at least four topographically distinct levels of older valley-fill and alluvial-fan deposits preserved as dissected, gravel-capped mesas and hilltops in the southeastern part of the quadrangle, in the “Mesa Staircase” area (figure 3). These units have formerly been described as till deposits (Atwood and Mather, 1932), valley-fill and landslide deposits (Dickinson, 1965, 1966), and pediment-gravel deposits (Sinnock, 1978). The resistant gravels and the capping gypcrete and calcic soils have minimized erosion to the extent that the flanking hillsides of Mancos Shale were eventually eroded away and lowered by downcutting, a classic case of repeated, topographic inversion (figure 10). The deposits may form flat to saddle-shaped

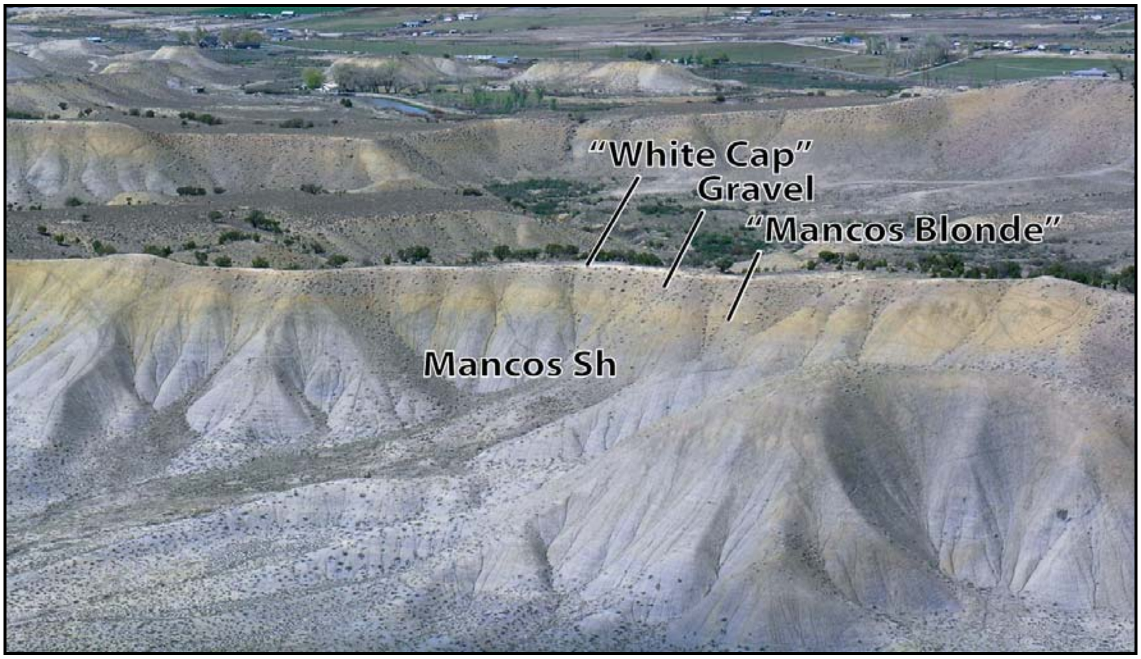

Figure 10. Elongate mesas in the "Mesa Staircase" area, capped by Qg_1 gravels. Color bands, from bottom to top of the slopes, may be used to discern Mancos Shale (gray), highly oxidized and weathered "Mancos Blonde" shale (yellowish), gravels (light brown), and mesa-capping gypcrete horizons (whitish). The mesa tops are vegetated with abundant sagebrush and scattered stands of pinon pine and juniper. [UTM83 256162, 4253023]

surfaces or gently rounded hilltops. In many places the surface underlying the deposit defines the base of an individual paleovalley (figure 11). In one case it forms a broader, erosional pediment. In terms of depositional processes, these deposits are similar in origin to the Holocene alluvial mudflow and fan (Qamf) deposits described previously. The main difference is that these older deposits contain significant gravel as a consequence of the wetter climate and higher erosion associated with Pleistocene glacial cycles, whereas gravel transport has been minimized during the later, drier Holocene period.

The gravel-clast compositions within these deposits consist primarily of tuffaceous and porphyritic rhyolite, andesite, metaquartzite, and lesser amounts of granite, vein quartz, and andesitic and rhyolitic breccias. These clasts are derived from Cimarron Ridge to the southeast and the western San Juan Mountains near Ouray to the south. In particular, the pebble and cobble clasts may be reworked from older alluvial-gravel deposits, including the Eocene Telluride Conglomerate and the middle Pleistocene Shinn Park-Bostwick Park paleovalley system (Dickinson, 1966; 1987). A defining characteristic of these debris-flow deposits is the presence of concentrations of boulders, or boulder bars that mark former debris-flow levees, snouts, and broad boulder-field deposition areas that may indicate a localized decrease in the paleovalley

Figure 11. Saddle-shaped mesa near Kinikin Heights. The interior is composed of bouldery Qg_1 gravels (above and within white dashed line), which are flanked and underlain by Mancos Shale. This view is essentially a cross section of a small, gravel-filled, tributary channel deposit. [UTM83 256253, 4254512]

gradient. The boulders are commonly up to 8 feet long and in cases may be up to 40 feet in length. Many of the largest boulders are flat, tabular, or elongate and are occasionally stacked or imbricated. Such bodies may be carried for large distances by rafting upon the dense, viscous mass of a muddy debris flow (Cruden and Varnes, 1996). The large boulders are primarily composed of pale-red-purple to grayish-red, moderately hard, tuffaceous or brecciated rhyolite. Their source may be the Oligocene Ute Ridge Tuff or Sapinero Mesa Tuff, from heavily eroded outcrops in the Cimarron Ridge area near Storm King (Dickinson, 1987) that probably once covered a greater area than is indicated by present exposures.

Qg_1 **Gravel deposit one (lower Holocene to upper Pleistocene)** — Grayish-orange-pink to pale-red to light-brown, poorly sorted, moderately to poorly stratified silt, sand, pebble, cobble, and boulder gravel. The gravel clasts are subangular to rounded, and some are coated with broken, discontinuous rinds of calcium carbonate, indicating reworking. The matrix typically consists of sandy, clayey silt. The deposits are predominantly matrix supported and chaotic and contain occasional boulder bars, especially at the base and outer margins (figure 12). Boulders are up to 3 feet long in the western part of the "Mesa Staircase" and up to 10 feet long in the eastern part, near the highlands. In the western part, the sediment near the base of the unit is moderately well stratified and contains moderately sorted sand and pebble gravel lenses (figure 13a).

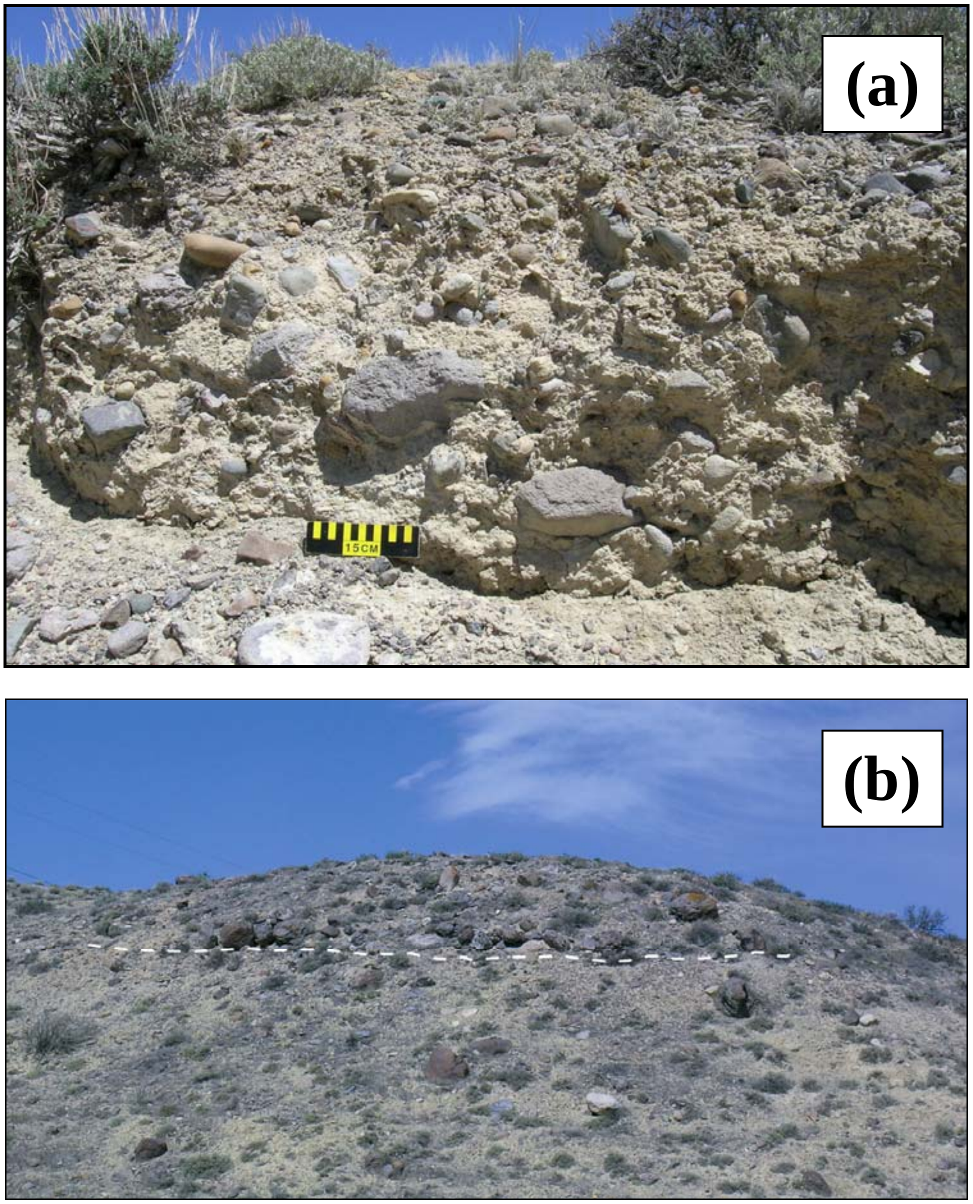

Figure 12. Qg_1 gravel deposits along the “Mesa Staircase.” (a) Matrix-supported, chaotic, cobble and pebble gravel that is typical of much of the deposit [UTM83 252840, 4256174]. (b) Boulder bar at base of gravel (dashed line), underlain by Mancos Shale. A few boulders have moved downhill by rolling or colluvial processes [UTM83 252636, 4256522].

Typically, this unit fines upward, as the silt content increases and the clast content and size decreases. A weak, Stage I calcic soil is found within the upper 2 to 5 feet, and is seen as filaments and surface coatings in the silt matrix. A 0.5- to 2-foot thick layer of very pale orange, finely to coarsely crystalline gypsum (gypcrete) commonly forms the top of the deposit (figure 13b). These gypcrete “white caps” are a good

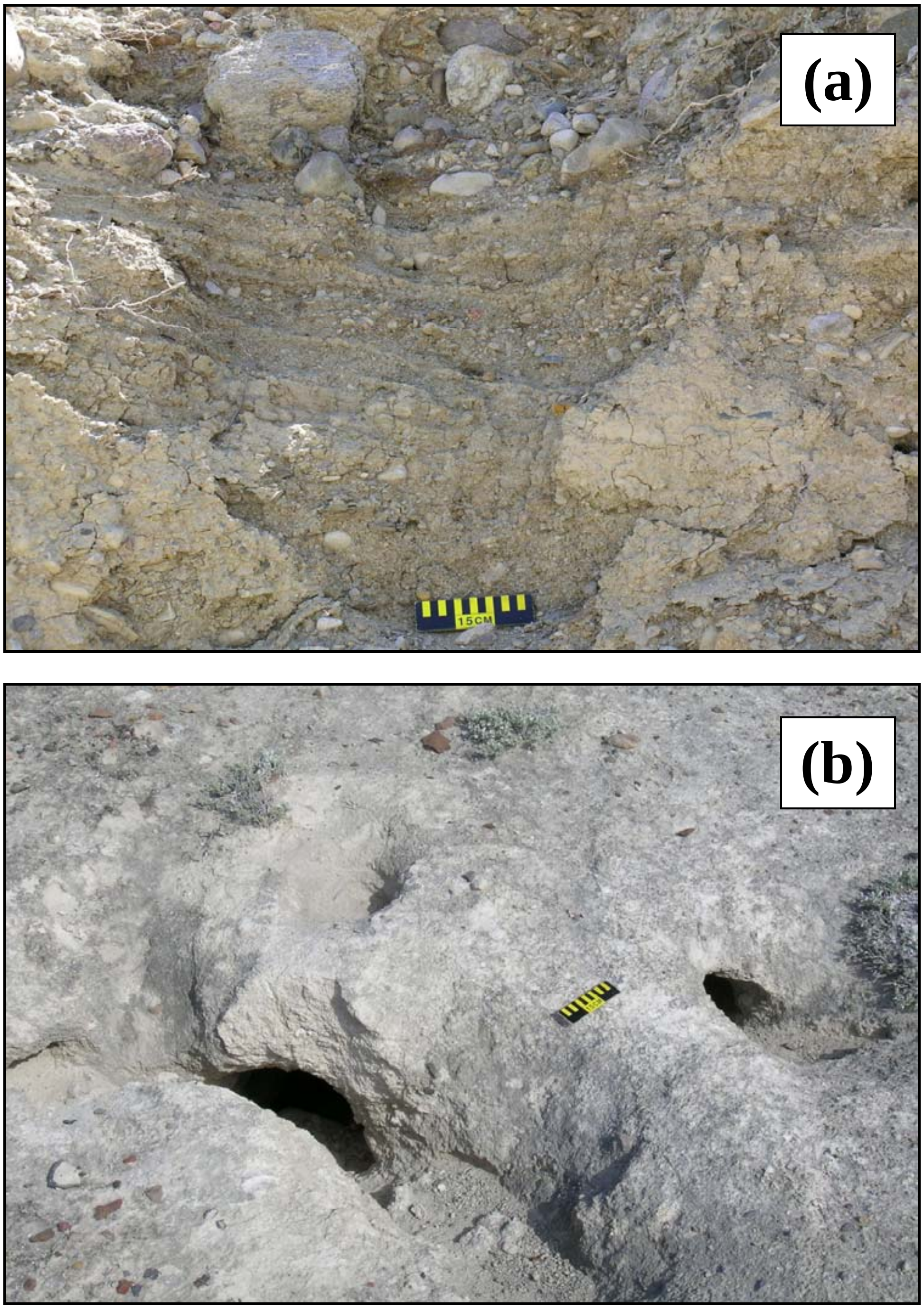

Figure 13. Qg_1 gravel deposits along the "Mesa Staircase." (a) Clast-supported, cross-stratified sand and pebble gravel, overlain by chaotic, matrix-supported cobble and pebble gravel [UTM83 252827, 4256299]. (b) Very pale-orange, gypcrete soil horizon that typically caps the unit and shows abundant burrowing. It is typically comprised of sandy, pebbly gypsum. [UTM83 253639, 4255721].

indicator of mappable gravel deposits. Rodents and small carnivores such as foxes, badgers, and coyotes often heavily burrow the gypcrete horizons.

This unit forms numerous, elongate mesas that extend from southeastern corner of the quadrangle to the edge of the modern Uncompahgre River valley in the west-central part. Scattered remnant Qg_1 deposits are also found to the north in the “Adobe Hills” area. In longitudinal section, they descend from an elevation of 6,775 to 5,960 feet (or from 895 to 80 feet above the present-day river level. The former course of this tributary valley probably continued to the north, along the eastern side of “Sunset Mesa.” The tributary may have joined the river beyond the northern tip of that mesa. The modern Uncompahgre valley appears to have been captured and redirected along this course. The mesa tops are about 120 to 140 feet above the level of the flanking, incised Holocene (Qamf) tributary valleys in the southeastern part of the quadrangle. The two levels converge toward the west. The elevation offset is about 80 feet at the downstream end of the “Mesa Staircase,” in the western part of the quadrangle. In cross section, the mesa tops are either saddle shaped or half-saddle shaped. The higher rims are typically along the southwestern side. The highest mesas in the east appear to merge with the adjacent, and topographically higher, Cerro Summit highlands. The merger occurs along a series of ski-tip-shaped, colluvial ramps.

The sand-rich, fluvial facies in the western part of the unit (at the location shown in figure 13a) was age-dated using optical dating (also known as optically-stimulated luminescence or OSL dating) methods. The analysis was conducted using the Single Aliquot Regenerative (SAR) protocol on 90-150 µm quartz grains. Pre-heat and cut-heat temperatures of 220° C were used. A final age estimate of 25.2 ± 3.1 ka was obtained based on the mean of 19 aliquots. The optical age estimate for sample DN-019 falls within or shortly before age estimates for Pinedale glacial advances from cosmogenic dating in the Wind River Range (23 to 16 ka) (Gosse and others, 1995; Phillips and others, 1997; Hancock and others, 1999). During this time period, glaciers were advancing in high elevation uplands due to lowered mean annual temperatures. Greater stream discharge and sediment availability is evident from late Pleistocene Central Rocky Mountain alluvial deposits. It is document in both glaciated (Baker, 1974; Reheis and others, 1991) and non-glaciated (Pierce and Scott, 1982; Reheis and others, 1991; Hanson and others, 2006) basins. The sedimentation is attributed to greater permafrost activity and/or snow pack thickness (Pierce and Scott, 1982).

We interpret this unit to be deposited within a series of tributary paleovalleys that flowed from the Cerro Summit-Cimarron Ridge highlands toward the Uncompahgre River in the west. These valleys were subjected to muddy, gravelly, channelized debris-flows. The sediments were derived from the Mancos Shale, volcanic rocks in the highlands, and from occasional stream reworking of older gravel deposits. The unit locally exceeds 15 feet in thickness. It is correlated with the Uau_2 alluvium of the Uncompahgre River valley by virtue of height above stream level and soil characteristics. This deposit generally forms a stable building surface, although there may be localized pockets of collapse-prone sediment. Areas along the outer mesa edges may be prone to landsliding and rockfall. Because of its high silt content and an abundance of non-durable volcanic clasts, it is a marginal to fair source of commercial sand and gravel.

Qg_2 **Gravel deposit two (upper Pleistocene)** — Grayish-orange-pink to pale-red, poorly sorted, poorly stratified silt, sand, pebble, cobble and boulder gravel. The gravel clasts are subangular to rounded, and some are coated with broken, discontinuous rinds of calcium carbonate, indicating reworking. The matrix typically consists of sandy, clayey silt. The deposits are predominantly matrix supported and chaotic, although some clast-supported deposits occur near the base. Boulders up to 3 feet are present, but larger boulders are rare. The gravel in lower part of the deposit is predominantly comprised of subround, quartzite and tuffaceous or andesitic volcanic cobbles, some of which are highly weathered in place (figure 14). This unit fines upward as the silt content increases and the clast content and size decreases. The diversity of clast compositions increases upward, with a smaller proportion of tuffaceous clasts in the uppermost part. A Stage I calcic soil is developed within the upper 5 feet and is seen as filaments and surface coatings in the silt matrix. In irrigated areas, carbonate-cemented matrix and coated clasts (Stage III) are present. A 0.5- to 2-foot thick layer of very pale-orange, finely to coarsely crystalline gypsum (gypcrete) is found near the top of the deposit in unirrigated areas. These gypcrete “white caps” are a good indicator of mappable gravel deposits. Eolian sand and silt deposits are present within the upper 2 feet of the unit.

This unit forms a series of coalescing mesas in the Kinikin Heights area (Secs. 16 and 17, T. 48 N., R. 9 W.). To the west are a few remnant, hilltop deposits in the vicinity of “Water Tank Mesa” (center, sec. 24, T. 48 N., R. 9 W.). In longitudinal section, the deposits descend from an elevation of 7,000 feet at the head of Kinikin Heights (in the Cerro Summit quadrangle) to 6,380 feet at “Water Tank Mesa.” The mesa tops are about 200 to 240 feet above the Holocene (Qamf) tributary valleys. The Kinikin Heights mesas appear to consist of three to four individual surfaces, all of which slope toward a common point at the western, downhill edge of the mesas. These mesas have been subject to long-term agricultural use for irrigated crops and pastures.

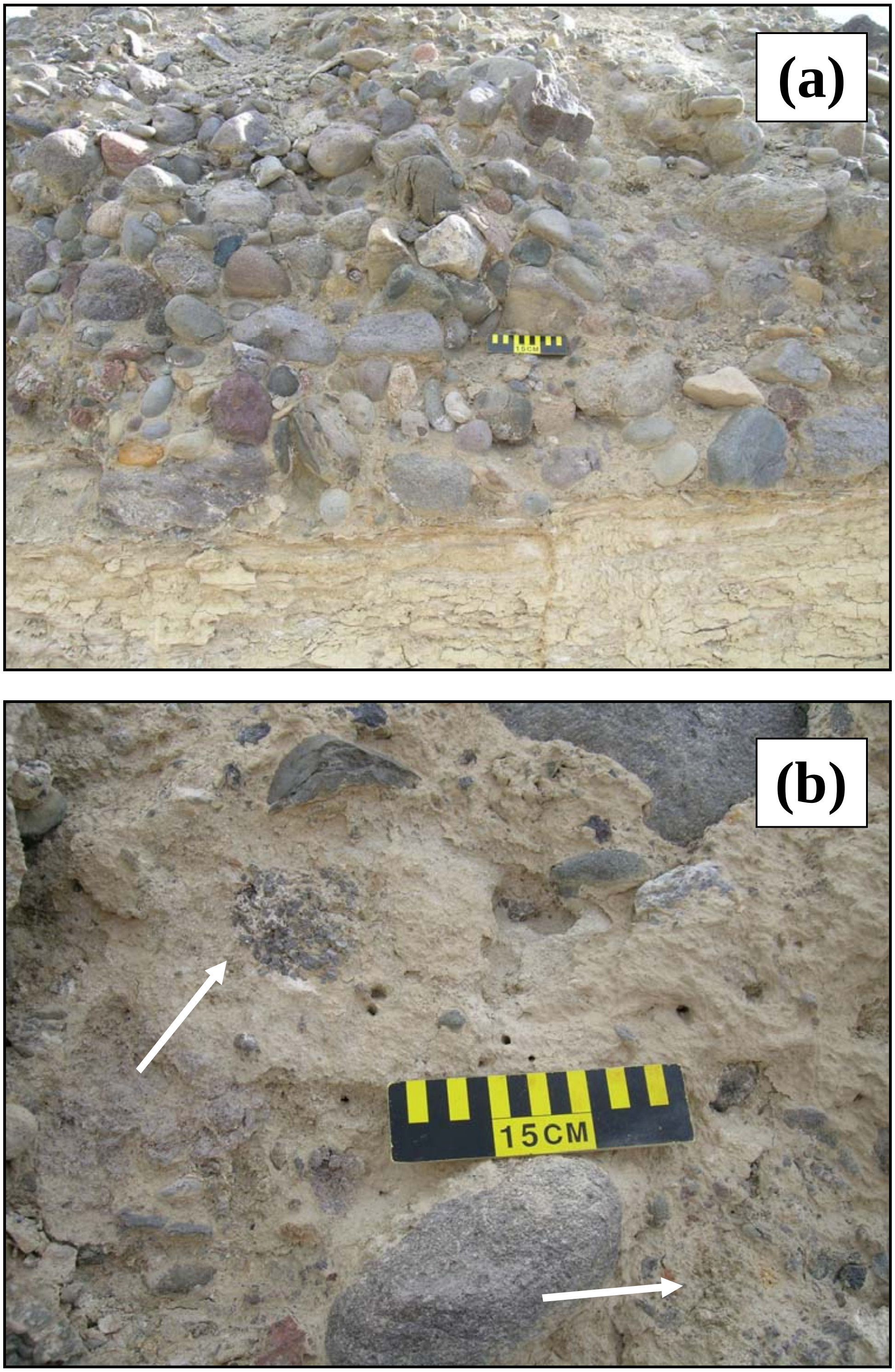

Figure 14. Qg_2 gravel deposits along the “Mesa Staircase” at the northwestern point of “Water Tank Mesa.” (a) Basal matrix- and clast-supported cobble gravel overlying sharp erosive contact with the Mancos Shale. (b) Matrix-supported gravel containing highly weathered and disaggregated volcanic clasts (arrows). [UTM83 254280, 4255334]

Optical dating analyses were attempted for a sandy, slightly gypsiferous sample from this unit near the location of figure 14b, using the same methodologies described previously for unit Qg_1. The sample yielded no meaningful optical age estimates because of extremely low and highly variable natural luminescence signals.

We interpret unit Qg_2 to be deposited within a series of alluvial fan and tributary-paleovalley systems that flowed from the highlands in the southeast toward the Uncompahgre River in the west. In particular, the Kinikin Heights deposits appear to be a set of coalescing alluvial fans in a triangular-shaped paleobasin. It is similar in size and shape with the present-day "Dry Cedar Creek Basin," just to the northwest. A paleovalley probably extended to the west of the Kinikin Heights paleobasin and eventually reached the Uncompahgre River. This basin-and-valley system was subjected to muddy, gravelly debris-flows derived from the Mancos Shale and volcanic highlands to the southwest. The Kinikin paleobasin appears to be a site of extensive breaching of a former drainage divide. The breach resulted in the subsequent erosion and redeposition of gravels from the next-oldest unit (Qg_3, the Shinn Park- Bostwick Park paleovalley system) at a higher topographic elevation. As a result, many of the gravel clasts in Qg_2 are hard, rounded, originally alluvial pebbles and cobbles that were reworked into the debris flow deposits.

The unit locally exceeds 15 feet in thickness. It is correlated with the Qau_3 alluvium of the Uncompahgre River valley by virtue of height above modern stream level and soil characteristics. This deposit generally forms a stable building surface, although there may be localized pockets of collapse-prone sediment, and areas along the outer mesa edges may be prone to landsliding and rockfall. Because of its variable silt content and an abundance of non-durable volcanic clasts, it is a marginal to fair source of commercial sand and gravel.

Qg_3 **Gravel deposit three (middle Pleistocene)** — A complex deposit of stratified clast-and matrix-supported gravel and silt, sand, and volcanic ash. The clast-supported layers are comprised of moderately sorted cobble and pebble gravel with a matrix of grayish-orange-pink to pale-red, silty coarse sand, up to 40 feet thick. The clasts are rounded to subrounded and reflect a wide variety of volcanic and quartzite source-rock types (figure 15a). Occasional, rounded quartzite boulders of up to 4 feet long are locally present. The matrix-supported layers are up to 17 feet thick and contain similar rounded cobbles and pebbles plus numerous, subrounded to subangular, welded tuff and brecciated rhyolite boulders up to 10 feet long (figure 15b). The matrix consists of grayish orange pink, sandy to clayey silt. These layers are poorly sorted. The middle part of the unit is relatively fine grained and contains 6 to 10 feet of slightly pebbly, grayish-orange-pink,

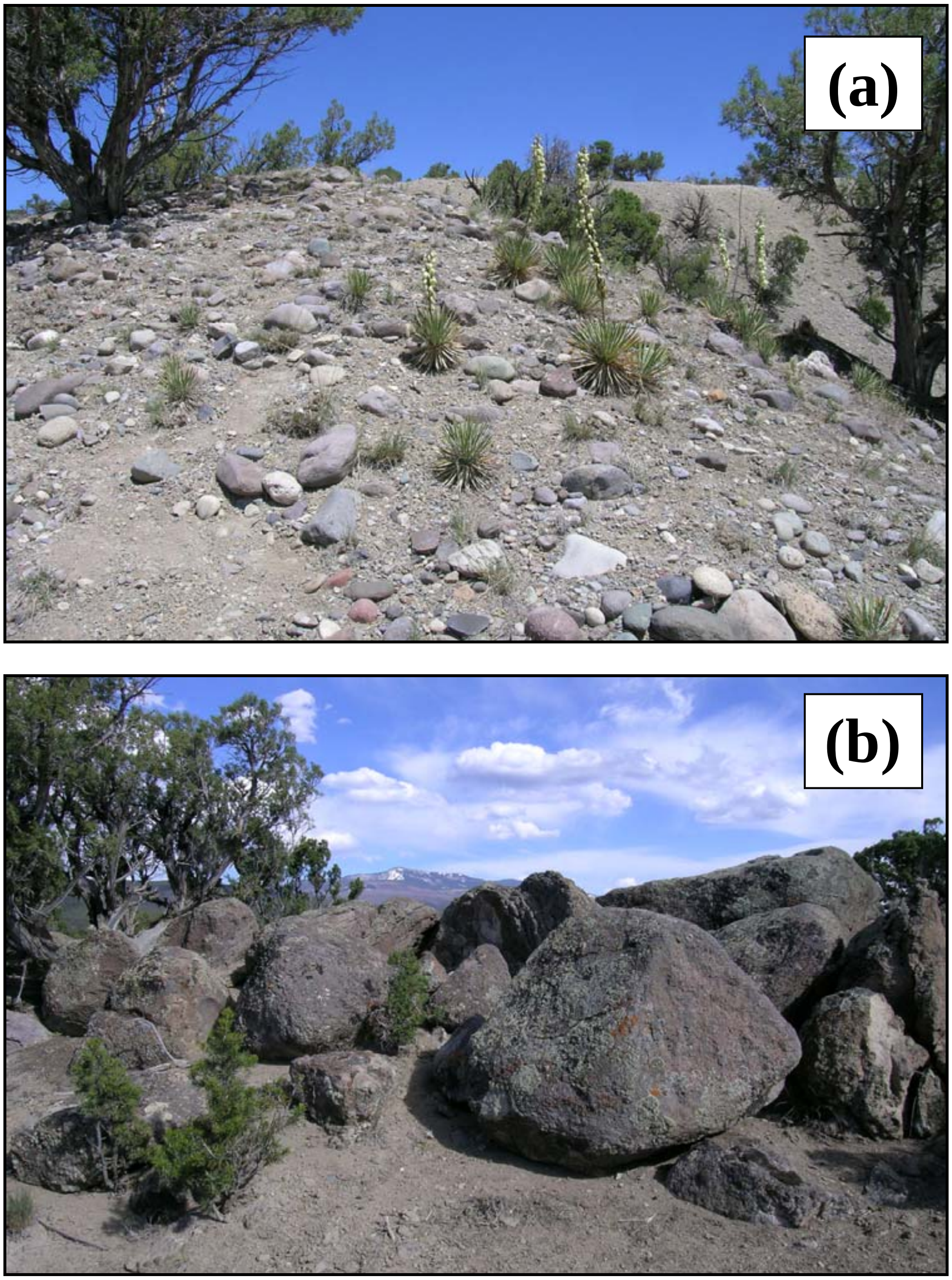

Figure 15. Qg_3 gravel deposits along the “Mesa Staircase” on top of “Chicken Wing Mesa.” (a) Clast-supported, rounded cobble and pebble gravel near base of the deposit [UTM83 258230, 4251999]. (b) Boulder bar weathering out of matrix-supported gravel deposits, exposed at the top of the unit [UTM83 256681, 4252597].

sandy to clayey silt, along with a bedded to reworked ash layer that is less than 1 foot thick. The top part of the unit consists of 1 to 3 feet of gypcrete within a matrix-supported layer, overlain by 1 to 2 feet of eolian sand and silt, with abundant exposed cobbles and boulders. These gypcrete "white caps" are a good indicator of mappable gravel deposits. A Stage III calcic soil occurs as cemented silt matrix, and clast coatings are found within the upper 6 feet. Boulder bars are occasionally present and contain very large boulders, up to 15 feet in length. The interbedded nature of the deposit is shown in a pair of measured sections in figure 16.

This unit is found capping a pair of high mesas, "Chicken Wing Mesa" and "Drumstick Mesa," in the southeastern corner of the Montrose East quadrangle and the northeastern corner of the Colona quadrangle (figure 3), in Sections 29, 30, 32, and 33, T. 48 N., R. 8 W. In map view, these deposits have fan-like shapes that spread and descend westward from narrow, well-defined apex points at elevations of 6,907 and 7,219 feet. The unit also caps a small mesa to the south of Kinikin Heights, in Section 21, T. 48 N., R. 8 W, at an elevation of over 7,060 feet. The mesa tops are about 480 to 560 feet above the Holocene (Qamf) tributary valleys.

We interpret this unit to be a valley-fill deposit with multiple depositional facies. The clast-supported gravel layers are alluvial deposits associated with the Shinn Park-Bostwick Park paleovalley system, a major drainage that extended from the San Juan Mountains northward to Red Rock Canyon and the Black Canyon of the Gunnison (Dickinson, 1965, 1966; Hansen, 1971). The boulder-rich, matrix-supported gravel layers represent debris-flow deposits that entered this paleovalley from tributary drainages to the east, which headed in the Cerro Summit-Cimarron Ridge highlands. These debris flows may have dammed the valley at certain times. The present, narrowed mesa summits coincide with the eastern edge of the paleovalley and may mark the location of major alluvial fan apexes at the tributary-drainage mouths. The fine-grained deposit in the middle of the unit, with its volcanic ash layer, may represent locally reworked colluvial and lacustrine depositional environments.

A sample of the ash layer from the southern slope of "Chicken Wing Mesa" was analyzed by the USGS Tephrochronology Laboratory in Menlo Park, CA, and was confirmed to be the Lava Creek B ash bed. The age of this ash bed is approximately 640 ka (Lanphere and others, 2002). Dickinson (1965, 1966) and Hansen (1971) described volcanic ashes within the valley-fill deposits in Shinn and Bostwick Parks. Hansen mapped a single ash layer that was petrographically similar to the Pearlette Ash Member of the Sappa Formation in Nebraska (which has since been re-defined and is identified as the Lava Creek B ash). Dickinson described this ash at 210 feet below the top of the valley-fill deposits, and a second ash at 70 feet below the top.

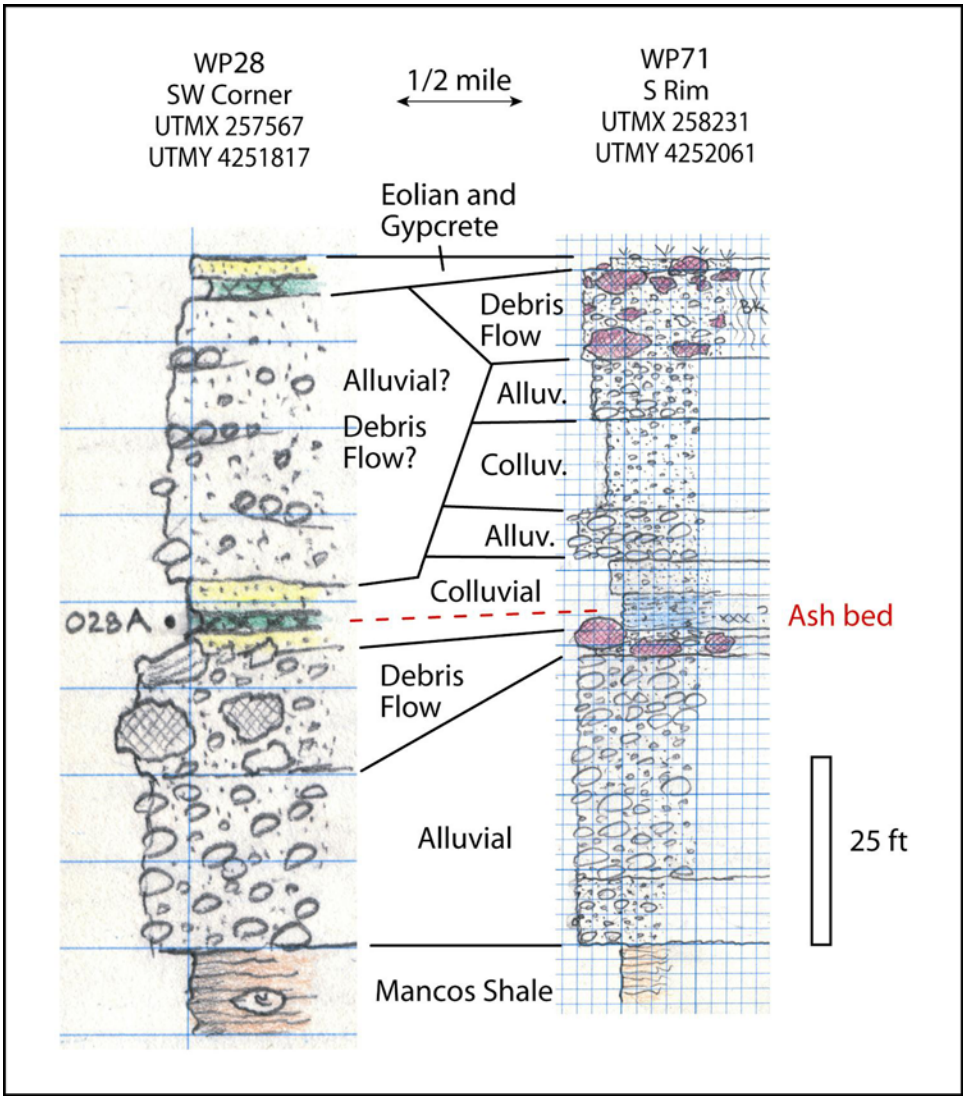

Figure 16. Measured sections of Qg_3 mixed alluvial-colluvial-debris flow deposits from exposures along the southern rim of "Chicken Wing Mesa." These sections show the complex nature of deposits within the Shinn Park-Bostwick Park paleovalley system. The ash bed has been verified as the Lava Creek B ash (640 ka), which is also found in nearby quadrangles.

Hudson and others (2006) recognized similar alluvial and valley-fill deposits to the south of the study area, in the Colona quadrangle. They postulated a connection between those deposits and those in Shinn and Bostwick Parks, and applied the name "Cerro River Valley" to the paleovalley system. Our mapping in the Montrose East quadrangle further defines this system by adding two intermediate outcrops along its course. Additionally, it identifies that the north-trending paleovalley took a major jog to the east between "Chicken Wing Mesa" and the Kinikin Heights area, possibly along a fault zone or adjacent to older paleovalleys associated with unit Qg_4.

The unit locally exceeds 90 feet in thickness. Correlation with any of the high alluvial terraces of the Uncompahgre River valley to the west is uncertain, as the two valley systems appear to have been separate and non-connected. The unit generally forms a stable building surface, although there may be localized pockets of collapse-prone sediment, and areas along the outer mesa edges may be prone to landsliding and rockfall. The debris-flow deposits are a marginal to fair source of commercial sand and gravel, whereas the alluvial gravel deposits may yield high-quality sand and gravel.

Qg_4 **Gravel deposit four (lower Pleistocene? to Pliocene?)** — Pale-red to moderate-orange-pink, poorly sorted, poorly stratified silt, sand, pebble, cobble, and boulder gravel. The gravel clasts are subangular to rounded, and some are coated with calcium carbonate. The matrix typically consists of clayey, silty, fine to coarse sand that has a distinct orange-pink color (figure 17a). The deposits are predominantly matrix supported and chaotic, with some cobble and boulder bars. Boulders up to 10 feet long are present, with occasional large to very large boulders that are as much as 40 feet long (figure 17b). The gravel is predominantly comprised of rhyolitic and andesitic tuff and breccia, porphyry, and quartzite, with some clasts of pink and red granite and black vitrophyre. A Stage III calcic soil is developed in places within the upper 10 feet, and is seen as carbonate-cemented sand matrix and coated gravel clasts. A discontinuous, 2- to 3-foot thick layer of very pale-orange, finely to coarsely crystalline gypsum (gypcrete) is found near the top of the deposit in some areas. These gypcrete “white caps” are a good indicator of mappable gravel deposits. Thin eolian sand and silt deposits are present within the upper 2 feet.

This unit caps a series of gently rounded hills within the Cerro Summit-Cimarron Ridge highlands and is best exposed in the southeastern part of the Montrose East quadrangle, along the western margin of the highlands where they drop away into the “Mesa Staircase.” There are no associated flat-topped or saddle-shaped mesas as were described for the younger upland gravels (Qg_1-Qg_3). Also in contrast with those younger gravels, its pinkish matrix may signify that more of the sand- and silt-sized material is volcanic in origin and less has been derived from the Mancos Shale.

The origin of this unit has been controversial. Atwood and Mather (1932) described it as being a till deposit and named it the Cerro Till. Dickinson (1965, 1966) reinterpreted it to be a blanket landslide deposit and later recognized younger mudflow deposits within the larger landslide complex (Dickinson, 1987). Sinnock (1978) compromised by interpreting the deposits to be till that underwent later landsliding.

Our interpretation differs from these previous ones in that we recognize two types of deposits in the Cimarron Ridge uplands. There are indeed landslide deposits (which

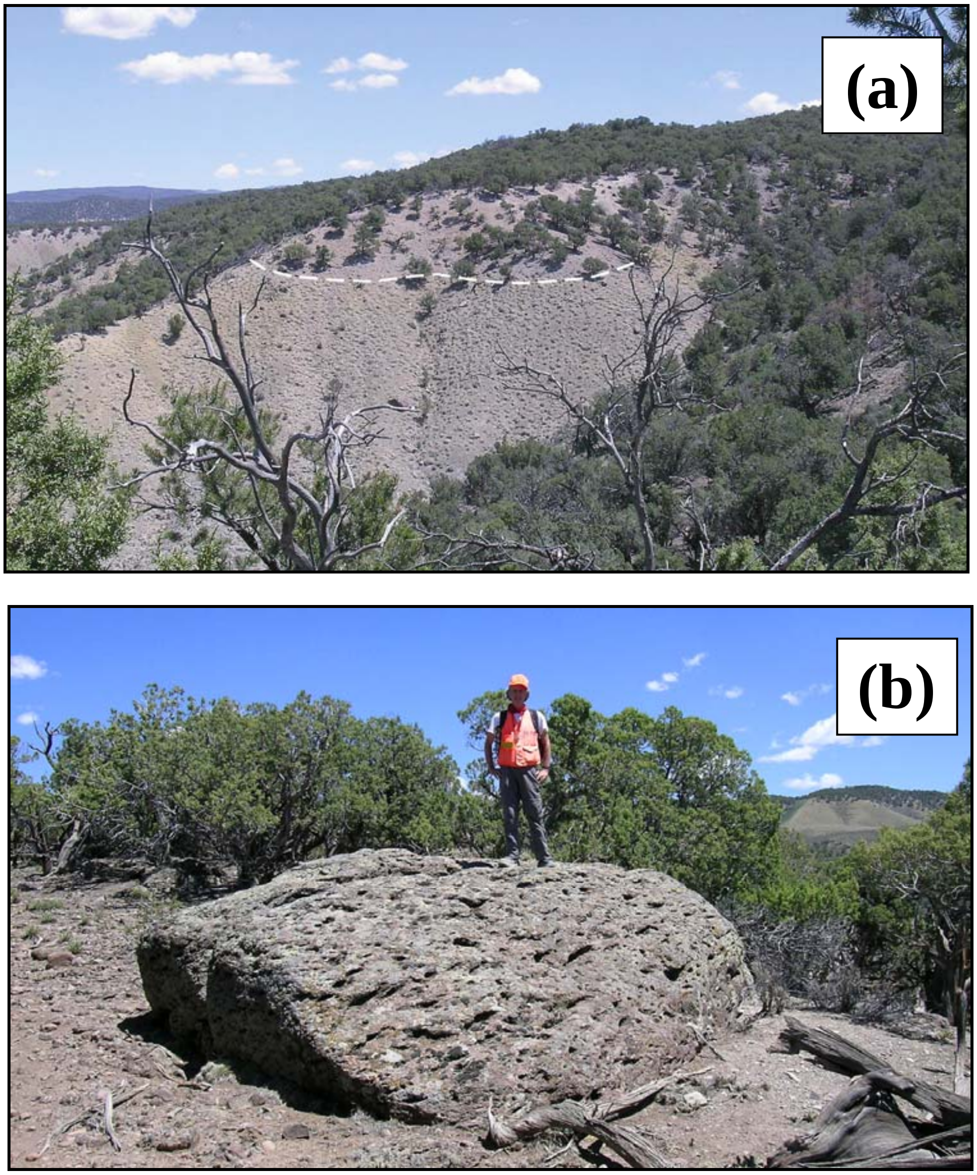

Figure 17. Qg_4 gravel deposits capping the Cerro Summit-Cimarron Ridge highlands to the east of the "Mesa Staircase." (a) Distant view of matrix-supported gravel deposits (above dashed line) showing rounded shape of hilltops and characteristic pinkish color. (b) Large, 20-foot-long boulder of welded, tuffaceous rhyolite exposed at the top of the unit. [UTM83 258883, 4252197]

are mapped and described as a separate unit, Qls), but there are also Qg_4 gravel deposits that appear to be in place. These deposits have a sharp lower contact with the underlying the Mancos Shale that dips gently to the southwest and also have well developed, calcic and gypsiferous soils. We searched in several locales and could not find evidence of glacially derived striations on boulders or cobbles. This, plus the fact that many of the larger boulders are composed of brittle and non-durable tuff and breccia, argues against the deposit being a till. In terms of stratification, depositional style, and composition, these deposits are nearly identical to the gravelly, bouldery debris-flow deposits described for the three younger upland gravel units.

Because of its broad extent and the abundance of large, locally sourced tuff boulders, we interpret that this unit was deposited as a large complex of coalescing alluvial fans that blanketed the side of the nearby, eroding Cimarron Ridge highlands. These deposits later underwent significant landsliding and redeposition in some places. Contemporaneous landsliding may have occurred in the erosional headland area to the east and southeast of the Montrose East quadrangle. The rounded clasts of quartzite and other hard lithologies may have been derived, at least in part, from the older fluvial deposits, particularly Eocene Telluride Conglomerate outcrops along Cimarron Ridge.

It is also possible that the lowest-elevation Qg_4 deposits form part of a major-stream paleovalley that is the precursor to the Qg_3 Shinn Park-Bostwick Park paleovalley system. We could not verify this because of generally poor and weathered exposures, but this would be a cause for further investigation. Such an interpretation would explain the abundance of well-rounded, San Juan-type clasts in the southeastern corner of the mapped area. It would explain the northward extension of these deposits along the remnant upland west of Shinn and Bostwick Parks. Dickinson (1965) described one of the ridge-capping deposits as being fluvial in origin. According to Andres Aslan (Mesa State College, oral communication, 2007), this exposure contains an alluvial cobble gravel at the base overlain by bouldery debris-flow deposits. Debris flows would have entered the paleovalley from the fan system along its eastern side. The westward extent of the deposit would be constrained by a valley wall of Mancos Shale under this scenario.

The unit locally exceeds 15 feet in thickness. It generally forms a stable building surface, although there may be localized pockets of collapse-prone sediment, and areas along the outer hilltop edges may be prone to landsliding and rockfall. Because of its variable silt content and an abundance of non-durable volcanic clasts, it is a marginal to fair source of commercial sand and gravel.

Qbg **Boulder and gravel lag deposits, undivided (lower Holocene to middle Pleistocene)** — Poorly sorted, pebble, cobble, and boulder gravel or isolated boulders, mostly within the “High Adobe Hills” area (figure 3). Erosion in this area has produced badland topography of conical shale hills and rounded, often-narrow ridges. Many of these hilltops and spur ridges are capped by thin lag deposits of gravel (typically less than 2 feet thick), or by grouped or individual boulders of pale-red, rhyolitic tuff up to 25 feet long (figure 18). Some of the lower-elevation lag deposits are areally extensive and either form caps along the tops of flat mesas or elongate fingers of gravel atop shallow slopes and spur ridges. The gravel-clast compositions are similar to those described for Qg_1, Qg_2, and Qg_3. In addition, basalt clasts are found in the lag deposits in the northeastern corner of the quadrangle within the Cedar Creek drainage basin.

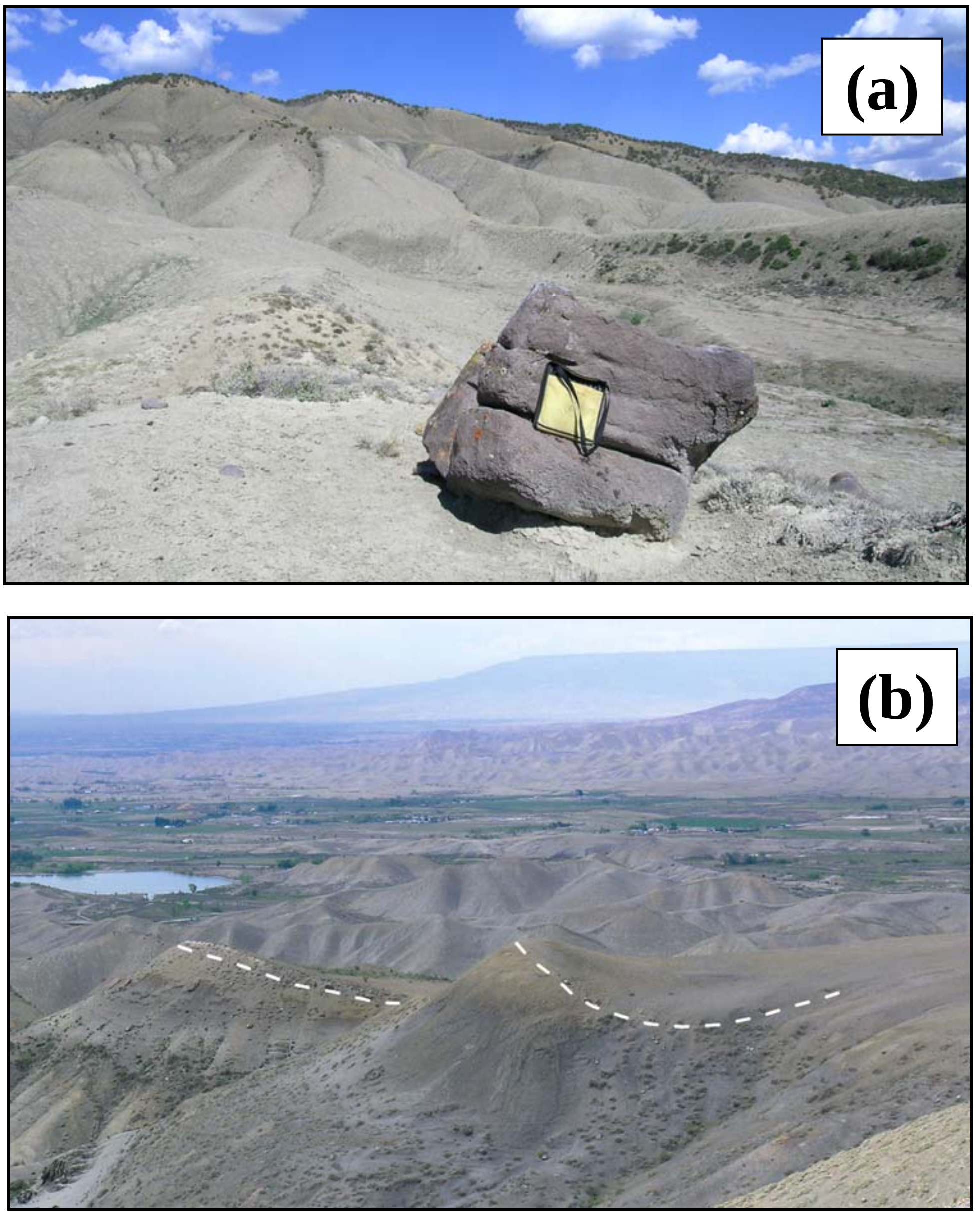

Figure 18. Qbg gravel lag deposits in the "High Adobe Hills" area. (a) Tuffaceous rhyolite boulder and a few, remnant cobbles atop an elongate shale ridge [UTM83 259656, 4257582]. (b) Two saddle-shaped erosion surfaces cut into Mancos Shale, high on the western flank of "Lujane Point" above Cedar Creek, both of which are lined around the rims with gravel lag deposits (immediately above dashed lines) [UTM83 260205, 4259966].

Although too thin to be mappable units, these lag deposits are important in that they mark the former courses of arroyos or tributary valleys that headed just to the east of the quadrangle, in the shale cliffs that form the drainage divide with Shinn Park. Unlike the "Mesa Staircase" area to the south, which had large drainage basins and an abundant supply of material to produce gravelly mudflows, we interpret that the upland source areas in the "High Adobe Hills" were smaller in area and contained less gravel. The arroyos were mostly eroded into Mancos Shale. Gravel that was transported from headwall areas into the arroyos formed thin, narrow, pod-like deposits. Using modern analogs, the bulk of the original deposits may have consisted of shale clasts, which slaked apart and washed away during subsequent rainstorms. Later erosion and incision preserved these isolated boulder and gravel deposits on high ground, as inverted topography. Hansen (1971) mapped similar gravel-lag occurrences to the north, in the Red Rock Canyon quadrangle.

We delineate the occurrences of isolated boulders or gravel pods on the geologic map with small bulls-eye circles (plate 1). A few, areally extensive lag deposits are shown as crosshatched areas on plate 1. These deposits occur at several elevation levels and therefore may have been related to and deposited coincident with the Qg_1, Qg_2, or Qg_3 units described above. The youngest (Qg_1-equivalent) lags are at the lowest elevation level and are the most extensive and best preserved, while the older lags are preserved as isolated pods or clasts that are either in place or remain after erosion of the hilltops. The youngest lag deposits often show a branching pattern near their western terminus or on sloping ground to the north side of elongate, gravel-capped mesas at certain locations. These deposits may be the remnants of alluvial fans, either at the mouths of the arroyos, or at the locations where the gravel-bearing tributary channels were breached by adjacent, laterally headward-eroding arroyos that cut through a Mancos Shale-cored drainage divide. A few thicker, mappable gravel deposits in this area have been mapped as Qg_1.

EOLIAN DEPOSITS

Eolian deposits within the Montrose East quadrangle consist of predominantly sand, silt, and disc-shaped shale chips that have been transported and deposited by wind. Many of the mesas within the Montrose East quadrangle are covered with thin, unmappable deposits of eolian sand and loess (silt) that post-date the mesa-top gravel deposits. Mappable eolian deposits in this area are of limited extent and mark localities where wind-deposited dunes have accumulated.

Qe **Eolian deposits (upper Holocene)** — This unit includes two different types of eolian deposits. The first is a single area of sand dunes on top and near the center of "Chicken Wing Mesa." This deposit has a maximum thickness of approximately 8 feet and consists of poorly formed, partially vegetated mounds and dunes of light-brown silt and sand. It sits on the north side of a cliff-top reentrant, and the sand and silt particles are probably blown onto the rim from the broad topographic amphitheater below. The source materials are wind-eroded, sandy shale and landslide deposits on the mesa slopes.

The second type of eolian deposit consists of shale-particle dunes deposited on the lee sides of shale ridges and mesas that are undergoing active and rapid wind erosion. One of these deposits is mapped adjacent to a gravel-capped ridge to the west of Kinikin Heights (figure 19a), where a spur ridge of Mancos Shale is being eroded by the wind. This deposit has the appearance of a "blowout" dune, with a bowl-like area of erosion bounded on the lee side by a semicircular apron of shale-particle dunes. The sediment in these unusual dunes consists of paper-thin, tabular, angular to jagged sheets of gray to yellow-brown, silty clay (consisting of irregular pieces of eroded Mancos Shale). The shale particles range in size from less than 0.1 inch to 2 inches in diameter. The dunes are accumulations of shale particles that aggrade onto the outer dune-face surfaces to form inclined, parallel layers. Smaller-diameter particles may be incorporated into wind ripples that migrate across the dune face.

Incipient shale-particle dunes are forming in two locations within the Montrose East quadrangle. These are unmapped because of their limited size and thickness. They are important to note, however, as they may be indicative of the effectiveness of wind as an erosional agent in shale terrain. The most impressive example is an isolated butte on the north side of Dry Cedar Creek basin near the South Canal. This butte is circular in plan view and bell-shaped in cross section, as shown on the 1962 USGS topographic map and in the 1966 aerial photographs. Today this butte looks radically different, as if it has been cleaved in half. A 40-foot-deep, east-west oriented slot has been eroded through its center, with incipient shale-particle dunes forming on the slopes below both ends of the slot (figure 19b). According to a nearby, long-term resident, the mesa became a favored locale for off-road motorcycle (dirt bike) use during the 1960s. Deep ruts were eroded into the hill slopes, directly up the fall line to the top. A resistant column of limy shale caprock was toppled from the top of the mesa at one point. Shortly thereafter, the butte began eroding away rapidly, a process that has continued to the present day (N. Edgell, oral communication, 2006). Although off-road access has been curtailed by the BLM for several decades, the amount of erosion and downcutting that occurred within a 40-year span is remarkable. It appears that the extreme wind erosion at this site may have occurred as a consequence of the loss of the protective caprock,

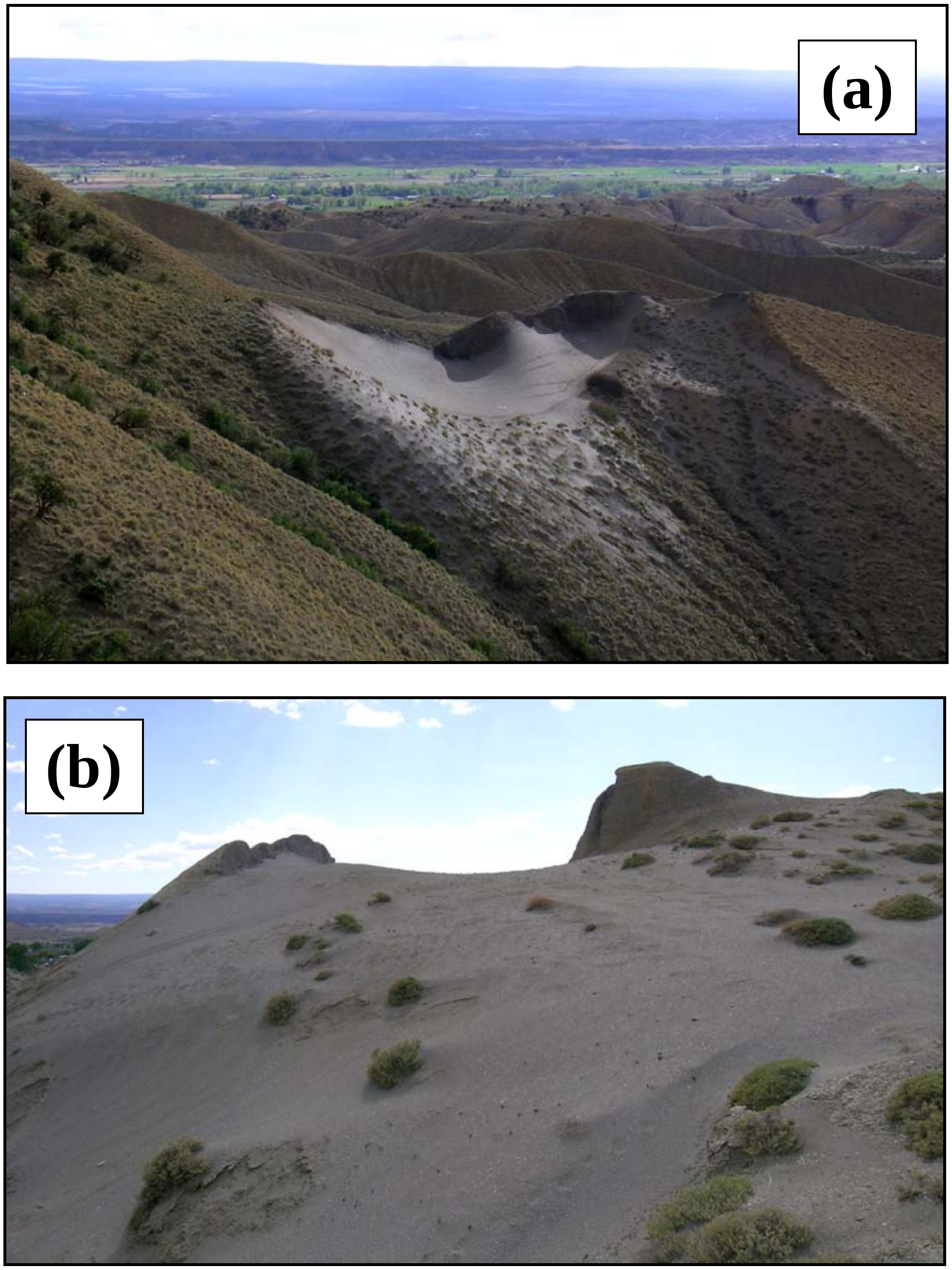

Figure 19. Shale-particle eolian dunes. (a) Dune in the lee of an eroding spur ridge of Mancos Shale (dark cliffs) flanked to the leeward (toward camera) by a non-vegetated blowout area and a semicircular, partially vegetated apron of shale-particle dunes [UTM83 257054, 4254452]. (b) Incipient shale-particle dunes on the lee side of a butte that began rapidly eroding after the protective cover of colluvium and weathered shale was breached by off-trail vehicle use [UTM83 256399, 4257370].

as well as the loss of the protective layer of residuum and weathered shale along the rutted vehicle tracks. We postulate that the exposure of fresh, laminated shale at these points allowed the wind to gain an erosional foothold.

A similar, although naturally eroding butte is located just to the east of "Water Tank Mesa." At this location, it appears that the former Qg2 gravel cap was completely eroded away only recently. Without the protective cover, the top of this conical butte is beginning to be abraded away by the wind. Within the coming decades, we postulate that this butte will be lowered by downcutting. The flanking, incipient shale-chip dunes will become larger during this episode.

Shale-particle dunes were recognized in Texas near back-barrier lagoons in coastal-plain settings (Coffey, 1909; Huffman and Price, 1949), and in Utah in badlands terrain (Hunt and other, 1953). Shale-particle dunes up to 10 ft high formed during the dust-bowl years of the 1930s in South Dakota. They aggraded down-wind from deflation basins in the Pierre Shale (oral communication, G. Avery, USDA Soil Conservation Service, in Flint, 1955, p. 132). On the basis of the lack of widespread shale-particle dune deposits across the mapped area, these deposits may exist only temporarily at actively eroding sites. Once the parent butte has eroded away, the dunes themselves may become unprotected and exposed to direct wind, resulting in dispersal of the dune materials. The shale particles could also be eroded and removed from the dunes by sheetflow from rainstorms.

The eolian sand and silt deposits may form stable building surfaces where they are thin and widespread, such as the deposits that cap the mesa-top gravels. The collapse potential and bearing strength of such deposits should be evaluated if the sand is more than a few feet thick. The unusual shale-particle dunes may mark sites of concentrated wind exposure, intense erosion, and loose, shifting sediments. As such, the dunes and their associated erosional areas are undesirable as building sites for both climatological and geological reasons.

MASS-WASTING DEPOSITS

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

Qc **Colluvial deposits (Holocene to upper Pleistocene)** — Pale-red to light-brown, poorly sorted pebble to boulder gravel in a sandy silt matrix. Unit contains subangular to round clasts and is poorly to weakly stratified. The clast lithologies consist mainly of volcanic rocks and quartzite reworked onto hillsides below exposures of older alluvial and gravelly mudflow deposits. May include local sheetflow or landslide deposits and may interfinger with alluvial, landslide, and alluvial-mudflow deposits. Scattered deposits of colluvium occur on slopes of some of the higher mesas in the "Mesa Staircase" area and underlie the ramp-like heads of some of the gravelly mudflow valleys against the Cimarron Ridge upland. Deposits locally exceed 5 feet in thickness, but many are too thin to map. Areas mapped as colluvium may be susceptible to rockfall, debris flows, or landslides.

Many of the Mancos Shale exposures within the quadrangle are covered with a thin skin of residual or colluvial mud, as a result of in-place weathering (figure 20). The coverings range from a few inches to a few feet in thickness and are too thin to map. They are worth noting, however, because much of the weathering, erosion, and removal of formational shale from hillsides in this area occur by colluvial processes rather than by water or wind erosion or deeper-seated landslides. The coverings typically consist of intermixed silt and clay (mud) that have undergone numerous wetting and drying cycles

The resulting surface exposures often have "popcorn" or "mud crack" textures that are often associated with swelling soil (Noe, 2007). In steeper terrain, the coverings may undergo small-scale, downhill flowage or slumping when wetted by rainstorms. Occasionally, failure of the coverings occurs, forming very thin-skinned landslides and exposing the underlying shale/colluvium interface. Many of the muddy surfaces are relatively resistant to wind and water erosion in their wet and dried states, and as such, these thin coverings appear to protect the underlying formational shale from erosion. Destruction of this crust by vehicles may accelerate subsequent wind and water erosion.

Qls **Landslide deposits (Holocene to middle Pleistocene)** — Heterogeneous deposits consisting of unsorted and unstratified clay, silt, and sand, and cobble- and boulder-size rock fragments. The unit includes individual rotational and translational landslides, areally extensive landslide complexes, and earthflows. In most places, the landslides show an obvious geomorphic expression that disrupts the profile of the hillslopes. Head scarps (near-vertical detachment scars exposed at the top of and sides of the landslides) are generally readily recognizable; however, some may be eroded or covered and therefore are not pronounced. Other common diagnostic features include hummocky topography, closed depressions, fissures, terracettes, tension cracks, and pressure ridges at the toe of the mobilized mass.

Figure 20. Thin-skinned colluvial and residual coverings over Mancos Shale. (a) “Popcorn” textured mud residuum with white efflorescence of sulfate salts [UTM83 257684, 4263698]. (b) Slumped colluvial mud in a road cut along US-50, a few days after a heavy rainstorm [UTM83 259318, 4263556].

The landslides typically form in weathered Mancos Shale and may incorporate coarse materials from hilltop gravel deposits. Soil piping and lubrication of fracture and bedding planes within the Mancos Shale, caused by infiltration of meteoric or irrigation water, are responsible for many of the slope failures in this unit. Soil profiles were not developed on any of the examined deposits; however, it is possible that buried soils may occur and may represent multiple slope movements. The relative ages and movement histories of the landslides are highly variable.

Most of the landslides in the map area occur along the flanks of flat-topped mesas, including Sims, “Moonlight,” “Drumstick,” and “Chicken Wing” mesas, and Kinikin Heights (figure 3), particularly along the north- and northeast-facing slopes. The head scarps for these landslides are typically coincident with the mesa rims. The slide material consists of blocks of Mancos Shale, highly disturbed clay, and some gravel. Gravel occurs within the uppermost parts of the deposits and occasionally along the slip planes. Most landslide initiation and movement probably occurred during the middle to late Pleistocene, and some of the landslide deposits show evidence of subsequent erosion and dissection. The largest of these landslides is the Sims Mesa landslide complex (figure 21a), which is developed within the Graneros Member of the Mancos Shale. Active landsliding is occurring in a smaller landslide complex along Dry Cedar Creek, on the north-facing slopes of Kinikin Heights, and appears to be driven by infiltration and seepage of waters derived from agricultural irrigation on the mesa top.

Elongate, earthflow-type landslides occur along the eastern edge of the mapped area (figure 21b). These landslides begin in the Cerro Summit-Cimarron Ridge highlands and the remnant uplands and shale cliffs to the north (figure 3), in areas that receive appreciably greater precipitation than the lowlands near Montrose. They typically occupy tributary valleys or steep, bowl-like slopes, and primarily consist of remobilized Mancos Shale and reworked clay and Qg_4-level bouldery gravel.

Landslides are subject to future movement during episodes of heavy rain or snowfall. They may be reactivated by human-made disturbances such as cutting of slopes for roads, quarries, and housing developments, or by water infiltration from irrigation and septic systems. In particular, poor irrigation practices may create slope instability or remobilize landslide deposits. Landslide deposits are prone to settlement when loaded or wetted. The deposits may contain expansive soils where they are derived from shale and mudstone formations. The thickness of landslide deposits locally exceeds 10 feet and may exceed 100 feet in the large Sims Mesa landslide complex.

BEDROCK UNITS

The Upper Cretaceous Mancos Shale comprises nearly all of the exposed bedrock within the mapped area; the Upper Cretaceous Dakota Sandstone, found in the southwestern corner, comprises the remainder. The Mancos Shale is marine in origin. It consists of clayey to sandy to

Figure 21. Qls landslide deposits. (a) Extensive landslide complex with well-developed hummocky topography, which blankets the entire eastern slope of Sims Mesa, as seen across the valley of Dolores Creek from Moonlight Mesa [UTM83 250112, 4254812]. (b) Snout of elongate, earthflow landslide (outlined by dashed line) filling a valley at the western edge of the Cerro Summit-Cimarron Ridge highlands [UTM83 259216, 4253122].

calcareous silt-shale with minor limestone, marlstone, and sandstone strata. The Dakota Sandstone consists of marginal-marine sandstone with minor shale interbeds.

Previous mapping in the Uncompahgre River valley treated the Mancos Shale as an undifferentiated, single unit. Coordinating with the USGS, we used lithofacies associations and diagnostic fossils and biostratigraphy to differentiate ten stratigraphic members within the Mancos Shale. From youngest to oldest, they are the Lujan Point shale unit (informal name) and the Sharon Springs, Prairie Canyon, Smoky Hill, Montezuma Valley, Juana Lopez, Blue Hill, Fairport, Bridge Creek, and Graneros Members. Several of the older members are combined for mapping purposes because some are relatively thin or are not well exposed, resulting in seven mapping subunits that are described below. The nomenclature for these stratigraphic members is imported from the Front Range Piedmont near Pueblo (Scott and Cobban, 1964, 1975; 1986; Scott, 1969; Cobban and Scott, 1972), the Mesa Verde area in southwestern Colorado (Leckie and others, 1997; Molenaar and others, 2002), and the Book Cliffs near Grand Junction (Cole and others, 1997; Hettinger and Kirschbaum, 2002). Sawyer and others (in prep.) applied a similar nomenclature to the Mancos Shale just to the north of the Montrose East quadrangle. Figure 22 contains a stratigraphic column for the Montrose East quadrangle. The biostratigraphy reported herein is based on fossil collections made by the authors, as well as fossil collections made by previous workers (Dickinson, 1965; Merewether and others, 2006). The collections were made within the quadrangle, and from outside within a mile of its borders. A table showing these fossil collections is included as digital Appendix A on the CD-ROM. This table includes USGS-assigned locality numbers (which correlate to points shown on the map plate), fossils identified, mollusc and ammonite zones guide-fossil zones for the Western Interior Seaway, age, lithologic unit, location, and collection data. The entire section was deposited during the Upper Cretaceous, from Middle Campanian (less than 80.5 ma; Lujane Point shale unit of the Mancos Shale) to Middle Cenomanian (95.7 ma; Dakota Sandstone).

Thin coverings of colluvium and residuum (described in the previous section) present a challenge to mapping in areas of Mancos Shale because they obscure the shale bedding and make it difficult to find in-place fossils. As a rough estimate, about 80 to 90 percent of the Mancos Shale exposures in the mapped area are obscured in this manner. Leckie and others (1997) responded to this challenge by hand-digging shallow trenches down the fall lines of hills to expose fresh shale for detailed description. Such detail was not possible for the present mapping project. Our descriptions rely on isolated, relatively fresh outcrops or road and canal cuts.

Mancos Shale (Upper Cretaceous)

Kml **Lujane Point shale unit** — Brown to dark-reddish-gray, non-calcareous, silty, marine shale. Outcrops are found in the far northwestern part of the Montrose East quadrangle. This unit becomes increasingly sandy upward, culminating in a very pale-brown sandstone or sandy shale interval in the “shale cliffs” and “Lujane Point” areas just to the east of the quadrangle (figure 23). The basal contact with the underlying Sharon Springs Member appears to be sharp and conformable. The upper contact lies outside of the mapped area and was not investigated.

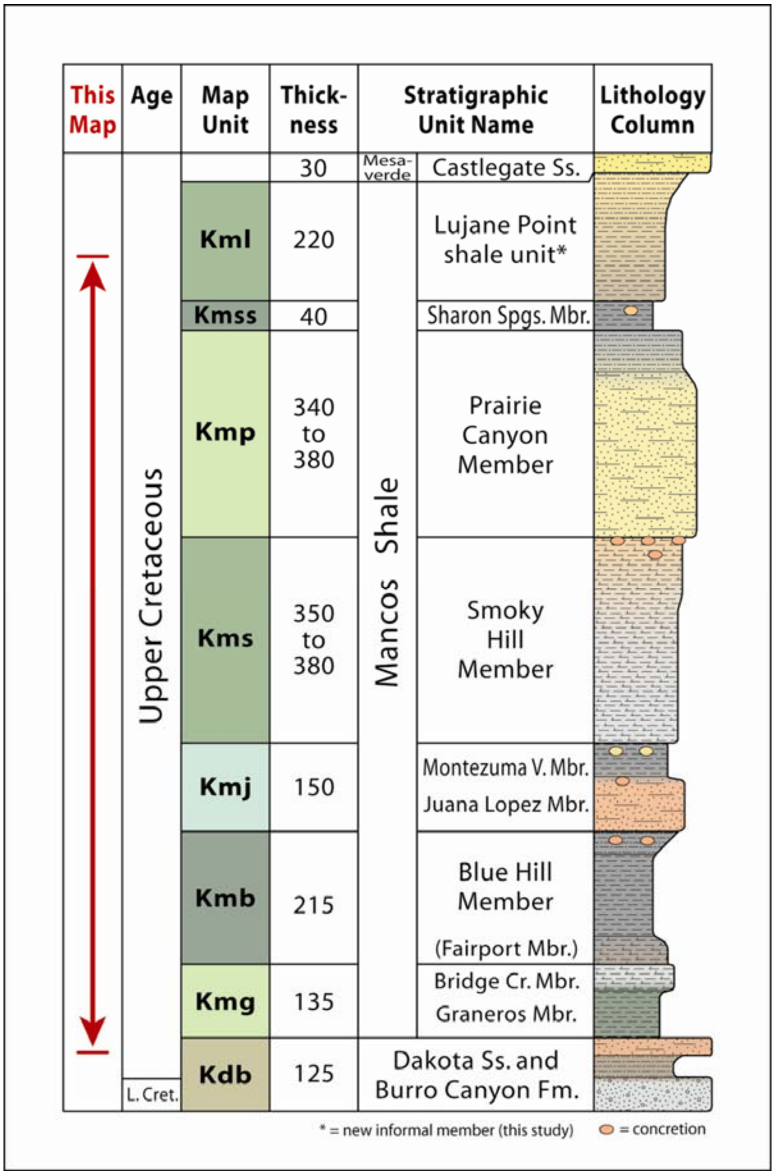

Figure 22. Bedrock stratigraphic column for the Montrose East quadrangle.

This unit is the fine-grained, offshore-marine equivalent of the Castlegate Sandstone of the Mesaverde Group in the Book Cliffs. Sawyer and others (in prep.) call this unit the Castlegate Member of the Mancos Shale. It is sometimes informally known as the Castlegate siltstone (D. Sawyer, USGS, oral communication, 2007). However, because members of the Mesaverde Group are of continental and marginal-marine origin (Hayden, 1875; Hettinger and Kirschbaum, 2002), we have chosen not to use the term, "Castlegate," for a unit within the Mancos Shale. A new informal name, "Lujane Point shale unit," is applied to this unit for this study. It is stratigraphically equivalent to the upper Blue Gate Member of the Mancos Shale in east-central Utah and west-central Colorado (Cole and others, 1997), the lower part of the Lewis Shale in southwestern Colorado (Molenaar and others, 2002), and the rusty zone of the Pierre Shale in east-central Colorado near Pueblo (Cobban and Scott, 1972).

Dickinson (1965) collected *Baculites aspiriformis* (ammonite) fossils from this unit in the Cerro Summit quadrangle, and *B. perplexus* (indicating the base of the Buck

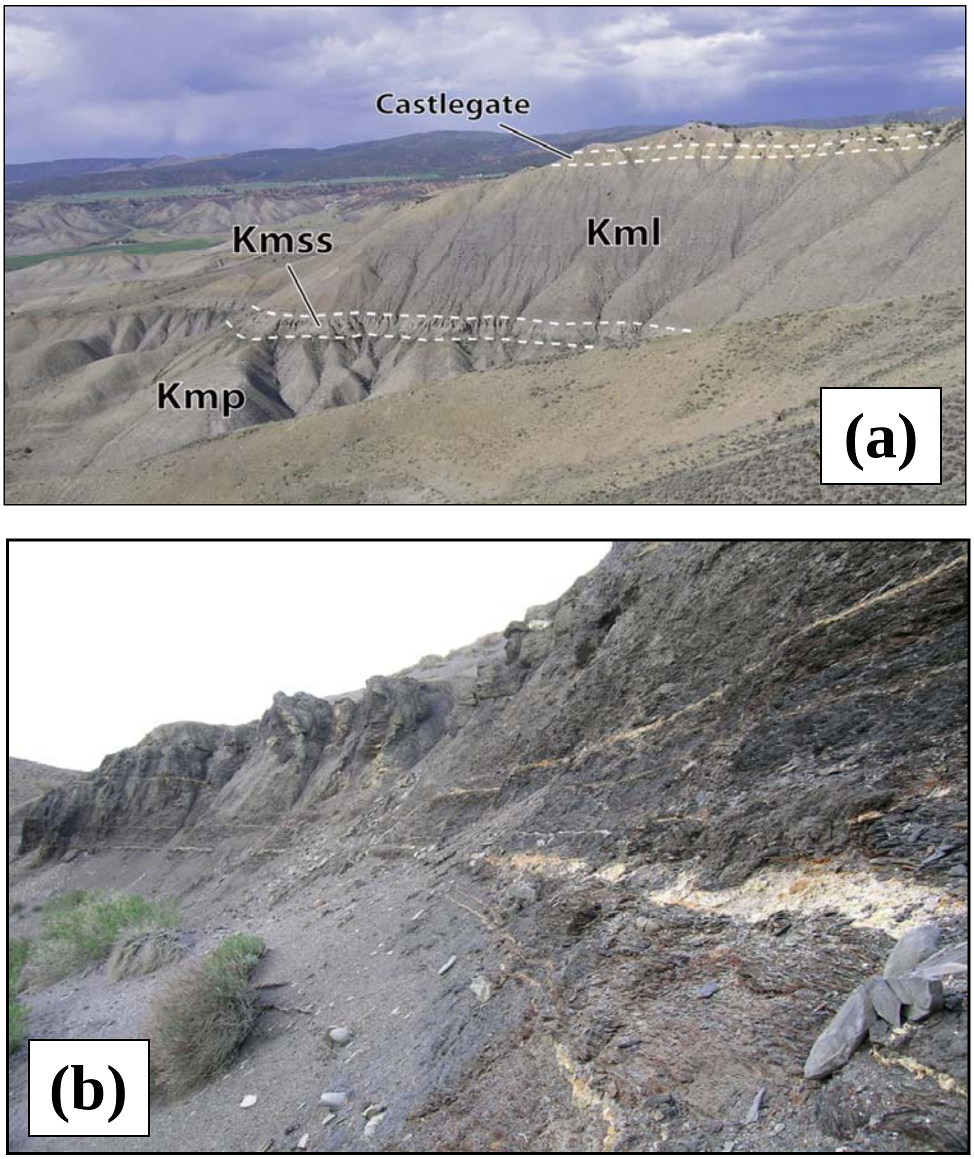

Figure 23. Lujane Point shale unit (Kml) and Sharon Springs Member (Kmss) of the Mancos Shale. (a) Black-and-white Kmss shale band exposed at mid-slope in the "shale cliffs" area to the north of "Lujane Point," overlain by Kml and the Castlegate Sandstone, and underlain by the Prairie Canyon Member (Kmp). (b) Outcrop view of Kmss showing dark, organic shale with white bentonite beds. [UTM83 259956, 4260316]

Tongue of the Mancos Shale) from a shale unit above the sandy interval. We collected a *Cataceramus balticus* (inoceramid) from this unit on the north side of "Lujane Point," within a landslide head-scarp area. These fossils indicate that the unit is of Middle Campanian age (less than 80.6 ma) (Cobban and others, 2006). The thickness of this unit is approximately 250 feet.

The Lujane Point shale unit typically forms steep slopes. Small to large earthflow-type landslides form in these slopes along the "shale cliffs," along the western edges of Bostwick and Shinn Parks. The unit contains moderately expansive clays, especially in the lower, shaly part of the section.

Kmss **Sharon Springs Member** — Dark-bluish-gray to light-bluish-gray, noncalcareous, organic-rich, marine shale. This unit contains numerous bentonite beds up to 8 inches in thickness, abundant gypsum in fractures, and occasional light-reddish-brown concretions up to 12 inches in diameter. This unit forms a prominent, resistant, thin, black-and-white band in the mid-slope area of the "shale cliffs" (figure 23), in the northeastern part of the quadrangle. The contact with the underlying Prairie Canyon Formation is sharp. No fossils were collected. This unit is stratigraphically equivalent to the Sharon Springs Member of the Pierre Shale, a widespread black shale unit that is recognized from northern New Mexico to eastern Kansas, the Dakotas, and Montana. It is the offshore equivalent of the Grassy Member of the Blackhawk Formation in the Books Cliffs of Utah. In west-central Colorado, it appears in well logs as a thin, bentonitic (high gamma ray) shale (Hettinger and Kirschbaum, 2002). Sawyer and others (in prep.) call this the Grassy marker. It may correlate with the top of the type section of the Mesaverde Group in southwestern Colorado (the basal Cliff House Sandstone of Molenaar and others, 2002). The thickness of this unit in the mapped area is approximately 40 feet.

Many of the small-to-large, earthflow-type landslides in the "shale cliffs" area have basal failure planes within the Sharon Springs Member. The bentonite beds within the Sharon Springs Member comprise natural planes of weakness. The unit contains moderately to highly expansive clays within both the black shales and especially the bentonite seams. The shale may be corrosive as a result of its high gypsum content.

Kmp **Prairie Canyon Member** — Gray to light-brownish-gray, noncalcareous, sandy marine shale. Contains small discs of bioturbated sandstone up to several inches in diameter (figure 24). Concretions are rare except at the top of the unit, which contains a single zone of abundant, reddish-brown, sometimes fossiliferous, micritic concretions up to 6 feet in diameter. In the upper part of the section, there are zones of dark-gray, silty shale with abundant gypsum-filled fractures. Outcrops occur in the "High Adobe Hills" area in the northeastern part of the quadrangle and in the upper slopes of Kinikin Heights, “Chicken Wing Mesa,” and Cerro Summit-Cimarron Ridge highlands in the southwestern part. The unit typically forms steep, broad-shouldered, rounded ridges with abundant small-scale rilling, or smooth slopes below gravel-capped mesas. The basal contact with the underlying Smoky Hill Member is sharp and appears to be conformable (figure 25).

Figure 24. Discoidal fragment of bioturbated sandstone from the Prairie Canyon Member of the Mancos Shale, with a *Baculites aquilaensis* mold (outlined). [UTM83 257684, 4263698]

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

2002) and in Delta County (967 feet thick; Sawyer and others, in prep.). It is also much thinner than the Cortez Member at Mesa Verde (1,289 ft thick; Leckie and others, 1997).

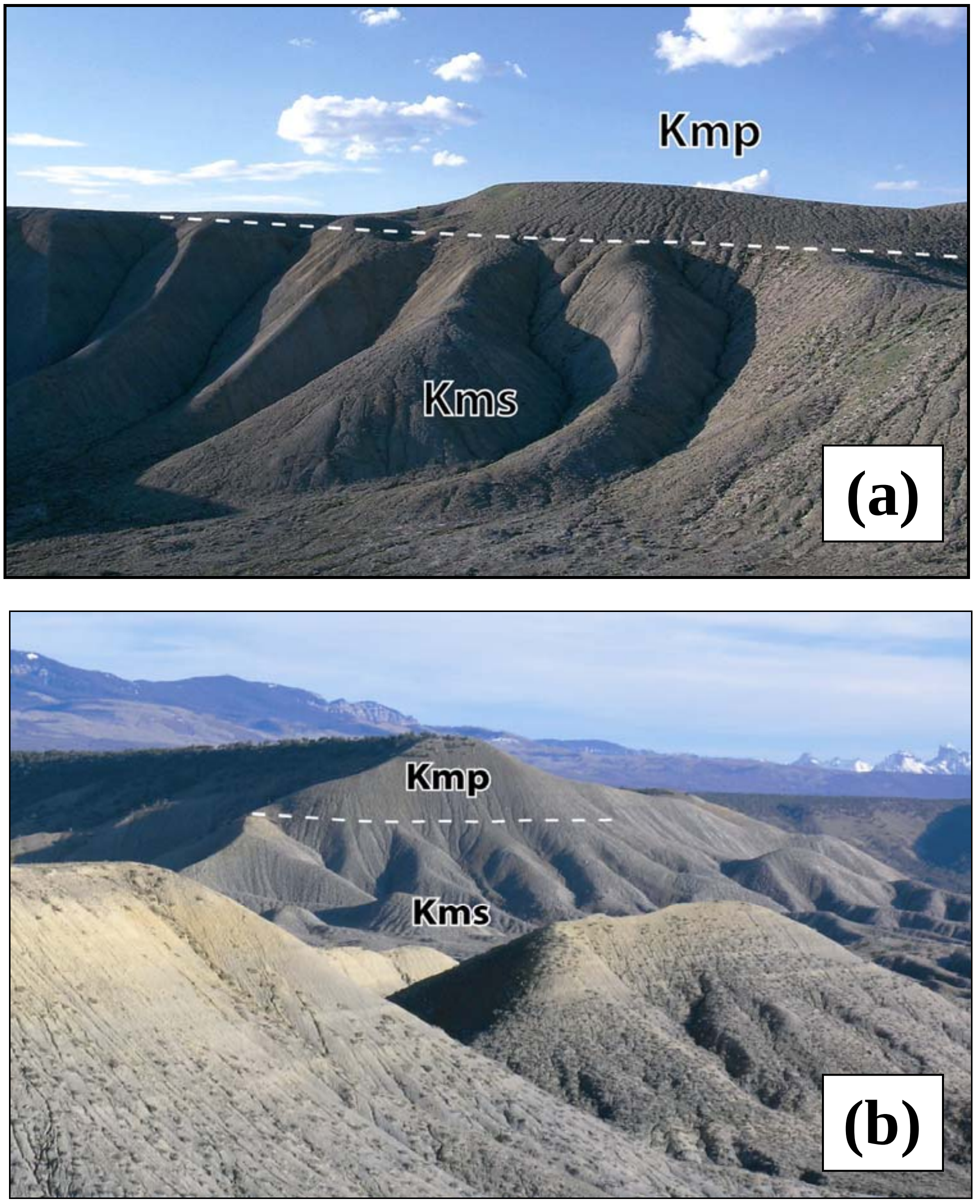

Figure 25. Boundary between the Prairie Canyon (Kmp) and Smoky Hill (Kms) Members of the Mancos Shale. The Prairie Canyon Member appears smooth with small-scale rilling, while the uppermost Smoky Hill Member contains large spur ridges capped by micritic concretions. (a) In the "High Adobe Hills" area [UTM83 258544, 4257852]. (b) On the slopes of "Chicken Wing Mesa," in background, with weathered, "Mancos Blonde" Kms shale capping the buttes in the foreground [UTM83 254587, 4254636].

The Prairie Canyon Member may be prone to landsliding in areas having ground-water discharge and seepage, such as the "Shale Cliffs" area, the northern flanks of high mesas such as "Chicken Wing" and "Drumstick" mesas, and along the eastern face of the Cerro Summit-Cimarron Ridge highlands. In the dry "High Adobe Hills," thin-skinned landsliding and surficial creep of the residual layer is common, but deeper landsliding is uncommon. The unit contains moderately expansive clays, especially in the upper, shaly part of the section.

Kms **Smoky Hill Member** — Dark-gray to light-gray to very pale-brown, calcareous to slightly calcareous, silty marine shale. The lower part of the unit is shaly (figure 26a) and moderately fossiliferous, with abundant plant debris, shell fragments, coccoliths, and fish scales concentrated along bedding planes. Multiple bentonite beds and bentonitic zones are located throughout the lower part. The upper part of the unit consists of interbedded limestone, marlstone, and shale beds. The limestone beds are typically 12 inches thick and may form minor benches (figure 26b). These lithologies may weather to a distinctive golden or very pale-brown color, giving rise to the local term, "Mancos Blonde" shale (figures 10 and 25(b)). It is suggested the blonde coloration arises from the presence of the sulfate mineral, jarosite as a product of pyrite weathering (R. Grauch,USGS, oral communication, 2006). The "Mancos Blonde" is most well developed in shale slopes on gravel-capped mesas, immediately below the gravels. Such weathering zones are not dependent on shale stratigraphy. In addition, thin "blonde" zones occur lower in the section where limestone beds are exposed to weathering. Seams of gypsum, both fibrous and crystalline (selenite) are present throughout the unit.

Concretions are abundant in the upper part of the unit, especially at the very top, which contains a zone of abundant, reddish-brown, micritic concretions up to 6 feet in diameter (figure 27). These concretions sometimes cap a series of distinctive, sharply defined spur ridges in the upper part of the unit (as in figure 25).

The unit is equivalent to the Smoky Hill Member at Mesa Verde in southwestern Colorado (Leckie and others, 1997) and is probably equivalent to the lower and middle parts of the Smoky Hill Shale Member of the Niobrara Formation near Pueblo (Scott and Cobban, 1964). The Fort Hayes Limestone Member, which underlies the Smoky Hill Shale Member in eastern and central Colorado, was recognized in core by the USGS in the northern part of the Olathe quadrangle, but was not recognized on the basis of lithologic or biostratigraphic criteria in the Montrose East quadrangle. Molenaar and others (2002) show the Fort Hays as pinching out near Pagosa Springs.

In terms of diagnostic fossil assemblages, the entire interval contains the remains of very large, thick-shelled bivalves (figure 28). These are rarely preserved in the whole

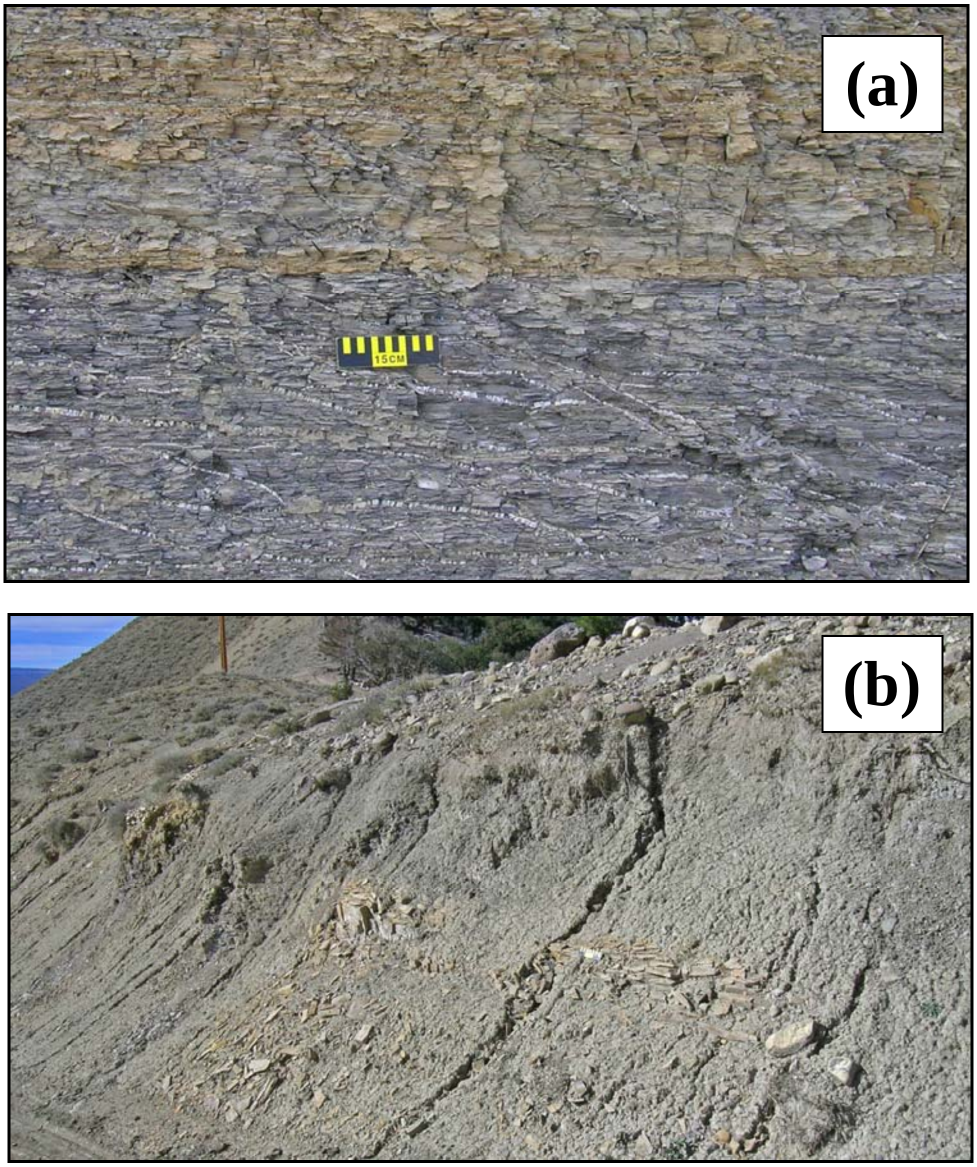

Figure 26. Smoky Hill Member of the Mancos Shale. (a) Calcareous shale with oxidized zones and abundant gypsum-filled fractures, freshly exposed by erosion at “Squaw’s Teat,” in the middle part of the unit [UTM83 256399, 4257370]. (b) Thin, discontinuous limestone bed in calcareous shale near “Chicken Wing Pass,” in the upper part of the unit [UTM83 258706, 4252337].

and most often appear as thousands of highly fragmented pieces of prismatic shell material, 0.5 to 2 cm thick, with ornamented, thickened, and curved outer edges. Some individuals appear to be quite large, and range from one to nearly eight feet in diameter. In most cases, the upper surfaces of these shell fragments are covered with colonies of the small, encrusting oyster, *Pseudoperna congesta*. Most of our collections from this

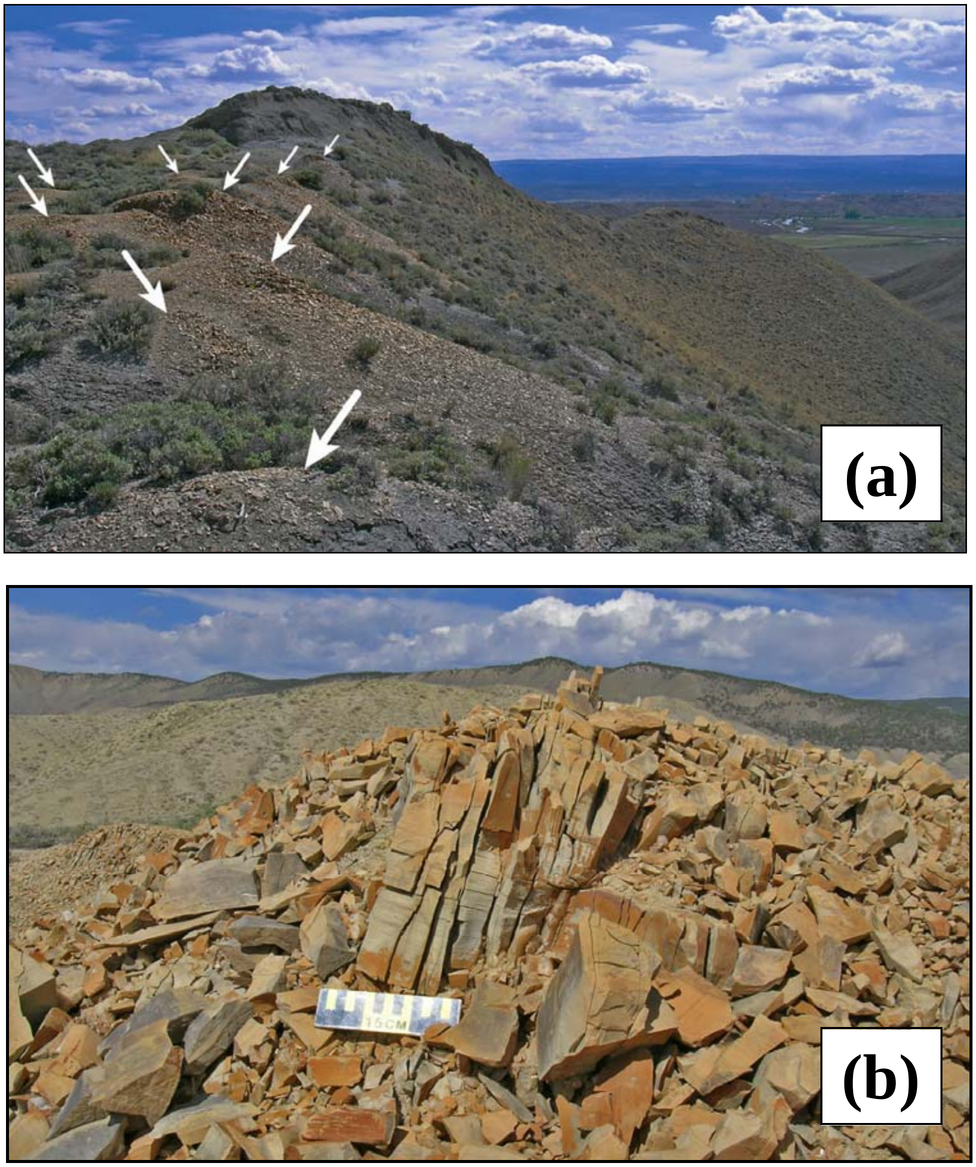

Figure 27. Concretion zone at the top of the Smoky Hill Member of the Mancos Shale. The concretions are micritic and highly fractured [UTM83 258591, 4256295]. (a) Numerous concretions along the bedding horizon, expressed as crumbling piles of micritic limestone chips in the left middleground. (b) Detail of single concretion.

unit could not be positively identified and are listed in the USGS Mesozoic fossil collection as "*Inoceramus*" *sp*., although they may represent large inoceramids such as *Magadiceramus*, *Platyceramus* (a.k.a., *I. Platinus*), or *Volviceramus* (W. Cobban, USGS, oral communication, 2006). Specimens of *M. subquadratus crenulatus* and *I. Platinus* were collected by the authors at two locations from the middle of the unit. Dickinson (1965) collected an ammonite, *Baculites asper*, from the unit in the Cerro Summit

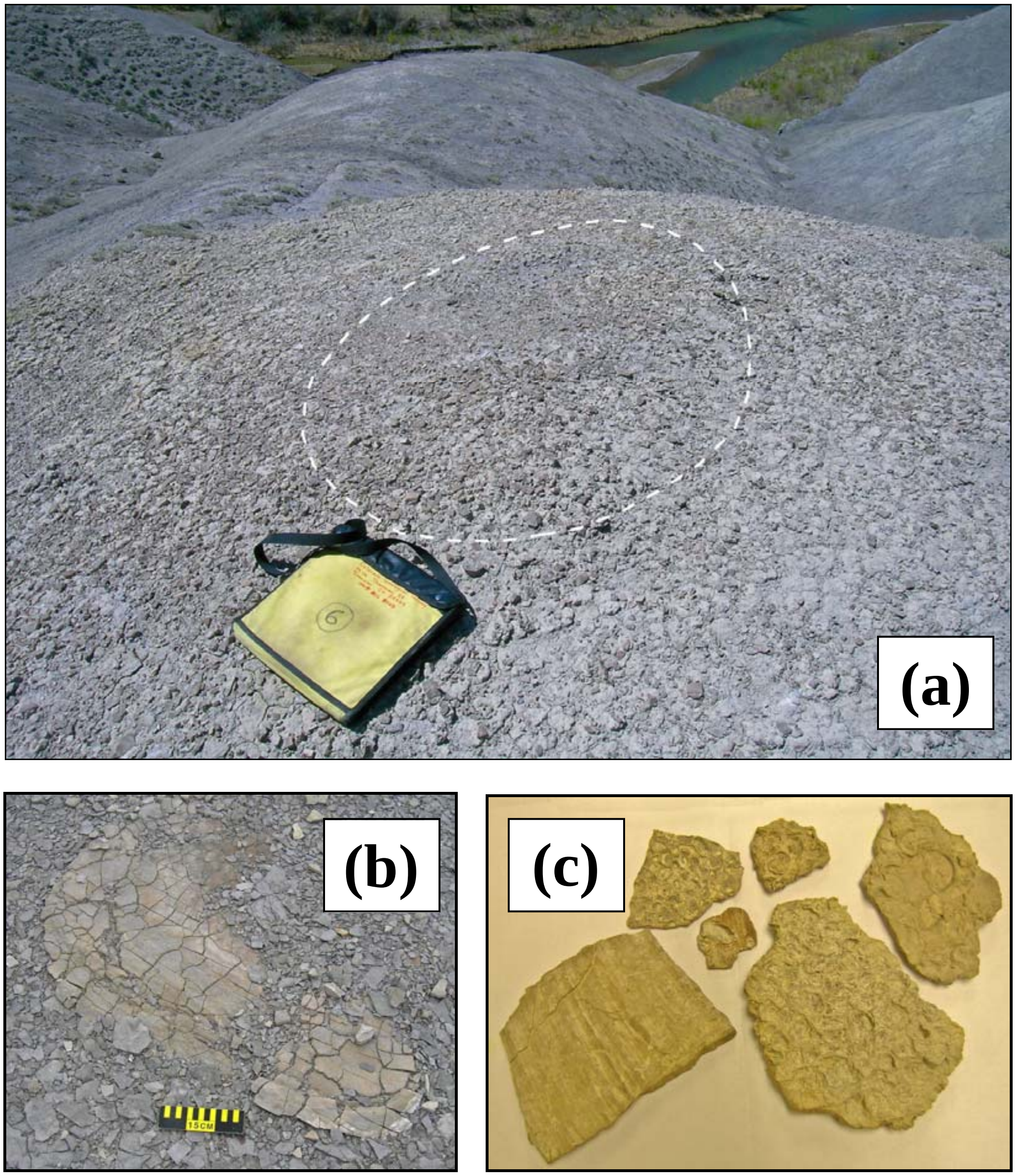

Figure 28. Large inoceramid fossils from the Smoky Hill Member of the Mancos Shale.

(a) Fragmented remains of a single, large inoceramid shell covering an area of approximately eight feet in diameter (outlined) [UTM83 252555, 4256167].

(b) Specimen of *Magadiceramus subquadratus crenulatus* [UTM83 256399, 4257370].

(c) *"Inoceramus" platinus* shell fragments up to five inches long, some of which are encrusted on their upper surfaces with irregular colonies of *Pseudoperna congesta* oysters [UTM83 255546, 4258093].

quadrangle, just to the east of the mapped area. This general collection of fossils indicates that the unit is of Middle Coniacian to Middle Santonian age (Cobban and others, 2006). The thickness of this unit is approximately 350 to 380 feet.

The upper contact of the Smoky Hill Member is sharp and possibly conformable. The lower contact with the Montezuma Valley Member, which was not positively 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 commonly forms narrow, branching ridges in the "Upper Adobe Hills" and broad, low-topography hills in the "Lower Adobe Hills." The mapped boundaries between Kms and alluvial mudflow fan deposits (Qamf) are not well defined within the "Lower Adobe Hills" area, and should be considered approximate. These boundaries are based on a change from relatively flat ground (Qamf) to slightly elevated, convex-upward slopes (Kms). It is possible that areas mapped as Kms may have capping residual or colluvial soils that could locally exceed 5 ft in thickness. Site-specific investigations are needed in this area to determine the soil thickness and the engineering properties of the soil and bedrock.

Similar to the overlying Prairie Canyon Member, the Smoky Hill Member may be prone to landsliding in areas having ground-water discharge and seepage, such as the "shale cliffs" area, the northern flanks of high mesas such as "Chicken Wing" and "Drumstick" mesas and Kinikin Heights (where irrigation of the mesa has resulted in an extensive, active landslide complex). In the dry "Adobe Hills" and the lower reaches of the "Mesa Staircase," thin-skinned landsliding and surficial creep occasionally occurs, but deeper landsliding is rare. The unit contains moderately to highly expansive clays, especially in the lower and middle, shaly, bentonitic part of the section.

Kmj **Juana Lopez and Montezuma Valley Members, undivided** — This mapping unit contains two members of the Mancos Shale: the Juana Lopez Member, which is identified in outcrops in the western, southwestern, and southern parts of the mapped area, and the overlying Montezuma Valley Member, which is mostly covered and is identified in a single location, a road cut along Otter Road near the western end of the "Mesa Staircase" [UTM83 250099, 4258545].

The Juana Lopez Member consists of light-red to reddish-yellow calcarenite and calcareous marine shale. It is moderately to highly fossiliferous and sandy, and the calcarenite beds exhibit low-angle cross bedding and laminar bedding. The bedded units probably represent distal turbidite facies (D. Anderson, Colorado School of Mines, and B. Ball, USGS, oral communication, 2006). The unit is best exposed along the edges of "Moonlight Mesa" where it forms a distinctive rim-rock of reddish-yellow cliffs (figure 29a). To the east of the Uncompahgre River, it forms a minor topographic bench at the base of

Figure 29. Juana Lopez Member of the Mancos Shale. (a) Outcrop of reddish-yellow Juana Lopez Member (Kmj) overlying black shale of the Blue Hill Member (Kmb) along “Moonlight Mesa” [UTM83 252901, 4251937]. (b) Molds of *Prionocyclus macombi* ammonites (outlined) collected from the Juana Lopez Member in the lower slopes of “Sunset Mesa” [UTM83 248940, 4259326].

the “Mesa Staircase.” The authors collected coiled ammonites (*Prionocyclus macombi*) (figure 29b), inoceramids (*I. Dimidius*), and the encrusting oyster, *Lopha lugubris*, from several outcrop and construction-site locations in the mapped area. Nearby collections by other researchers within this interval (Merewether and others, 2006) include these same fossils, plus the half-coiled ammonite, *Scaphites warreni*. These fossils establish that the unit is of Middle Turonian age (approx. 90 ma) (Cobban and others, 2006).

The overlying Montezuma Valley Member consists of gray to dark-gray, slightly fissile, silty, moderately calcareous shale, locally containing large, light-reddish-brown concretions up to 3 feet in diameter. This unit corresponds to the Montezuma Valley Member of the Mancos Shale at its type section in southwestern Colorado (as defined by Leckie and others, 1997). This unit is mostly nonresistant and covered. It was positively identified at only one location, at a recent road cut along Otter Road near U.S. Highway 550, by the presence of the inoceramid, *Mytiloides incertus*. The presence of this guide-fossil inoceramid establishes the unit as being Upper Turonian in age (Cobban and others, 2006). The upper and lower contacts of the Montezuma Valley Member were not recognized within the study area and are probably mostly covered; however, the upper boundary and regional unconformity may correspond with a break in slope with the overlying, steeper-sloped Smoky Hill Member near the base of the "Mesa Staircase," along the eastern side of the Uncompahgre River valley.

The thickness of the combined, Juana Lopez-Montezuma Valley map unit is approximately 150 feet (80 feet for the Juana Lopez Member and possibly 70 feet for the Montezuma Valley Member). These units, along with the underlying Blue Hill Member, are prone to landsliding along the edges of "Moonlight Mesa." The Juana Lopez Member is mostly non-expansive, whereas the Montezuma Valley Member contains moderately expansive clays.

Kmb **Blue Hill and Fairport Members, undivided** — This mapping unit contains two members of the Mancos Shale: the Blue Hill Member, which is identified in outcrops in the southwestern part of the mapped area, and the underlying Fairport Member, which was not positively identified in the mapped area.

The Blue Hill Member consists of light-olive-brown to dark-olive-gray, glauconitic, non-fossiliferous, non-calcareous, silty, marine shale. The upper part of the unit consists of slightly oxidized, platy, silty shale with local seams of gypsum along bedding planes and fractures. Disc-shaped septarian concretions and calcareous sand lenses occur within the upper 40 feet of this unit (figure 30). The middle part of the unit is fissile shale with distinct bedding planes. The bedding surfaces often contain abundant glauconite grains and occasional coatings of yellow residue, presumably related to sulfide (pyrite) oxidation. The glauconite and sulfides give the unit its overall olive-gray appearance on weathered surfaces. The lower part of the unit is slightly silty, wavy-bedded, fissile shale. Glauconite and sulfide decrease toward the base of the unit. Rare, calcareous, cone-in-cone structures are found within float derived from the shale and concretions.

Specimens of *Prionocyclus macombi* and *Scaphites carlilensis* were collected from this interval just to the south of the mapped area, in the Colona quadrangle (Merewether and others, 2006), which mark the unit as being Middle Turonian in age (Cobban and others, 2006). The upper contact of the Blue Hill Member with the overlying Juan Lopez Member is sharp and appears to be conformable.

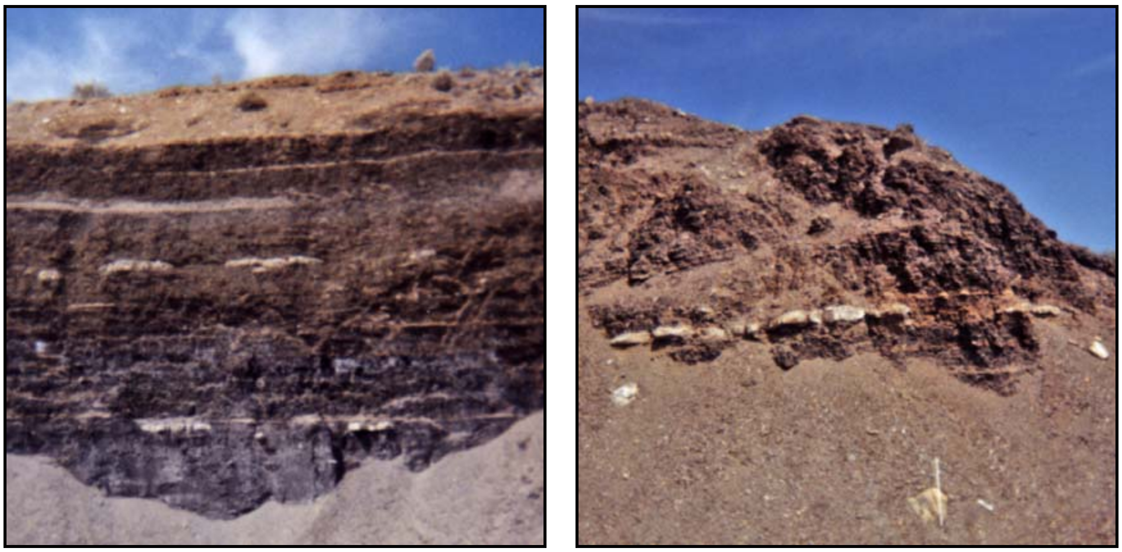

Figure 30. Two views of dark shale and light-colored, sandy concretions of the Blue Hill Member exposed in a cut above the West Canal, along the eastern side of "Moonlight Mesa" [UTM83 257684, 4263698]. The staff at the bottom of the right-hand photo is 1 m high.

The Fairport Member was not specifically identified by biostratigraphy and is probably covered in the mapped area. It is mentioned here to retain consistency with the sections described in the Front Range Piedmont near Pueblo (Scott, 1969) and in southwestern Colorado (Leckie and others, 1997). In those reports, the Fairport Member consists of fossiliferous, calcareous shale with numerous, thin bentonite beds and limonite seams. Leckie and others (1997) suggested that an interval of condensation or a surface of erosion may separate the Fairport and Blue Hill Members. It is possible that the Fairport Member may be erosionally removed in the Montrose area. Just to the north, Sawyer and others (in prep.) did not specifically identify the Fairport Member at the Gunnison Gorge National Conservation Area, nor was it identified just to the south of the mapped area (Merewether and others, 2006). However, marine fossils from the Fairport Member were identified in the subsurface from a USGS core in the northern part of the Olathe quadrangle (W. Cobban, USGS, oral communication, 2006).

The thickness of the combined, Blue Hill-Fairport map unit is approximately 215 feet, on the basis of a section measured at the southern end of "Moonlight Mesa," just to the south of the mapped area (Merewether and others, 2006). These units, along with the overlying Juana Lopez Member, are prone to landsliding along the edges of "Moonlight Mesa." The Blue Hill Member contains moderately expansive clays.

Kmg **Graneros Member and Bridge Creek Limestone Member, undivided** — This mapping unit contains two members of the Mancos Shale: the Bridge Creek Limestone Member and the underlying Graneros Member, which are identified in outcrops in the Duckett Draw area in the southwestern part of the mapped area.

The Bridge Creek Limestone Member occupies the upper 35 feet of the mapped unit. It consists of interbedded, thin and wavy-bedded limestone, calcareous shale, and marlstone. These layers are dark gray in fresh exposures and weather to light gray to light olive-gray. The unit appears as a whitish band on aerial photos. It is equivalent to the Bridge Creek Limestone Member of the Greenhorn Limestone in the Front Range Piedmont and the Great Plains (Cobban and Scott, 1972) and the Bridge Creek Limestone Member of the Mancos Shale in southwestern Colorado (Leckie and others, 1977). No fossils were found within the mapped area; however, *Pycnodonte newberryi* bivalves were collected from the same strata just to the south, in the Colona quadrangle (Merewether and others, 2006). This fossil falls within the *Mytiloides hattini* inoceramid zone and the *Nigericeras scotti* ammonite zone, which indicate an age of Upper Cenomanian to Lower Turonian (Cobban and others, 2006). The Bridge Creek Limestone Member represents the maximum extent of marine transgression within the Cretaceous Western Interior Seaway (transgression T-1 of Molenaar, 1983).

The Graneros Member occupies the lower 100 feet of the mapped unit. It consists of olive-gray, slightly calcareous, marine shale that commonly weathers to small platy chips. Discontinuous, 8-inch-thick limestone beds occur in the middle and base of the unit in the nearby Olathe quadrangle (Morgan and others, 2007). Most of the unit has distinct bedding planes that may be lined by gypsum crystals. Glauconite and disseminated sulfide is locally present within the upper half of the unit. Much of the outcrop is covered with thin residuum or gravelly slope wash. We did not collect any fossils from the Graneros Member. Previous researchers collected the bivalves *Pycnodonte* aff. *kellumi* and *Plicatula sp.* from the area (Merewether and others, 2006). These fossils indicate an age of Upper Cenomanian for the unit (*pre-I. pictus*, greater than 94 ma) (Leckie and others, 1997; Cobban and others, 2006). The Graneros Member is a time-transgressive unit. It is younger in this area of western Colorado than in the Front Range, where the base of the type section of the Graneros Shale is Middle

Cenomanian in age (*Acanthoceras ampnibolum* to *A. granerosense*, 95-96 ma) (Cobban and Scott, 1972; Cobban and others, 2006). The Graneros Member in southwestern Colorado (including the Montrose East quadrangle) is roughly age equivalent with the Hartland Shale Member of the Greenhorn Limestone in the Front Range area (Leckie and others, 1997).

The thickness of the Graneros-Bridge Creek map unit is approximately 135 feet. These units are prone to extensive landsliding along the eastern edge of Sims Mesa and other smaller, unnamed mesas in the far southwestern corner of the Montrose East quadrangle. The Bridge Creek Member contains slightly expansive clays separated by non-expansive layers, whereas the Graneros Member contains moderately to highly expansive clays.

Kdb **Dakota Sandstone and Burro Canyon Formation, undivided (Upper to Lower Cretaceous)** — This mapping unit contains two formations that are typically mapped together in western Colorado: the Upper Cretaceous Dakota Sandstone and the underlying Lower Cretaceous Burro Canyon Formation. Only the upper part of the Dakota Sandstone is exposed in the far southwestern part of the Montrose East quadrangle, in scattered outcrops in the Duckett Draw area.

The Dakota Sandstone at Duckett Draw is composed of light-brown to pinkish-gray, well sorted, very fine- to medium-grained, structureless to cross-bedded sandstone interbedded with light-brown mudstone and black carbonaceous shale (figure 31a). Symmetrical ripple marks and burrows (typically *Thalassinoides*) are present along some bedding planes, and there are irregular areas of near-complete bioturbation along or within some of the sandstone beds (figure 31b). The paleoenvironmental setting for this unit includes nearshore, shoreface, tidal flat, coastal plain, and peat swamp environments. It was deposited in an overall transgression during the initial incursion of the Cretaceous Western Interior Seaway across the North American continent.

No fossils were collected from the Dakota Sandstone within the mapped area. Previous researchers collected fossils from nearby, within the Montrose West and Government Springs quadrangles, from the guide-fossil zones of *Colinoceras terrantense* and *Plesiacanthoceras wyomingensis* (Merewether and others, 2006). These zones establish that the unit is of Middle Cenomanian age (95 to 96 ma) (Cobban and others, 2006). The Dakota Sandstone is a time-transgressive unit. It is younger in the mapped area than in the Front Range, where it is Late Albian in age (McGookey and others, 1972). The Dakota Sandstone in the Montrose East quadrangle is roughly age equivalent with the type Graneros Shale in the Front Range area (Cobban and Scott, 1972). The Dakota Sandstone is approximately 100 feet thick in the nearby Olathe quadrangle (Morgan and others, 2007).

Although the Burro Canyon Formation is not exposed anywhere in the mapped area, it probably exists in the shallow subsurface beneath the Dakota Sandstone outcrops. This sandstone, conglomerate, and mudstone unit is fluvial in origin. It is of

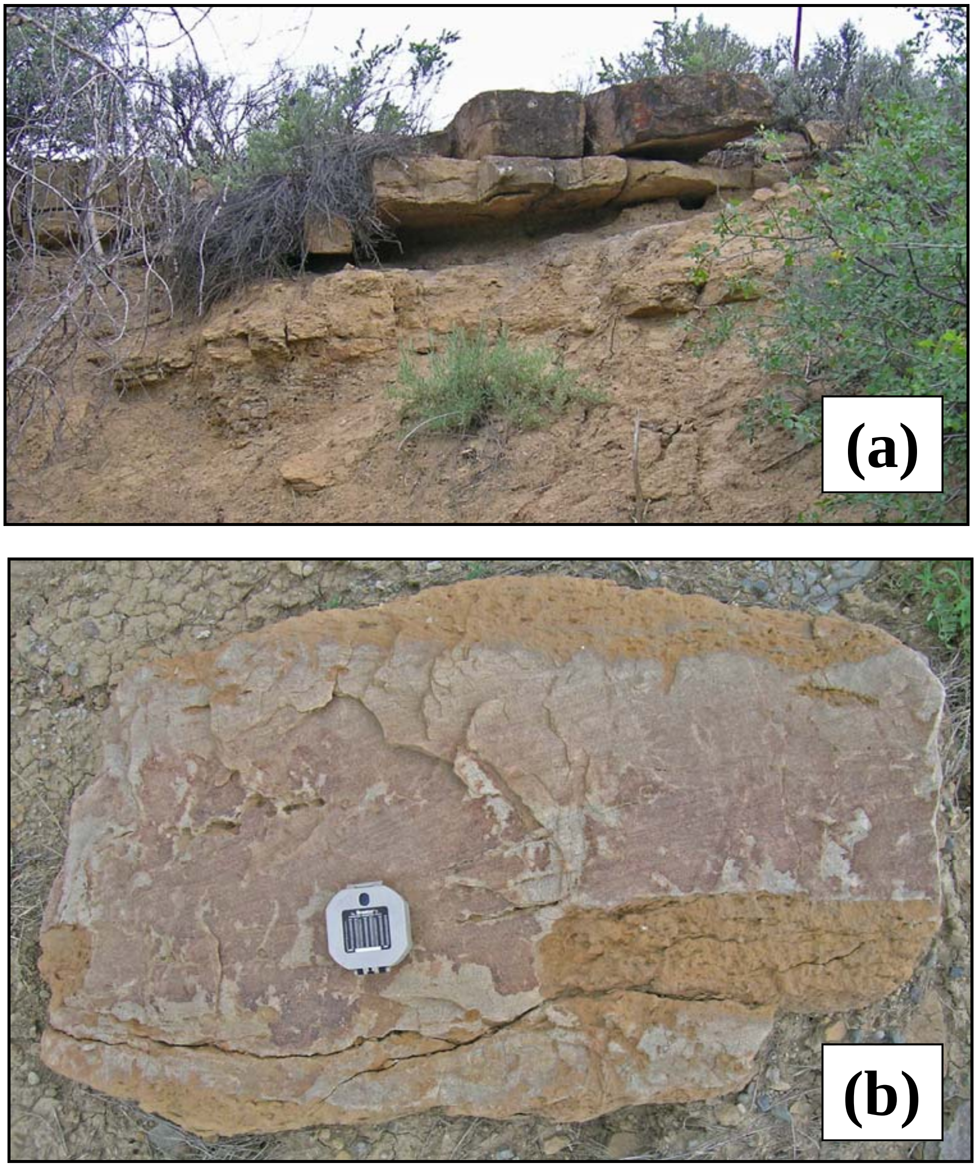

Figure 31. Dakota Sandstone. (a) Outcrop of interbedded sandstone and mudstone in an arroyo along Solar Road, near Duckett Draw. (b) Boulder of cross-bedded sandstone with oxidized areas of heavy bioturbation. [UTM83 249971, 4252358]

Early Cretaceous (Albian-Aptian?) age in southwestern Colorado (Molenaar and others, 2002, section D-D'). The Burro Canyon Formation is approximately 25 feet thick within the nearby Olathe quadrangle (Morgan and others, 2007).

Only the uppermost 30 to 40 feet of the 125-foot-thick Dakota Sandstone and Burro Canyon Formation are exposed within the Montrose East quadrangle. The top of the unit forms a resistant bench that may serve as a stable base beneath the extensive landslides in the overlying Graneros Member of the Mancos Shale. This contact is typically covered. Mudstone layers within the Dakota Sandstone may contain slightly to moderately expansive clays.

The following formations do not crop out within the Montrose East quadrangle. However, based on regional geologic mapping descriptions, they are known to underlie the Dakota Sandstone and Burro Canyon Formation and are included as subsurface units in the geologic cross-section for this quadrangle (Plate 2). The reported thickness values are from Tweto and others (1976) and Kellogg (2004).

Jm **Morrison Formation (Upper Jurassic)** — shown on cross-section plate only. Thickness: 450 to 500 feet.

Jw **Wanakah Formation (Middle Jurassic)** — shown on cross-section plate only. Thickness: 50 to 300 feet.

Je **Entrada Sandstone (Middle Jurassic)** — shown on cross-section plate only. Thickness: 75 to 85 feet.

Pc **Precambrian Rocks** — shown on cross-section plate only.

STRUCTURAL GEOLOGY

The cross-section plate shows the general structural geology of the Montrose East quadrangle. The Montrose syncline, a gentle synclinal fold, trends roughly northwest to southeast through the far northeastern corner of the quadrangle. This structure may by caused by folding of the Mancos Shale over a blind fault in the subsurface or possibly the result of compression from the adjacent Uncompahgre and Gunnison uplifts (figure 3). The syncline is quite broad. Strata within 3 to 4 miles on both sides of its axial trace have shallow dips of 1 to 3 degrees, mainly toward the axis. Farther away from the axis, the strata in the southwest part of the quadrangle have slightly steeper dips ranging from 5 to 12 degrees. Those strata reflect the northeast- to east-dipping surface of the Uncompahgre uplift. Eccentric dip orientations are found in a few locations, associated with upper portions of steep topographic slopes. The strata at these locations appear to dip toward the modern valleys. It is possible that the shales have undergone some amount of localized, near-surface, down-slope creep, with the bedding sagging toward the valleys. In certain places, these eccentric bedding orientations may be indicators of slump blocks or other slope failures.

The Uncompahgre uplift is a faulted and tilted basement block. It is thought to be the result of movement along bounding basement faults during the Late Cretaceous-Paleocene Laramide orogeny (Stone, 1977; Tweto, 1977). Additionally, researchers such as Cater (1966) and Steven (2002) postulate that additional uplift occurred during the late Cenozoic. The uplift and tilting of this basement block and its sedimentary cover created shallow easterly dips of the Cretaceous rocks across much of the mapped area.

The Gunnison uplift, which is located several miles beyond the northeastern edge of the mapped area, is the result of high-angle movement of basement blocks during Laramide and possibly late Cenozoic time. The core of the uplift consists of a series of northeast-tilted basement blocks, bounded on its western side by the Red Rocks and Cimarron reverse faults (Hansen, 1971). Neither of these faults is exposed in the mapped area. Deformation along the western margin of the Gunnison uplift created gently to steeply dipping folds that warped the overlying Cretaceous rocks in the Red Rock Canyon and Olathe quadrangles (Hansen, 1971; Morgan and others, 2007). Steeply dipping strata are absent from the Montrose East quadrangle.

Some authors cite evidence for recent uplift in the Black Canyon of the Gunnison. Hansen (1987) postulated that cutting of the canyon commenced about 2 million years ago. This is based on the presence of Pleistocene terrace gravels along the Black Canyon and Miocene-Pliocene gravels containing Hinsdale Formation volcanic clasts near the head of the Canyon. He suggested that recent uplift along faults during the Quaternary caused increased rates of down-cutting within the canyon. Recent work by Karl Karlstrom and students (Schneeflock and others, 2002; Sandoval and Karlstrom, 2006) stated that knickpoint migration within the Black Canyon may be the result of neotectonics or modification of drainage networks. Currently this is a topic of great interest and continued research will undoubtedly yield additional clues to the origin of the Black Canyon of the Gunnison.

Large-displacement faults are not recognized within the Montrose East quadrangle. The largest fault that we mapped passes through the far northeast corner of the mapped area. This normal fault is oriented northwest to southeast and is downthrown to the southwest. Strata from the middle of the Lujane Point shale unit of the Mancos Shale are downthrown against an unknown interval within the Prairie Canyon Member of the Mancos Shale. This constrains the offset to be on the order of 300 to 500 feet.

Smaller faults may be present in other parts of the quadrangle, although the residual-colluvial skin that typically covers the Mancos Shale precludes recognition of fault planes. In the southeastern part of the mapped area, just to the east of the Uncompahgre River valley, a resistant bench underlain by the Juana Lopez and Blue Hill Members of the Mancos Shale appears to be offset against an area underlain by the lower part of the Smoky Hill Shale Member. The trend of this fault, which is concealed by valley-floor mudflow deposits, is southwest to northeast, and the offset is on the order of 100 feet. There is a corresponding, 80-foot offset of the base of the Prairie Canyon Member of the Mancos Shale along this trend, on the upper slopes of the western face of "Chicken Wing Mesa."

Numerous small-displacement faults may be present within the "High Adobe Hills" section of the mapped area. They are recognized along the ridgelines, at places where the contact between the Prairie Canyon Member of the Mancos Shale and the underlying Smoky Hill Member abruptly drops on the order of 40 to 100 feet in elevation. This is typically accompanied by a widening of the ridge on the down-dropped side. These inferred normal faults appear to have generally northwest to southeast orientations. They define a number of bedrock blocks that have undergoing step-like down dropping toward the west. Another possible explanation is that the stratigraphic contact is deeply erosional, and that the Prairie Canyon sandy shales are filling sub-sea paleovalleys. However, this is unlikely because the top of the Smoky Hill Member consists of a zone of distinctive concretions throughout the mapped area, and a similar, conformable, transition sequence of beds is seen at all locations (that is, there does not appear to be any channeling of the boundary).

A normal fault of unknown displacement is recognized along the southern edge of "Dry Cedar Creek Basin" (figure 32), within the Smoky Hill Member of the Mancos Shale. The fault trace is sharp and continuous over several hundred feet, and no landsliding is evident. It appears that the southern basin margin may be structurally down-dropped along this fault trace with respect to the topographically higher Kinikin Heights. The eastern and northern margins of this topographically low basin may be fault bounded as well. Similarly, it is possible that other topographic basins within the mapped area may be fault bounded.

Faulting may be necessary to explain the eastward jog of the Shinn Park-Bostwick Park paleovalley system (in which the map unit Qg_3, valley-fill sequence was deposited) during middle Pleistocene time. An abrupt, northeastward shift of the generally north-trending paleovalley occurred between the locations of today's "Chicken Wing Mesa" and Shinn Park (figure 3). This valley cut into the apron of an existing alluvial-fan complex (map unit Qg_4) along the margin of the Cerro Summit-Cimarron Ridge highlands. It is unlikely that a river system would cut through an alluvial-fan apron because of the low topography of such fan deposits. It is possible, however, that reactivation of a fault along this trend might cause a part of the fan apron to down drop, thus creating a topographic corridor for the river to follow. This area of down dropping may be evident along the mountain front of today's Cerro Summit-Cimarron Ridge highlands, along a southwest to northeast trend that links the eastern sides of "Chicken Wing Mesa" and Kinikin Heights. This trend is aligned with the trend of previously mentioned faults that run from southwest to northeast between the valley of the Uncompahgre River and the western face of "Chicken Wing Mesa."

Figure 32. Inferred shale-on-shale, down-to-basin, normal fault trace along the southern margin of "Dry Cedar Creek Basin." Fault trace is shown in black, and a possible, exposed, steeply dipping fault-plane surface is highlighted in yellow. [UTM83 256837, 4255213]

GEOLOGIC HAZARDS

Bedrock and soil structure, hydrogeology, topography, surface drainage, and lithology are important controls on the development of geologically hazardous areas within the Montrose East quadrangle. Landslides within the Mancos Shale affect portions of the western part of the quadrangle where residential development is increasing. Mudflows and hydrocompactive and swelling soils are also impacting residential and commercial structures throughout the area. Other significant and potentially damaging hazards in the mapped area include earthquakes, rockfall, and erodible and corrosive soils.

LANDSLIDES

Landslides are prevalent on the slopes flanking the high, gravel-capped mesas in many parts of the quadrangle. The landslide debris in these areas is almost exclusively a mixture of weathered Mancos Shale and gravelly alluvium. The slope failures are mainly rotational and translational slides where failure typically occurs along a vertical or nearly vertical system of fracture planes and weak, gently dipping bedding planes. These fractures may become exposed from desiccation of the surface soils and/or removal of the resistant gravel cap. Water seeping into the cracks may cause dispersion of less-resistant clay layers or dissolution of gypsum within the fractures (piping). The resulting landslides typically occur along gullies or steep hillsides where runoff can accelerate and move particles out of the soil or bedrock (Selby, 1993).

Occurrence of landslides within the Montrose-Delta region of the Uncompahgre River valley is accelerated by agricultural practices where runoff from irrigated farmland seeps into and lubricates open fractures, resulting in slope failures. This is evident along the northern slopes of the middle mesa at Kinikin Heights, along Dry Cedar Creek, which are undergoing active landsliding (figure 33). The mesa top is intensely irrigated for agriculture, and runoff typically flows over or seeps from the mesa sides.

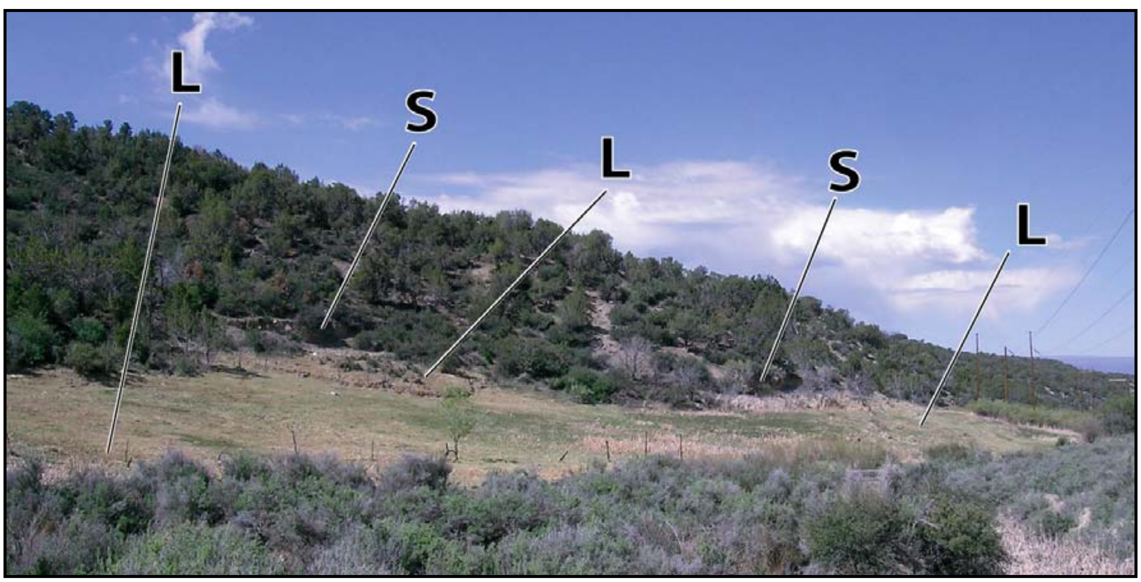

Figure 33. Apron of active landslides forming hummocky topography along the base of Kinikin Heights. The active nature of this landslide complex has been influenced by water from the irrigated mesa top [UTM83 259473, 4255255]. Several intermediate scarps (S) and lobes (L) are evident, as well as seep areas marked by greener shrubs above the meadow.

The highest potential for damaging landslides in the Montrose East quadrangle is found along the slopes of "Moonlight Mesa" and Sims Mesa, in the southwestern corner of the mapped area. Pervasive and extensive landslide complexes, formed within the Graneros Member of the Mancos Shale, blanket the eastern slopes of Sims Mesa and other nearby mesas. At least one large-lot subdivision with several tens of houses was built upon this landslide complex in the early 1990s. The performance of houses in this subdivision is not known. The longer-term stability of houses built on this landslide may depend on both the global (overall) stability of the slide mass (influenced by natural variations in precipitation) and local slope-cutting and water-management (site-irrigation) practices. Further development on this landslide, especially to the north where the North Canal cuts across the complex, should be avoided.

Several houses have been built on the landslides that ring "Moonlight Mesa," and two regional water canals cross portions of the landslide complex. Although these landslides are smaller than those at Sims Mesa, they are still capable of undergoing damaging movements. A number of houses built along the top of "Moonlight Mesa" have incurred damage from ground movements. These houses were built near the outer edges of the mesa (as "view lots"). In discussions with local geotechnical practitioners, two potential mechanisms of failure have been proposed: (1) landsliding and slope failure along the outer edges of the mesa, or (2) settlement of gravelly soil associated with the Qau_3 terrace-capping alluvial deposit. The unclear nature of the potential mechanisms of the failures illustrates the need for careful geotechnical assessments of soil and slope stability before future building occurs in near-slope areas.

It is important to recognize that landslide deposits do not always display a characteristic surface morphology, and related features such as head scarps and toe bulges may be covered or missing. Two examples of landslides that might not be easily recognized in typical geotechnical investigations are shown in figure 34. Figure 34a shows a deep, gravelly landslide beneath a hilltop at the northern tip of "Moonlight Mesa." There is no head scarp at the ground surface. Although this landslide is "old" (that is, the hilltop was higher when the landslide was formed and has since eroded away), it still has the potential to be reactivated. A house, to the right of the photo, was built in a cut and rests on the slide plane, which has reactivated as a failure surface. The part of the house built on shale has not moved, while the part built on the landslide has moved, causing serious structural damage. Geologists and geotechnical engineers performing drilling investigation on the slopes and edges of these mesas where shale is expected should look for anomalous, deep pockets of gravelly clays that may signify a buried landslide of this type. Figure 34b shows the toe of a landslide in a road cut near the northern end of Sims Mesa. The landslide toe consists of a deformed block of shale that slid for several hundreds of feet over undeformed, in-place shale. It is quite possible that a typical geotechnical site assessment done with auger drilling would not recognize a landslide in this situation. In the case of shale-on-shale landslides, it is important to look for clues when drilling, including changes in the weathering state

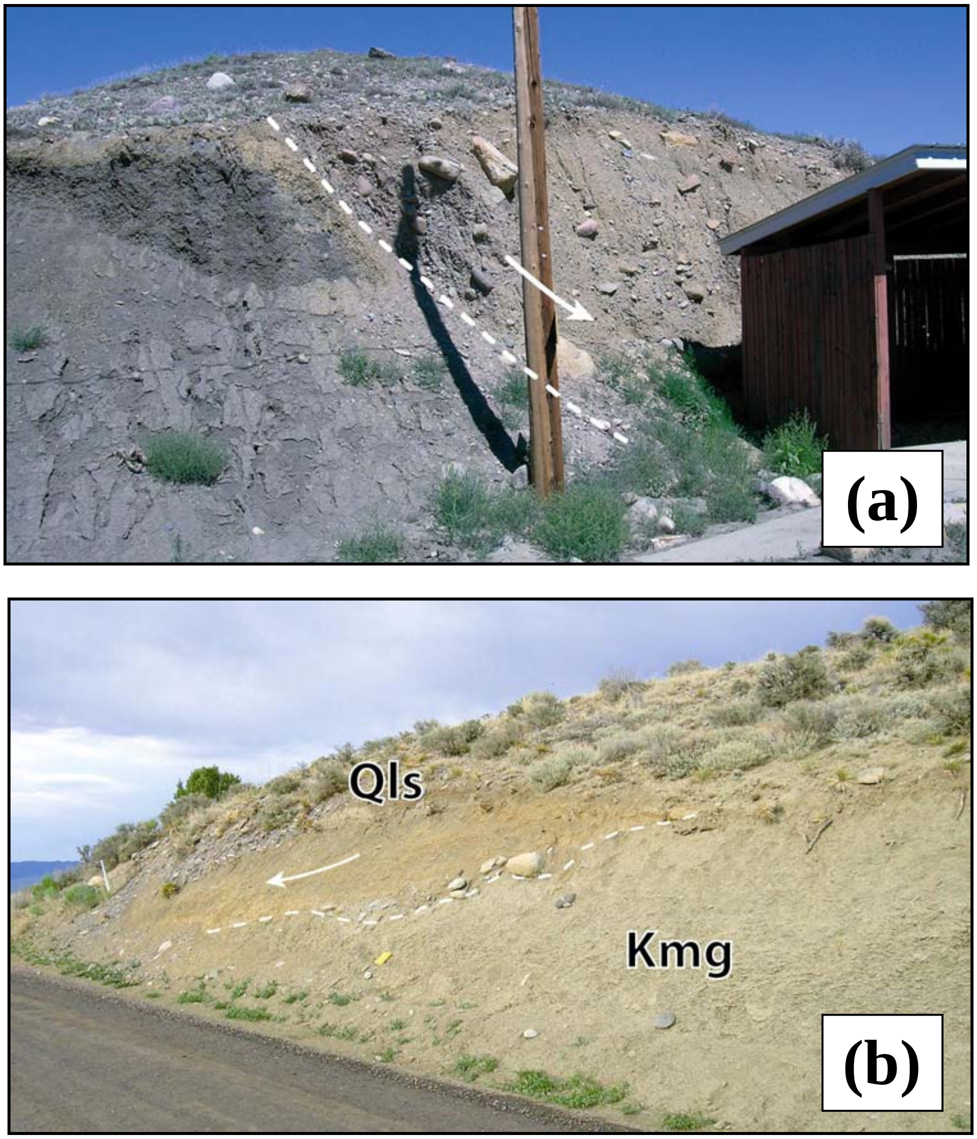

Figure 34. Cut slopes showing landslides in cross-section. (a) Circular landslide failure surface against shale, uncovered in a slope cut near the northern tip of "Moonlight Mesa." Note the rotated, near-vertical cobbles near the failure surface, and the lack of a geomorphic scarp at the ground surface [UTM83 250112, 4254812]. (b) Shale-on-shale slip plane containing anomalous gravel, exposed in a road cut at the edge of the Sims Mesa landslide complex, to the west of the mapped area [UTM83 248039, 4255300].

of the shale, changes in bedding dip, presence of disturbed shale, presence of perched ground water, and/or presence of anomalous gravel lenses or clasts. All of these may indicate the presence of a landslide slip plane that could be reactivated after development. This photo illustrates the importance of recognizing slip planes within similar lithologic sequences and identifying the presence of transported shale blocks.

Much of the eastern part of the quadrangle lies within federal (BLM) lands, and the mapped landslides within those areas pose minimal hazards in general. However, it is possible that landsliding may affect roads, canal, and power line alignments that cross BLM lands. In particular, the building of engineered structures upon the earthflow-type landslides along the front of the "Shale Cliffs" and the Cerro Summit-Cimarron Ridge highlands should be avoided.

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 increases, and it incorporates additional materials into the flow. Once the flow reaches an area of lower gradient, the flow drops its load and the suspended sediment is deposited at the mouth of the drainage. Debris flows can form at any point along a drainage including on the sides of valleys. They are the result of torrential rainfall or very rapid snowmelt runoff, where sediment supply is abundant and easily mobilized (Selby, 1993).

Much of the Montrose East quadrangle consists of mud-dominated alluvium and alluvial fan deposits (Qamf). These deposits were derived mostly from the Mancos Shale and were deposited as mudflows or mud-and-gravel debris flows in channels or in local drainage basins. In addition, alluvial-fan deposits (Qf) occur over the southwestern part of the mapped area where drainages are more confined and coarser sediment is available for transport. Small, localized debris flows occur in areas mapped as alluvium and landslides (Qls); however, these debris flows are typically of limited extent and are not mapped separately. Residents living within or in close proximity to these deposits and their associated drainage ways should be aware of the possibility of large precipitation events triggering future debris flows that may inundate these areas with dangerous amounts of water and sediment. Active debris flows and mudflows are occurring within the mapped area under modern conditions (figure 35).

ROCKFALL

Rockfall deposits are included in the landslide (Qls) and other Quaternary alluvial units in the Montrose East quadrangle. Much of the rockfall hazard occurs along the mesa edges where loose cobbles and boulders overlie unconsolidated Mancos Shale. Typically, the hazard is limited to the rolling of single or small numbers of gravel or boulder clasts down a hill. Large precipitation events and freeze-thaw processes may trigger rockfall. Areas mapped Qls and Qa_ at the base of gravel-capped hillslopes may be susceptible to future rockfall events; developers and homeowners should be cautious when building in proximity to these areas.

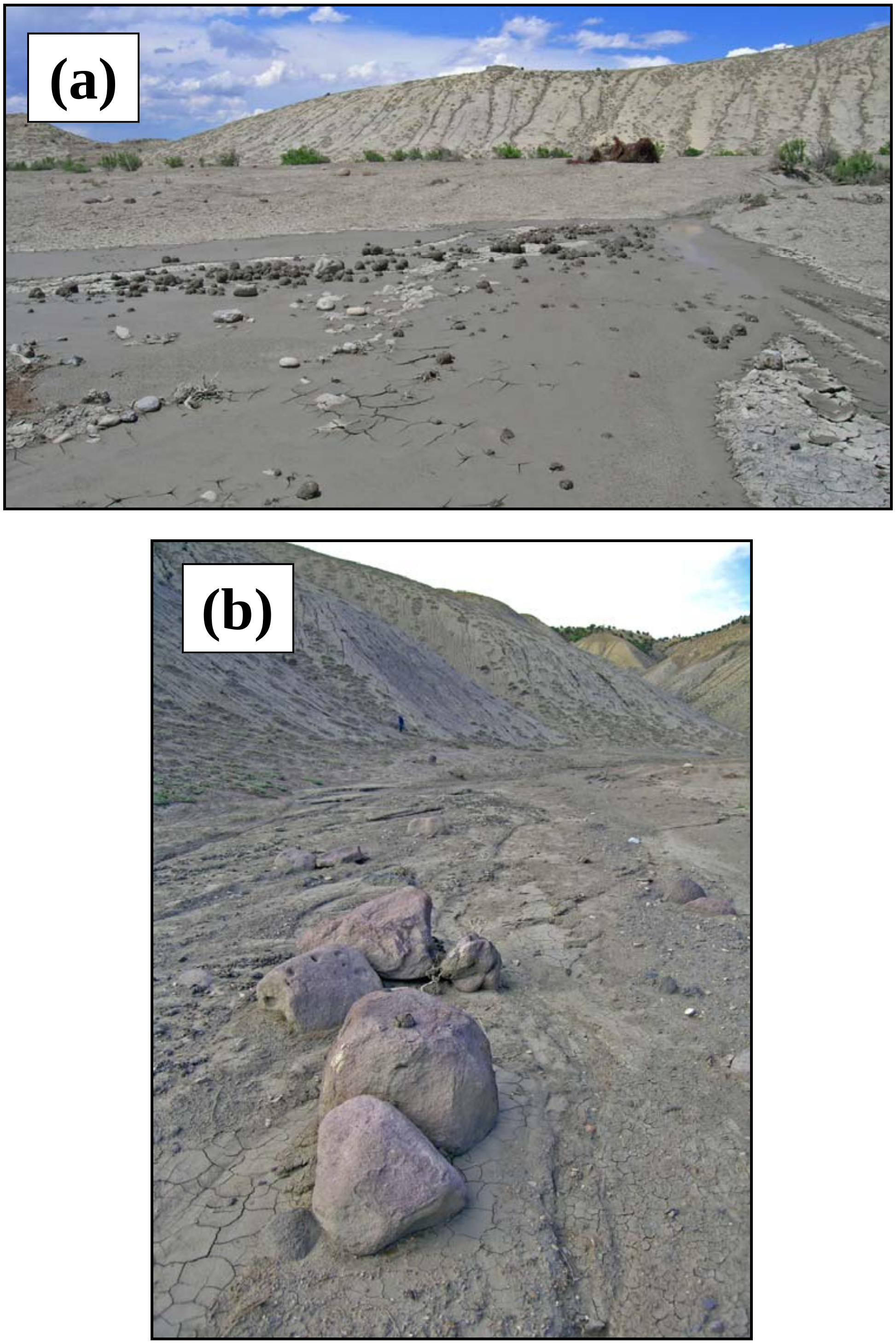

Figure 35. Recent mudflow deposits in the "Shale Cliffs" area that resulted from heavy rainstorms during the summer of 2006 [UTM83 259182, 4264256]. (a) Low-gradient mudflow fan with mud-encrusted gravel clasts at the mouth of a tributary valley. (b) Purple volcanic-tuff boulders that were entrained in the mudflow, which covered the valley floor.

EARTHQUAKES

The largest instrumentally recorded earthquake in Colorado history occurred on October 11, 1960. It was measured at magnitude 5.5 with an epicenter approximately 15 miles southeast of Montrose (Kirkham and others, 2004). Montrose and other nearby areas incurred intensity VI damage. Today, an event of this magnitude would cause approximately $23 million in damage (Colorado Geological Survey, 2008, unpublished HAZUS modeling data).

In May 1992, an earthquake of magnitude 2.8 occurred approximately 5 miles southeast of Olathe. On January 13, 1962, a magnitude 4.4 event occurred approximately 6.5 miles southwest of Montrose (Kirkham and others, 2004). Both events were felt at intensity IV in and around Montrose. The Olathe event epicenter lies along trend with the Cimarron and Red Rocks faults, which are suspected to have middle to late Quaternary movement (Lettis and others, 1996).

Additional information on faulting and earthquakes in this area is available in the CGS Colorado Earthquake Map Server (Kirkham and others, 2004) and 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, as well as surficial units derived from the Mancos Shale, may undergo volumetric swelling when wetted. This is due to the presence of smectite, an expansive clay mineral. Smectite is prevalent in marine shales of Cretaceous age in the North American mid-continent. Upon wetting, these clay minerals, which are relatively dry under natural climate conditions, draw water into their crystal matrices and expand to accommodate the added water molecules (Noe, 2007). The expansion of clays results in ground heaving with significant force that can potentially cause damage to residential, private, and public buildings, paved roads, concrete flatwork, and underground utility pipes.

In the Montrose East quadrangle, the Graneros, Blue Hill, Montezuma Valley, Smoky Hill, Prairie Canyon, and Sharon Springs Members and Lujane Point shale unit of the Mancos Shale contain clay-rich zones that may be prone to swelling in near-surface bedrock. The Graneros Member, in the Dudley Draw area, and the lower to middle parts of the Smoky Hill Member in the "Low Adobe Hills" area to the east and southeast of the city of Montrose, appear to be particularly swell prone. Derived soils, particularly the alluvial mudflow (Qamf) and the muddy, upland mudflow-gravel deposits (Qg_1 to Qg_4), may contain pockets or zones of swelling clays.

Geotechnical practitioners in the area have commented that the fine-grained alluvial soils along Dudley Draw and Horsefly Creek, in the southwestern part of the mapped area, have particularly high swell potentials. This may be due to erosion, transport, and deposition of highly expansive clay materials derived from the Dakota Sandstone and Morrison Formations, from the slopes of the Uncompahgre Plateau (L. Hauptmann, Buckhorn Geotech, oral communication, 2007).

According to geologists and engineers from many of the local geotechnical companies, 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. Swell-prone soil and rock are indicated in surface exposures by evidence of clay shrinkage and swelling, such as mud cracks and "popcorn" crusts (figures 20a and 36).

On the topic of site exploration for expansive soil and bedrock, the following cautions are offered by Buckhorn Geotech (oral communication, 2007):

> *"We have found that there is considerable variability in the plasticity and swelling potential of the Mancos Shale both laterally and vertically, even in a short distance and even within the same member. We have seen huge variations in swelling potential from lot to lot within a subdivision as well as from near the surface to a basement depth. We have not found it possible to make any blanket statements about the physical properties of the "black shale" or "blonde shale", etc. As a consequence, site-specific testing using a backhoe or drill rig is imperative to determine the range of properties and potential groundwater issues for each building site.*
>
> *Surface indicators of swelling potential, such as desiccation cracks or popcorn crusts, may not be representative of the soil conditions at depth. In addition, often the shale that appears like an unweathered and hard rock at depth may slake to a weak and crumbly rock when exposed at the surface for a few days. Simple soak tests, where a sample of shale is placed in a bucket of water for 3 to 4 days, can be a visual indicator of expansive shale. Some [samples] immediately react with water and "blow" apart, some become soft and break easily, while others have no reaction. Lastly, we have found that coring the solid shale and placing the "rock" in a swell/consolidation machine can be a good test of the true swell potential of the shale."*

Figure 36. “Popcorn” texture in thin, residual soils covering the middle part of the Smoky Hill Member of the Mancos Shale in the “Popcorn Hills” area [UTM83 255546, 4258093]. This texture is formed by multi-cyclic swelling and shrinking due to wetting and drying of bentonitic clay from the shale.

COLLAPSIBLE SOILS AND BEDROCK

Both the Mancos Shale and surficial units derived from the Mancos Shale may be prone to collapse. Where weathered Mancos Shale occurs in the shallow subsurface, gypsum crystals typically form along bedding planes and fractures (as in figure 26a). The crystal growth can create pressures that force or wedge apart bedding planes and fractures, causing the rock to heave. Upon further wetting, subsequent dissolution of the gypsum can create micro-pipes and subsurface voids that may cause the weathered claystone to collapse or recompress when loaded (White and Greenman, in prep.).

Surficial deposits derived from the Mancos Shale are especially prone to surface collapse due to hydrocompaction and dispersion. In these deposits, which are typically dry under modern climatic conditions, the addition of water causes soil-binding agents to weaken and the loose soil skeletal fabric to collapse, allowing the soil particles to reorient into a more compact structure. This often results in ground settlement. Collapse typically occurs in silt-rich, matrix-supported deposits, such as mudflow (Qamf) and mud-dominated, gravelly debris-flow deposits, where clay- and silt-sized particles dominate the matrix. In addition, dissolution of gypsum within these deposits may also contribute to collapse.

Dispersion is a form of piping erosion and is a function of the mineralogy and specific soil chemistry. In the presence of fresh water, clay and silt particles easily mobilize and begin to flow. Pseudokarst land features, such as sinkholes, pipes, soil bridges, and other subsurface voids are typical manifestations of soil dispersion in these collapse-prone units, including fine-grained, artificial fill (figure 37). Some of the voids are large enough to engulf people, cattle, and farm implements. Soils that are susceptible to hydrocompaction and dispersion-collapse phenomena may exist in areas mapped as alluvial fan (Qf), alluvium (Qa), mudflow (Qamf), and mud-rich, gravelly debris flow deposits (Qg). A few older, earthen dams across narrow tributary stream valleys in the area have failed presumably by this mechanism

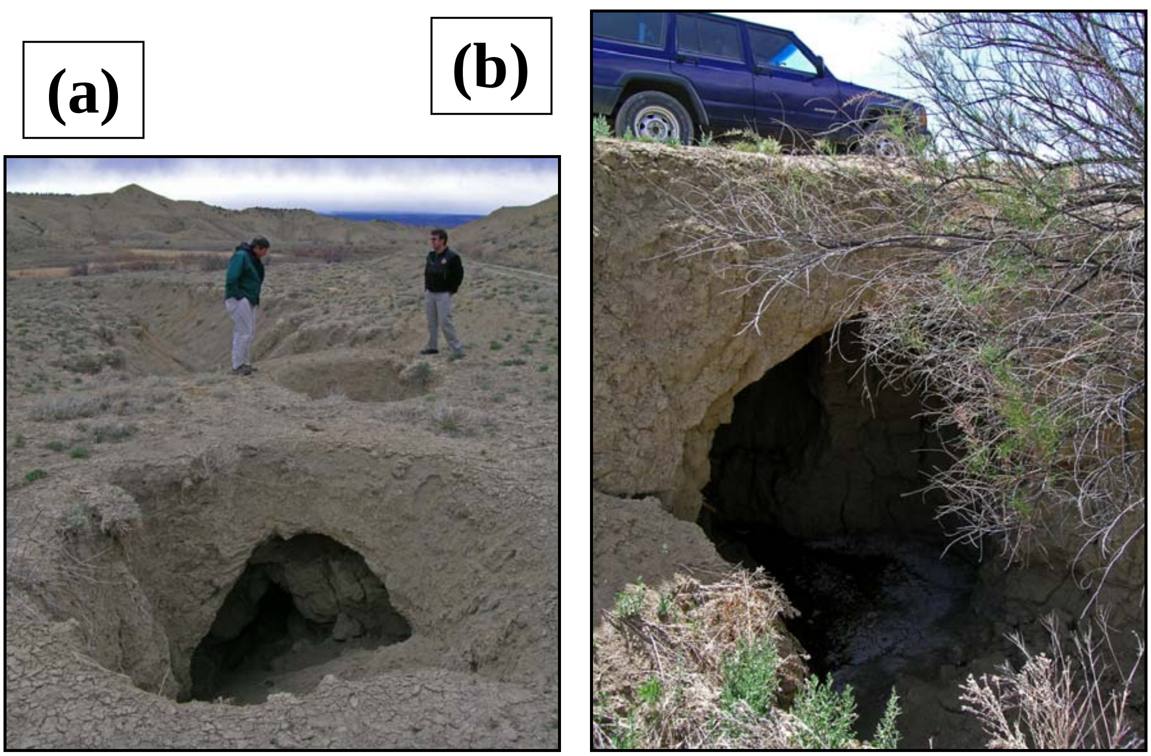

Figure 37. Pseudokarst features in the “High Adobe Hills” area [UTM83 258461, 4255860]. (a) CGS geologists inspecting sinkholes and soil bridges formed in alluvial mudflow (Qamf) deposits). (b) Large piping cavity that formed beneath an earthen fill embankment (af).

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

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

ERODIBLE SOILS

Wind action and water runoff are the biggest causes of erosion. These processes are amplified by development and grazing of vegetated lands where the soil is exposed and easily eroded. Exposed bedrock of the Mancos Shale and also its surficial derivatives are susceptible to moderately high erosion, especially where vegetation is absent or has been removed 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 National Resource Conservation Service (NRCS) estimates that 86 tons per acre per year of soil erosion is possible from the Mancos Shale and silty surficial units (NRCS, 2006). The least susceptible areas of erosion correspond to the gravel-capped mesas and Dakota Sandstone.

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 (NRCS, 2006). In the Montrose East quadrangle, an isolated butte has undergone tremendous wind erosion over a 40-year period, spurred by caprock removal and destruction of protective colluvial crusts by wheeled vehicles (for a more complete description, see the section about eolian deposits (Qe) earlier in this report). The center of the butte is now effectively eroded away (figures 19b and 38).

Figure 38. Dramatic results of wind erosion of a Mancos Shale-cored butte. Accelerated erosion of the butte began in the late 1960s, removing nearly 30 feet of shale from the center portion and creating a large, wide, scoured groove. [UTM83 256399, 4257370]

Wind and water erosion of geologic materials may have adverse effects upon humans, livestock, and aquatic life. In particular, airborne dust from the abundantly silty deposits in this area may reduce air quality and affect respiratory functions. Soil erosion increases the risk of pollution to surface and ground waters from natural salts and trace elements derived from the soil and bedrock (for example, Whittig and others, 1982; Tuttle and others, 2005), as well as pesticides and other human-derived pollutants.

TOXIC SOILS

Selenium, found in minute amounts in the Mancos Shale and soils derived from the Mancos Shale, is of particular concern. Selenium poisoning, or selenosis, may cause insomnia, headaches, numbness, chest tightness, high blood pressure, and intermittent bouts of shaking (MedicineNet.com, 2006). Many of the streams in western Colorado contain elevated levels of selenium, which, through food-chain bioaccumulation, may cause reproductive impairment in fish and aquatic birds (see Lemly, 1995, for a discussion for selenium hazard assessment). Humans and livestock may inhale airborne selenium during and following windstorm events. Precipitation brings the selenium and other salts to the surface, and these mineral species may form a crust on the surface soils when dry (for example, figure 20a).

CORROSIVE SOILS

The Mancos Shale and sediments derived from the Mancos Shale typically have high salt and sulfate content and should be considered a potentially corrosive soil. Corrosive soils may damage typical concrete and buried metal. According to a local resident, a one-inch-thick steel pipe was nearly dissolved after only one year of burial, 2 feet below the ground. Residents should frequently examine any pipes or storage tanks (for example, propane) that are exposed to these soils for signs of corrosion. The use of PVC pipes and plastic tanks, cathodic protection, or corrosion-resistant coatings is highly recommended in these areas. Geotechnical consultants in the Montrose area typically specify special corrosion-resistant concrete mixes for foundations and slab-on-grades, as well as protective coatings for buried metalworks.

MINERAL RESOURCES

Mineral resources within the Montrose East quadrangle include construction aggregates, primarily in the form of sand and gravel and possibly crushed rock. The following paragraphs discuss these particular resources, as well as other mineral and mineral-fuel resources such as clay, claystone, and shale; oil and gas; and coal. Figure 39 shows the locations of the active and inactive gravel pits, claystone and shale pits, oil and gas wells, and coal mines within the area that immediately surrounds the quadrangle.

CONSTRUCTION AGGREGATES (SAND, GRAVEL, CRUSHED ROCK)

Sand and gravel is presently a minor mineral resource in the Montrose East quadrangle. There is one active aggregate mine within the mapped area: the Hollenbeck Pit, located several miles to the southeast of Montrose [UTM83 252630, 4255372]. This pit, which is operated by Western Gravel, Inc., produces an estimated 12,000 tons of aggregate per year (Guilinger and Keller, 2004) from the modern flood plain of the Uncompahgre River (map unit Qau_1).

Thirteen other sand and gravel pits were once active within the quadrangle; these have ceased operation and are in various stages of reclamation (Keller and others, 2002). Production came primary from the Quaternary alluvium deposited by the Uncompahgre River. In addition to sand and gravel, crushed rock may have been produced from these operations. Several of the alluvial deposits contain quartzite and other relatively hard cobbles that could be used to make crushed rock aggregate.

Potential exists for the development of additional sand and gravel operations in the significant alluvial deposits in the mapped area. Map units that contain potentially high-quality gravel deposits include alluvial deposits associated with the Uncompahgre River (Qau_1, Qau_2, Qau_3, Qau_4, and Qau_5), Cedar Creek (Qac_2 and Qac_3), and the upland Shinn Park-Bostwick Park paleovalley system (Qg_3) (figure 40). In addition, marginal-quality gravel could be produced from the upland, muddy debris-flow gravel deposits from the "Mesa Staircase" and Cerro Summit-Cimarron Ridge highlands (Qg_1, Qg_2, Qg_3, and Qg_4).

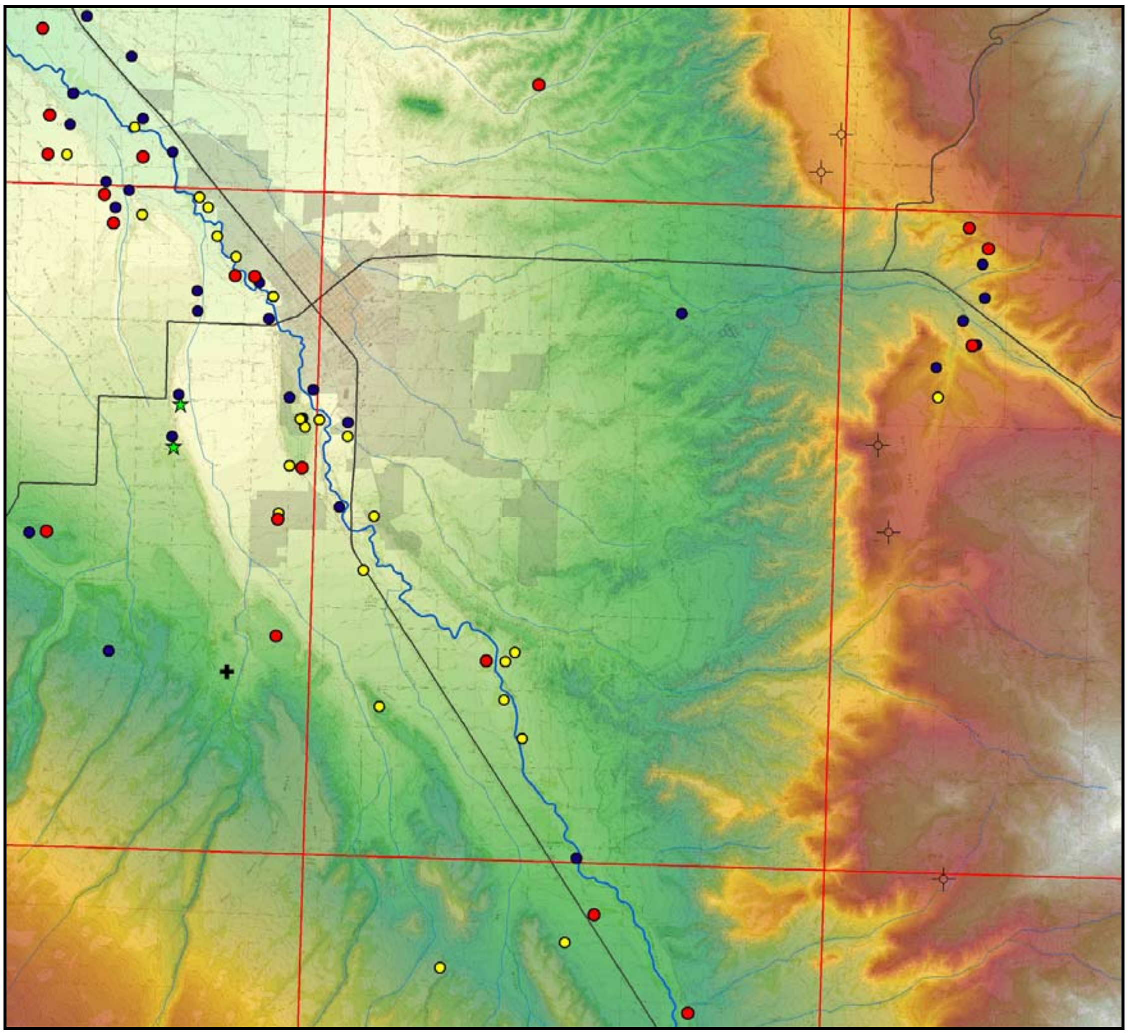

Figure 39. GIS map showing mineral resources of the Montrose East quadrangle and surrounding areas. The map includes sand and gravel pits that are active (red circles), inactive or closed post-1981 (yellow circles), or closed pre-1981 (blue circles); closed claystone and shale pits (green stars); drilled and abandoned oil and gas exploratory wells (crossed circles); and a closed coal mine (black cross). Data from Keller and others (2002), Guilinger and Keller (2004), and Colorado Oil and Gas Conservation Commission (2007).

CLAY, CLAYSTONE, AND SHALE

According to local residents, clay from the Mancos Shale was used to produce “adobe” bricks for building stone. Many of these turn-of-the-century structures are still standing today throughout the Montrose-Delta region. Two former surface mines produced claystone and shale from the Mancos Shale (presumably from the Graneros Member) within the nearby Montrose West quadrangle (Keller and others, 2002).

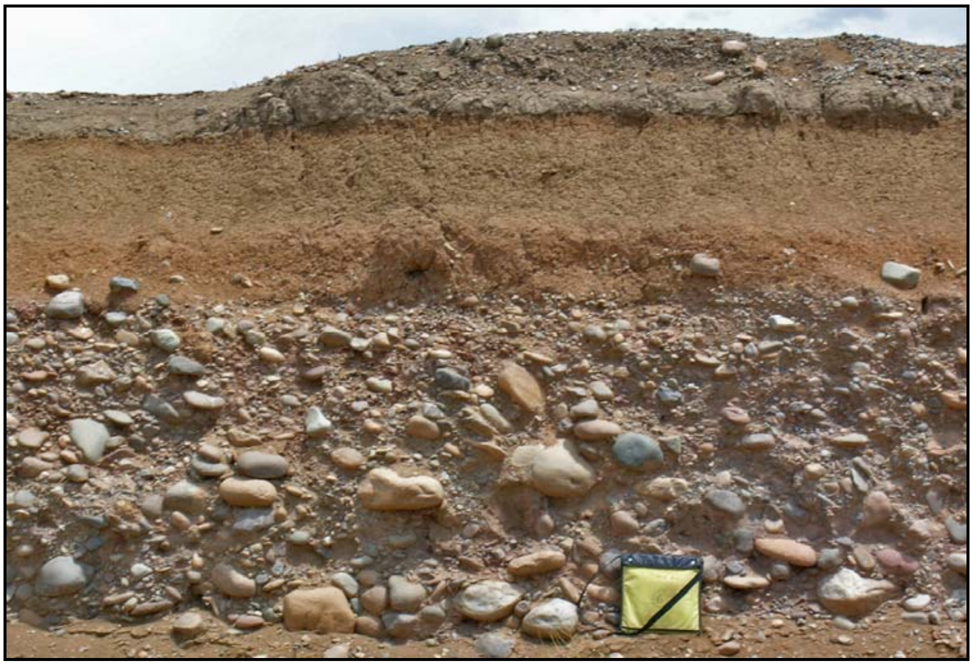

Figure 40. Wall exposure of Qau_2 alluvial sand and gravel layers at the United Companies’ Colona gravel pit, just south of the mapped area. Many of the alluvial units in the Montrose East quadrangle contain similar, high-quality aggregate deposits. [UTM83 255024, 4250047]

Potential may exist for brick production or other commercial uses of clay within the abundant shale outcrops from the area. The current mapping project, in which the Mancos Shale has been subdivided into ten stratigraphic members, each with its own distinct lithologic properties, may serve to enhance the exploration for suitable clay materials. Sand-bearing members, such as the Juana Lopez and Prairie Canyon Members, may be the least suitable for brick materials. There are no commercial deposits of bentonite within the mapped area. Bentonite beds observed by the authors were generally only a few inches thick, with a maximum thickness of approximately 1 foot.

OIL AND GAS

No oil and gas wells have been drilled within the Montrose East quadrangle (Colorado Oil and Gas Conservation Commission, 2007). At least five exploratory holes have been drilled just to the east of the mapped area in the vicinity of Bostwick Park, the "Shale Cliffs," and the Cerro Summit-Cimarron Ridge highlands. These wells were drilled between 1975 and 2003. Two of the wells reached their total depths (TD) in Precambrian granite, while others reached their TD in the Morrison Formation or Mancos Shale.

No production information is listed for any of the wells, and it is doubtful they were successful. In terms of future exploration, this remains a wildcat area. Potential drilling targets include the Dakota Sandstone, Sand Wash Member of the Morrison Formation, and the Entrada Sandstone. Additional information on oil and gas production may be obtained from the Colorado Oil and Gas Conservation Commission.

COAL

Although the area is recognized as being within a coal region and is underlain by the coal-bearing Dakota Sandstone, there is no current or historical coal production from the mapped area (Carroll and Bauer, 2002; Carroll, 2005). One mine, the Happy Canon, produced sub-bituminous coal from a sloping underground seam within the Dakota Sandstone just to the west of the mapped area, within the Montrose West quadrangle.

The potential for future coal mining from the Montrose East quadrangle is practically nil, as subdivisions have been built in the southwestern corner of the mapped area, where the formation is found in the near surface. An appreciable thickness of shale overburden makes coal extraction impractical in other parts of the quadrangle.

GROUND-WATER RESOURCES

The primary source of agricultural irrigation water and domestic drinking water within the Montrose East quadrangle comes from the Gunnison River as a result of the Uncompahgre Project (U.S. Bureau of Reclamation, 2007). This pioneering project was begun in 1907 and completed in 1937. Its purpose is to divert water into the Uncompahgre River valley from Taylor Park Reservoir in Gunnison County via seven diversion dams, the 5.8-mile-long Gunnison Tunnel, 128 miles of main canals, 438 miles of lateral ditches, and 216 miles of drain ditches.

The project provides irrigation water for over 76,000 acres of cropland in the valley and is administered by the Uncompahgre Valley Water Users Association. It also provides domestic water for a non-farm population of over 26,000 people in the Montrose-Delta area.

Another source of locally important, domestic drinking water is from on-site ground-water wells. The distribution of water wells in the vicinity of the mapped area and the initial water-level depth and well yields are shown in figures 41 and 42. Ground water in the Montrose East quadrangle is produced from two main hydrogeologic units: (1) consolidated bedrock aquifers associated with the Cretaceous-age Dakota Sandstone, and (2) Quaternary alluvial deposits.

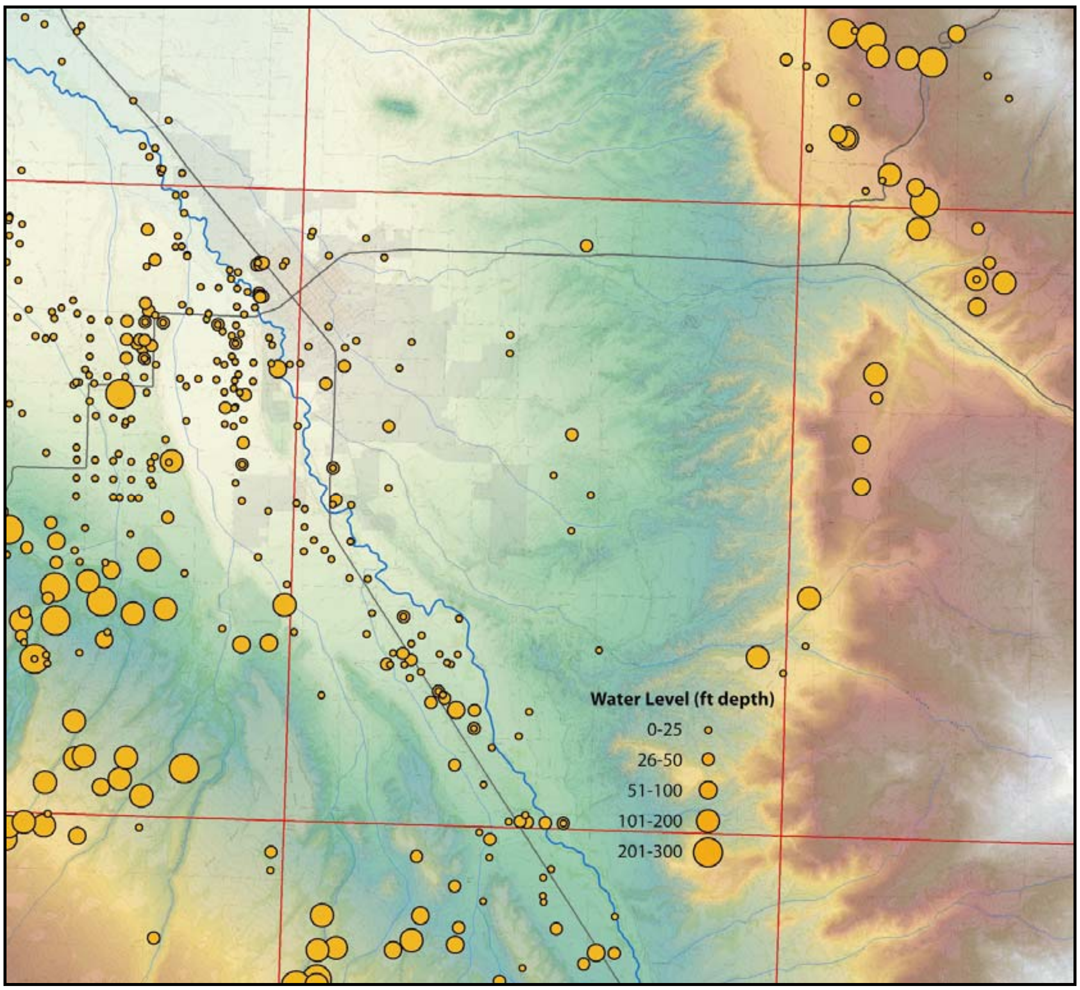

Figure 41. GIS map of ground water wells in the Montrose East quadrangle and surrounding areas, showing depth to water level upon well completion. Five depth categories are shown, with larger circles used for deeper water levels. Data from 2001 Colorado Department of Water Resources dataset used in Topper and others (2003).

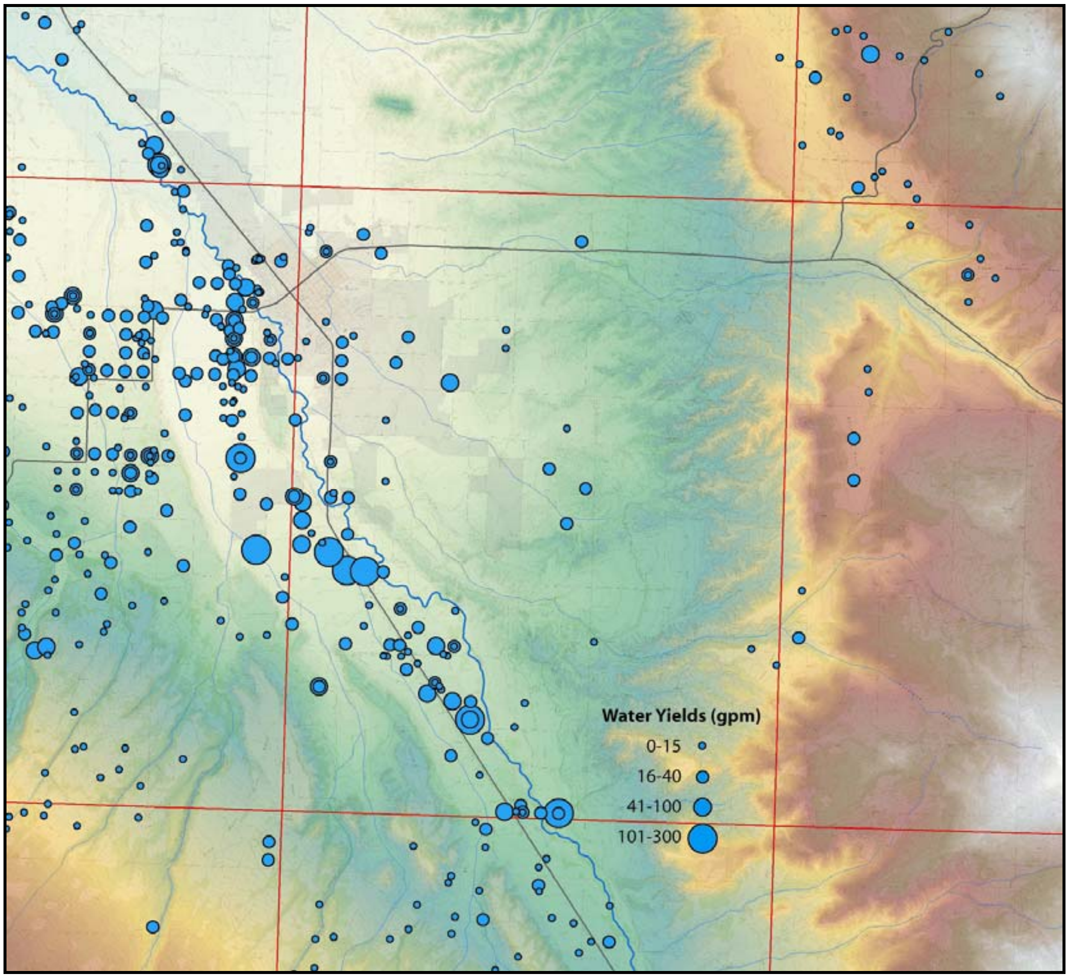

Figure 42. GIS map of ground water wells in the Montrose East quadrangle and surrounding areas, showing initial well yields upon well completion. Four yield categories are shown, with larger circles used for greater yield amounts. Data from 2001 Colorado Department of Water Resources dataset used in Topper and others (2003).

The following sections describe these hydrogeologic units and provide information about general hydrogeologic characteristics of the units. 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 may be obtained from available literature. Additional, conceptual information on ground water in Colorado may be found in the CGS Ground Water Atlas of Colorado (Topper and others, 2003).

ALLUVIAL AQUIFERS

A majority of the locally derived ground water for domestic use comes from Quaternary alluvial and alluvial terrace deposits associated with the Uncompahgre River valley. In particular, the Qau_1 and Qau_2 map units are areally extensive and appear to provide continuous subsurface conduits for ground-water flow along the river valley. The older alluvial units within the Montrose East quadrangle (Qau_3 to Qau_5) are isolated, elevated, and lack subsurface connection to other water sources. As a result, they do not carry appreciable ground water.

This alluvial aquifer is part of the Gunnison River basin, which extends west from the Continental Divide to Grand Junction and south to Telluride (Topper and others, 2003). Much of the alluvium within the modern flood plain (Qau_1) is in direct hydraulic connection with the river and forms an unconfined aquifer where saturated with ground water. The areal extent of the alluvial aquifer roughly coincides with the areal extent of the alluvium; however, the alluvium is not always saturated with ground water and the presence of alluvium at the surface does not imply the presence of an aquifer at depth.

On the basis of records obtained from the Colorado Department of Water Resources (DWR), water levels in wells completed in the alluvial aquifer along the Uncompahgre River valley generally lie between the surface and approximately 50 feet below the surface (figure 41). Well yields along this corridor vary from 0 to 100 gallons per minute (gpm) (figure 42) but are typically 30 gpm and do not significantly fluctuate by location. A small number of wells have been drilled into the older alluvial deposits of the Shinn Park-Bostwick Park paleovalley system, just to the east and northeast of the quadrangle. These wells typically have deeper water levels (20 to 100 feet; figure 41) and small yields (less than 30 gpm; figure 42). A handful of wells to the east of the city of Montrose produce small amounts of water from shallow, alluvial-mudflow aquifers.

Recharge of the alluvial aquifer occurs via natural precipitation, infiltration from the surface-water canal and irrigation system, and from the Uncompahgre River and its tributaries (Meeks, 1950; 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). Due to the possibility of natural and human-caused contamination from surface waters and the introduction of salts from bedrock and soil units, it is recommended that residents using alluvial water for domestic use complete a water-quality test. According to Apodaca and Bails (2000), water-quality data for the Uncompahgre River alluvial aquifer are as follows, with average values shown in parentheses:

Total Dissolved Solids (TDS), mg/L	Hardness, mg/L	Radon-222, pCi/L	Iron, µg/L
168 to 397 (279)	94 to 290 (195)	577 to 1,928 (1,033)	<3.0 to 7,439 (1,503)

BEDROCK AQUIFERS

The Dakota Sandstone (includes the underlying Burro Canyon Formation) is the primary bedrock aquifer in the mapped area for both domestic and livestock uses where ground water from alluvial aquifers is not obtainable. Regionally, sandstone bodies in the lower part of Mancos Shale are also used for domestic water, but to a limited extent (Meeks, 1950). West of the mapped area, in Shavano Valley, the Morrison Formation is a common domestic water target. No water wells in the Montrose East quadrangle produce from either the Mancos Shale or the Morrison Formation. Few wells have been drilled to the east of the US Highway 550 corridor because the thickness of the shale overburden.

The Dakota Sandstone generally consists of well-sorted, very fine- to medium-grained, light-brown to yellow-brown sandstone interbedded with gray to black siltstone and carbonaceous shale. The porosity of the sandstone beds is highly variable and is not published for the mapped area; the nearest and most recent available porosity values provided from northern Raton Basin oil fields are around 6 to 10 percent, and, it may be as much as 20 percent (Worrall, 2004). On the basis of surface outcrops and well logs, the potential thickness of the Dakota Sandstone aquifer ranges from about 100 to 180 feet in the mapped area (Meeks, 1950). The aquifer may be confined to partially confined, and artesian wells occur in some locations.

Few wells produce from the Dakota Sandstone within the Montrose East quadrangle; however, there are many Dakota wells along a northeast to southwest trend that passes through the southwest corner of the quadrangle. This marks the location where the Dakota Sandstone passes from outcrop (in the Uncompahgre uplift) eastward into the subsurface. Water-level data for the Dakota aquifer, obtained from the Division of Water Resources (DWR) well permit files, often list the water levels that existed when the wells were completed. These data are one-time measurements. Thus, the reported water level is not necessarily representative of current conditions in the well. Water levels in the Dakota aquifer can be expected to vary considerably depending on location and elevation. Values listed in the DWR permit database are between 20 and 300 feet below the surface (figure 41). Well yields from the Dakota aquifer near the quadrangle typically range from 1 to 40 gpm and average 12 gpm (figure 42). Ground water from the Dakota 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 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 eastern flank of the Uncompahgre uplift. In general, water quality of the Dakota aquifer in the area is adequate for domestic use with total dissolved solids (TDS) values ranging from approximately 210 to 4,200 mg/L and averaging 1,845 mg/L (ibid.).

There is a historical flowing artesian water well, 804 feet deep and completed in the Dakota Sandston, at the corner of South First and Uncompahgre at the Montrose City Hall. Called “Iron Mike,” this well was once used as water supply for a spa that touted the advantages of its mineralized water content. Over the years there have been at least four monuments to Iron Mike featuring some sort of fountain. The fountain is located 50 feet or so from the actual well, which is currently marked with a manhole cover (figure 43). Iron Mike is largely forgotten by the residents of Montrose. A former City Manager referred to this site as being the location of a prehistoric natural spring when excavation near City Hall turned up some Pleistocene bison bones (“…the bison came to the spring to drink…,” quoted in the *Montrose Daily Press*). (L. Hauptmann, Buckhorn Geotech, oral communication, 2007).

Figure 43. Fountain and manhole cover in downtown Montrose marking the location of the historic “Iron Mike” artesian water well.

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Panorama of the "High Adobe Hills" in the middle distance and the "Shale Cliffs" in the background, looking northeast from Kinikin Heights [UTM83 257054, 4254452].

Appendix A - Fossils Collected From the Montrose East Quadrangle and Vicinity, Colorado

CGS Locality Number	USGS Mesozoic Locality Number	Fossils Identified by W. Cobban, USGS	Mollusc or Ammonite Guide Fossil Zone	Age	Formation or Mancos Shale Member	Quadrangle	County	State	Land Survey Location	UTM83-X	UTM83-Y	Collected by	Date
---	D3850, 51		*B. perplexus*	Middle Campanian	Buck Tongue?	Cerro Summit	Montrose	CO	ne se sw 35-49N-8W	260914	4260670	R.G. Dickinson	pre-1966
---	D3852		*B. perplexus*	Middle Campanian	Buck Tongue?	Cerro Summit	Montrose	CO	nw se ne 35-49N-8W	261602	4261536	R.G. Dickinson	pre-1966
---	D3846, 47		*B. aspiriformis*	Middle Campanian	Lujane Point shale unit	Cerro Summit	Montrose	CO	nw ne ne 4-48N-8W	260138	4260010	R.G. Dickinson	pre-1966
---	D3848, 49		*B. aspiriformis*	Middle Campanian	Lujane Point shale unit	Cerro Summit	Montrose	CO	nw se sw 35-49N-8W	260825	4260777	R.G. Dickinson	pre-1966
DN059	D14534	*Cataceramus balticus*	*B. aspiriformis?*	Middle Campanian	Lujane Point shale unit	Cerro Summit	Montrose	CO	nw ne ne 4-48N-8W	260448	4260241	David C. Noe	05/19/06
DN1013	D14533	*Baculites sp; Cataceramus sp.; Ichthyodectes sp.*	*B. obtusus?*	Middle Campanian	Prairie Canyon Mbr	Cerro Summit	Montrose	CO	nw sw sw 23-49N-8W	261023	4264550	David C. Noe	11/08/06
DN045	D14525	*Baculites sp. (B. haresi?);* trace fossils	*C. balticus; Scaphites hippocrepis*	Lower Campanian	Prairie Canyon Mbr	Montrose East	Montrose	CO	se nw sw 9-48N-8W	259155	4256619	David C. Noe	05/19/06
DN072	D14529	*Cataceramus balticus*	*C. balticus; Scaphites hippocrepis*	Lower Campanian	Prairie Canyon Mbr	Montrose East	Montrose	CO	ne nw sw 29-49N-8W	255891	4262927	David C. Noe	05/25/06
DN064	D14530	*Baculites aquilaensis*	*C. balticus; Scaphites hippocrepis*	Lower Campanian	Prairie Canyon Mbr	Montrose East	Montrose	CO	se sw sw 21-49N-8W	257684	4263698	David C. Noe	05/25/06
DN066	D14531	*Baculites sp., Cataceramus balticus*	*C. balticus; Scaphites hippocrepis*	Lower Campanian	Prairie Canyon Mbr	Montrose East	Montrose	CO	sw se se 21-49N-8W	258478	4263760	David C. Noe	05/23/06
DN085	D14532	*Baculites aquilaensis; Ichthyodectes* scales	*C. balticus; Scaphites hippocrepis*	Lower Campanian	Prairie Canyon Mbr	Montrose East	Montrose	CO	n nw se 22-49N-8W	259930	4254357	David C. Noe	06/06/06
DN015	D14520	*"Inoceramus" sp.; Pseudoperna congesta*	(can't tell)	Coniacian or Santonian	Smoky Hill Mbr	Montrose East	Montrose	CO	sw nw nw 14-48N-9W	252555	4256167	David C. Noe	04/26/06
DN105	D14521	*"Inoceramus" sp.; Pseudoperna congesta;* trace fossils	(can't tell)	Coniacian or Santonian	Smoky Hill Mbr	Montrose East	Montrose	CO	nw nw sw 13-48N-9W	254138	4255410	David C. Noe	11/06/06
DN106	D14522	*"Inoceramus" sp.; Pseudoperna congesta;* fish scales	(can't tell)	Coniacian or Santonian	Smoky Hill Mbr	Montrose East	Montrose	CO	s nw sw 13-48N-9W	254265	4255165	David C. Noe	11/07/06
DN024	D14523	*"Inoceramus" sp.; Pseudoperna congesta;* fish scales	(can't tell)	Coniacian or Santonian	Smoky Hill Mbr	Montrose East	Montrose	CO	sw ne ne 31-48N-8W	256772	4251090	David C. Noe	05/02/06
DN027	D14524	*"Inoceramus" sp.; Pseudoperna congesta*	(can't tell)	Coniacian or Santonian	Smoky Hill Mbr	Montrose East	Montrose	CO	se se ne 29-48N-8W	258706	4252337	David C. Noe	11/07/06
DN044	D14526	*"Inoceramus" sp.; Pseudoperna congesta*	(can't tell)	Coniacian or Santonian	Smoky Hill Mbr	Montrose East	Montrose	CO	sw se se 8-48N-8W	258591	4256295	David C. Noe	05/17/06
DN082	D14527	*Magadiceramus subquadratus crenulatus; Pseudoperna congesta*	*M. subquadratus crenulatus*	Upper Coniacian	Smoky Hill Mbr	Montrose East	Montrose	CO	ne se nw 7-48N-8W	256399	4257370	David C. Noe	06/05/06
---	D3844	*Baculites asper*	*Scaphites depressus; M. subquadratus crenulatus*	Upper Coniacian	Smoky Hill Mbr	Cerro Summit	Montrose	CO	nw se sw15-48N-8W	260924	4254783	R.G. Dickinson	pre-1966
DN084	D14528	*"Inoceramus" platinus; Psuedoperna congesta*	(can't tell)	Middle to Upper Coniacian	Smoky Hill Mbr	Montrose East	Montrose	CO	se se se 1-48N-9W	255546	4258093	David C. Noe	06/05/06
DN010	D14518	*Mytiloides incertus*	*M. incertus; Scaphites negricollensis*	Upper Turonian	Montezuma Valley Mbr	Montrose East	Montrose	CO	c s 4-48N-9W	250099	4258545	David C. Noe	04/20/06
---	D3842	*Inoceramus perplexus; Prionocyclus macombi; Ostrea lugubris*	*I. Perplexus; I. dimidius; P. macombi*	Middle to Upper Turonian	Juana Lopez Mbr	Montrose East	Montrose	CO	n nw ne 27-48N-9W	251642	4252546	R.G. Dickinson	1962
---	D11880	*Inoceramus perplexus; Prionocyclus macombi; Lopha lugubris*	*I. dimidius; P. macombi*	Middle Turonian	Juana Lopez Mbr	Colona	Montrose	CO	ne ne 3-47N-9W	252090	4249787	E.A. Merewether and W.A. Cobban	1982
---	D11883	*Inoceramus dimidius; Prionocyclus macombi; Scaphites warreni*	*I. dimidius; P. macombi; S. warreni*	Middle Turonian	Juana Lopez Mbr	Colona	Montrose	CO	ne ne 3-47N-9W	252090	4249787	E.A. Merewether and W.A. Cobban	1982
K138	D14513	*Prionocyclus macombi; Lopha lugubris*	*I. dimidius; P. macombi*	Middle Turonian	Juana Lopez Mbr	Montrose East	Montrose	CO	se ne se 27-48N-9W	252175	4252052	Stephen M. Keller	05/23/06
K142	D14514	*Inoceramus dimidius; Prionocyclus macombi*	*I. dimidius; P. macombi*	Middle Turonian	Juana Lopez Mbr	Montrose East	Montrose	CO	e se nw 27-48N-9W	251496	4252598	Stephen M. Keller	05/23/06
K141	D14515	*Prionocyclus macombi; Lopha lugubris*	*I. dimidius; P. macombi*	Middle Turonian	Juana Lopez Mbr	Montrose East	Montrose	CO	s se sw 22-48N-9W	251303	4253215	Stephen M. Keller	05/23/06
DN005	D14516	*Inoceramus dimidius*	*I. dimidius; P. macombi*	Middle Turonian	Juana Lopez Mbr	Montrose East	Montrose	CO	e se ne 5-48N-9W	249160	4259797	David C. Noe	04/19/06
DN008	D14517	*Inoceramus dimidius*	*I. dimidius; P. macombi*	Middle Turonian	Juana Lopez Mbr	Montrose East	Montrose	CO	c ne ne 9-48N-9W	250698	4257871	David C. Noe	04/20/06
DN011	D14519	*Baculites sp.; Inoceramus dimidius?*	*I. dimidius; P. macombi*	Middle Turonian	Juana Lopez Mbr	Montrose East	Montrose	CO	e ne sw 4-48N-9W	249975	4259193	David C. Noe	05/20/06
DN006	D14535	*Inoceramus dimidius; Prionocyclus macombi*	*I. dimidius; P. macombi*	Middle Turonian	Juana Lopez Mbr	Montrose West	Montrose	CO	nw ne se 5-48N-9W	248940	4259326	David C. Noe	04/19/06
---	D3841	*Inoceramus dimidius; Ostrea lugubris*	*I. dimidius; P. macombi*	Middle Turonian	Juana Lopez Mbr	Montrose West	Montrose	CO	sw ne 5-48N-9W	248520	4259747	R.G. Dickinson	1962
---	D11879	*Prionocyclus macombi; Scaphites carlilensis*	*I. aff dimidius; P. macombi*	Middle Turonian	Blue Hill Mbr	Colona	Montrose	CO	ne ne 3-47N-9W	252062	4249749	E.A. Merewether and W.A. Cobban	1982
---	D11878	*Pycnodonte newberryi*	*Mytiloides hattini; Nigericeras scotti*	Upper Cenomanian to Lower Turonian	Bridge Creek Mbr	Colona	Montrose	CO	ne ne 3-47N-9W	252179	4249594	E.A. Merewether and W.A. Cobban	1982
---	D11882	*Pycnodonte newberryi*	*Mytiloides hattini; Nigericeras scotti*	Upper Cenomanian to Lower Turonian	Bridge Creek Mbr	Colona	Montrose	CO	ne ne 3-47N-9W	252179	4249594	E.A. Merewether and W.A. Cobban	1982
---	D11881	*Plicatula sp.*	*pre I. Pictus?*	Upper Cenomanian	Graneros Mbr	Colona	Montrose	CO	ne ne 3-47N-9W	252113	4249580	E.A. Merewether and W.A. Cobban	1982
---	D14164	*Pycnodonte aff kellumi*	*pre I. Pictus?*	Upper Cenomanian	Graneros Mbr	Montrose West	Montrose	CO	nw nw 20-48N-9W	247739	4254694	???	???
---	26946		*Plesiacanthoceras wyominensis*	Middle Cenomanian	Dakota Sandstone	Montrose West	Montrose	CO	19-48N-9W	???	???	???	???
---	D2040		*Colinoceras terrantense*	Middle Cenomanian	Dakota Sandstone	Government Springs	Montrose	CO	30-48N-9W	???	???	???	???

Includes collection sites within one mile of the Montrose East quadrangle. Sources of information for fossils collected previous to this study include Dickinson (1965) and Merewether and others (2006)
Note by W. Cobban: Pieces of large inoceremids are referred to as *"Inoceramus"* and may be either *Magadiceramus*, *Volviceramus*, or *Platyceramus*