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Olathe Northwest Quadrangle Geologic Map, Delta and Montrose Counties, Colorado

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FOREWORD

The purpose of Colorado Geological Survey's (CGS) *Olathe Northwest Quadrangle Geologic Map, Delta and Montrose Counties, Colorado* is to describe the geology, mineral and ground-water resource potential, and geologic hazards of this 7.5-minute quadrangle located southeast of Delta in western Colorado. CGS staff geologists David Noe, Matt Morgan, and field assistant Shannon Townley (now with Cornerstone Natural Resources) completed the field work on this project during the spring and summer of 2007. The geologic map plates and the Authors' Notes report were created using field maps, field notes, structural measurements, and photographs generated by the investigators. Surficial and bedrock unit descriptions were coordinated between this area and the adjacent Delta and Olathe quadrangles (Morgan and others, 2007; 2008).

This mapping project was funded jointly by the U.S. Geological Survey (USGS) and CGS. USGS funding comes from the STATEMAP component of the National Cooperative Geologic Mapping Program, award number 07HQAG0083, authorized by the National Geologic Mapping Act of 1997, reauthorized in 2009. CGS matching funding comes from the Colorado Department of Natural Resources Severance Tax Operational Funds, from severance taxes paid on the production of natural gas, oil, coal, and metals in Colorado.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

LIST OF PLATES

INTRODUCTION

The Olathe Northwest 7.5-minute quadrangle is located in Delta and Montrose Counties, Colorado, flanking the Uncompahgre River valley (**Figure 1**). No towns are located within the quadrangle. The town of Delta lies 4 miles to the west. U.S. Highway 50 passes through the southwestern corner.

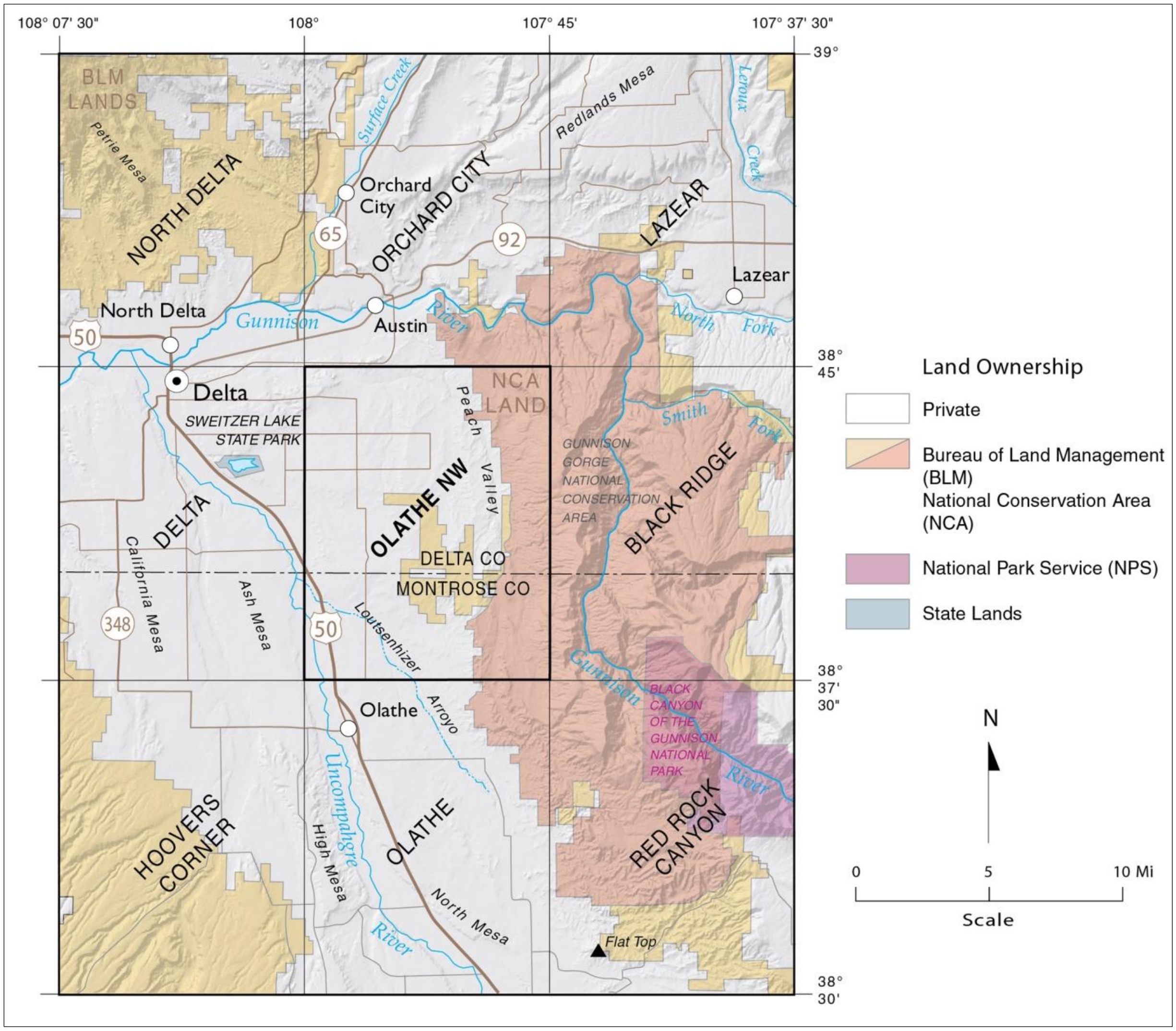

Figure 1. Index map of the Olathe Northwest quadrangle in western Colorado.
Most of the quadrangle consists of private land parcels; the remainder is BLM-administered public land.

Figure 2 shows the major physiographic features of the quadrangle. Few named features appear on the base USGS topographic maps, and we have applied some informal names to designate areas or features of specific interest. These names reflect local usage where possible and are signified by quotation marks. The highest elevation is 6,160 ft along a ridge in the northeastern corner. The lowest point is 5,035 ft along an unnamed arroyo near "Star Nelson Airport Mesa."

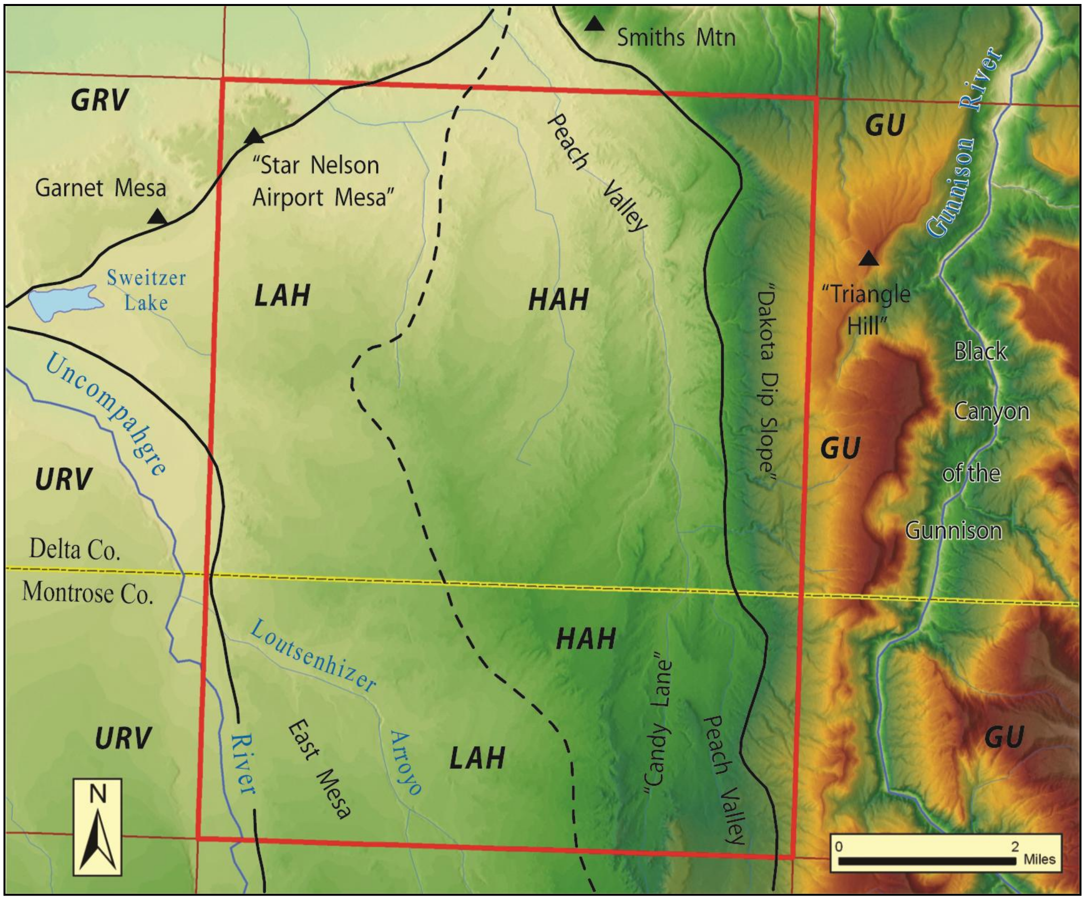

Figure 2. Shaded-relief index map of the Olathe Northwest quadrangle, showing physiographic features. Geomorphic areas marked by black lines include the Uncompahgre River valley (URV), Gunnison River valley (GRV), "low Adobe hills" (LAH), "high Adobe hills" (HAH), and the Gunnison Uplift (GU). The Uncompahgre Uplift is about 5 miles to the southwest of this map view.

Five geomorphic areas comprise the quadrangle (**Figure 2**). The Gunnison Uplift (GU) is a structural geomorphic feature that forms a westward-dipping escarpment ("Dakota dip slope") along the eastern edge. The Uncompahgre River valley (URV), consisting of the modern river flood plain and gravel-capped mesas that mark its former courses, cuts across the southwestern corner. Gravel-capped mesas associated with the former Gunnison River form the margin of the Gunnison River valley (GRV) across the northwestern corner. The dominant terrain within the quadrangle is typified by shale badlands, called the "Adobe hills" or, simply, the "Adobes" by local residents. This area can be divided into a high part (HAH), which contains moderately steep shale ridges and hills and deeply incised valleys, and a low part (LAH) that features broad basins and low shale hills.

A nearby structural geomorphic feature of note, the Uncompahgre Uplift, forms a northeastward-dipping escarpment several miles to the west of the quadrangle. The foot of its dip slope lies along the western edge of the Uncompahgre River valley, in the adjacent Delta quadrangle.

PREVIOUS MAPPING STUDIES

The earliest regional geological map of the region was published by Hayden (1877) (scale 1:253,440); a portion of that map is shown on the **Back Cover**. The study area is included in a regional geologic map of the Montrose 1° x 2° sheet (Tweto, 1976) (1:250,000) and in a geologic map by Ellis and others (1987) (1:100,000). Hansen (1968; 1971) mapped the adjacent, Black Ridge (1:24,000) and Red Rock Canyon (1:31,680) quadrangles to the east.

The Olathe Northwest quadrangle geologic map is a result of an ongoing project by the Colorado Geological Survey (CGS) to conduct geologic mapping of the Gunnison, North Fork, and Uncompahgre River valleys in western Colorado. Adjacent 1:24,000-scale geologic maps done by CGS include the Olathe and Delta (Morgan and others, 2007; 2008); the Hoovers Corner (White and others, 2008); and the Lazear, North Delta, and Orchard City quadrangles (Noe and others, in prep., a, b, and c).

Geologic mapping of the Olathe Northwest quadrangle was undertaken by the CGS as part of the STATEMAP program. STATEMAP is a component of the National Cooperative Geologic Mapping Act, administered by the USGS. The purpose of the CGS STATEMAP program is to produce 1:24,000 scale geologic maps that focus on surficial units, bedrock units, and structural features. The maps can be used for land-use planning, geologic-hazard assessment, geotechnical engineering, and mineral and ground-water resource development. They can also be used to investigate an area's unique geologic history. (For the current status of CGS STATEMAP projects, see http://geosurvey.state.co.us/mapping/Pages/24,000-ScaleMappingProgram.aspx.)

MAPPING METHODOLOGY

The Olathe Northwest quadrangle geologic map is shown on **Plate 1**. The geologic interpretations are based on (1) CGS field investigations conducted from April to July, 2007; (2) published and unpublished geologic maps and reports; and (3) interpretation of remote-sensing images. The image data include 1:20,000-scale, black-and-white aerial photography taken in 1966 by the Agricultural Stabilization and Conservation Service (ASCS); 1-m resolution digital orthophotos taken in 2005 and 2006 by the National Agricultural Imagery Program (NAIP); a 10-m resolution digital elevation model (DEM); and the Google™ Earth on-screen map viewer.

Bedrock geology and surficial deposits were mapped in the field on aerial photographs. Locations of key data points were recorded with a portable GPS receiver. ***All GIS locations reported herein and in the GIS database are in Universal Transverse Mercator (UTM), North American Datum 1983, Zone 13N projected coordinates, with units in meters.*** Bedrock structure measurements including bedding and fracture orientations were taken using a Brunton compass. Fossil, rock, and soil samples were collected, where possible, for age dating and material description purposes. After field-work was completed, the annotated aerial photos were scanned, georeferenced, and imported into Leica Photogrammetry Suite, where they were photo-grammetrically 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 shape-files. We used ERDAS IMAGINE 2010 to create the 3-D oblique geologic map shown in **Plate 2**.

DESCRIPTION OF MAP UNITS

This section contains descriptions of surficial and bedrock units from the geologic map. The surficial units are organized by the dominant process of deposition and by age, and are listed from youngest to oldest in terms of latest depositional activity. The bedrock units are organized by increasing age. The geologic time divisions and nomenclature used in this report are shown in **Appendix A**. Sediment-clast sizes are based on the modified Wentworth grain-size scale (Wentworth, 1922; Ingram, 1989). Grain sizes are listed in the order of their relative abundance. Color names are taken from Munsell rock- and soil-color charts (Geological Society of America, 1991; GretagMacbeth, 2000). Stages of calcic soil development are described using the classification system of Machette (1985). Length and distance measurements are given in terms of inches, feet ("ft"), and miles, as per CGS standard.

SURFICIAL DEPOSITS

The surficial deposits in the Olathe Northwest quadrangle are Quaternary (Holocene and Pleistocene) in age. The deposits shown on the map are generally more than 5 ft thick but may be thinner locally. Contacts between surficial units may be gradational, and mapped units locally may include deposits of other types. The deposits have not been age dated unless noted. Relative age assignments (early, middle, late) are based primarily on the degree of erosional modification of original surface morphology, height above modern stream levels, and degree of dissection, slope degradation, and soil development. Where possible, we adopted age assignments reported by previous authors, particularly those of Sinnock (1978), who traced stream-terrace levels along the Uncompahgre and Gunnison river valleys and correlated them with different glacial moraines near Ridgway, to the south of the mapped area.

HUMAN-MADE DEPOSITS

af **Artificial fill (late Holocene)** – Gravel, sand, silt, clay, and rock or concrete debris emplaced to construct dams or other human-made structures. Fills may be engineered (built with controlled compaction) or completely uncontrolled. Their compositions and properties are varied.

ALLUVIAL DEPOSITS

Gravel, sand, silt, and clay deposited in major river valleys and tributary drainages, in alluvial fans, and as older alluvial terrace, valley fill, or fan deposits. Erosion of the landscape through time has preserved the older deposits as elevated remnants, forming an *inverted topography*. Topographic inversion occurs when streams abandon their former courses and erode downward through soil or rock (in this case, soft shale) that borders the valley side. As a result, the stream migrates to a new course, and a newer, lower-elevation, stream valley is formed. Remnants of the older, abandoned deposits are preserved and are recognized today as mesa-capping gravel bodies.

We use an informal, numerical nomenclature for the alluvial deposits. The numbered map units refer to alluvial terrace levels along a major stream valley. Each level contains deposits that are generally correlative, in terms of age and topographic elevation above the modern river level. The youngest deposits, in modern stream valleys, are designated as level one ("Alluvium one"). Progressively older levels are designated as two, three, etc. Analytical age-dates are rare for these deposits; therefore, we use geomorphic principles (see discussion above, under **Surficial Deposits**) to group different types of alluvial deposits and assign relative ages. Our correlations and groupings are similar to, but more detailed than, those from previous studies of the region by Hail (1972), Sinnock (1978) and Cole and Sexton (1981). There appears to be a relationship between the alluvial river gravels in western Colorado and Pleistocene glacial moraines, as demonstrated by Sinnock (1978). The interpreted age relationship between our alluvial map units and Rocky Mountain glaciation episodes is shown in **Table 1**.

Table 1. Interpreted glaciation and age correlations of alluvial map units in the Olathe Northwest quadrangle

Alluvial Unit (this map)	**Glaciation Episode**	**Marine Oxygen Isotope Stage (MIS)**	**Age Range** (in thousands of years)
1b and 2	Pinedale	MIS 2	11.7-30 ka
3	Late Wisconsin	MIS 4	50-89 ka
4 and 5	Bull Lake	MIS 6	130-190 ka
6	Pre-Bull Lake	MIS 10-12	340-480 ka
Units and ages are regionally comparable to those of Hail (1972), Sinnock (1978), and Cole and Sexton (1981). Approximate age ranges from Porter (1989), Pierce (2003), Madole and others (2005), and Aber (2006).			

In the descriptions that follow, the reported alluvial-terrace elevation heights represent the elevation difference between the modern river level (from the USGS topographic map) and the top surface of the terrace gravel. Thickness refers to the maximum exposed thickness of the unit.

Alluvial Deposits of the Uncompahgre River

Gravel, sand, silt, and clay deposited by the Uncompahgre River. The youngest deposits (**Qau$_1$**) comprise the modern Uncompahgre River flood plain. Two levels of older deposits (**Qau$_2$** and **Qau$_3$**) are present as alluvial terraces that increase in age with increasing height above the modern river. One local terrace remnant (**Qau**) is not correlative with any other terrace surfaces. Top-of-terrace elevation gradients are similar to the modern river gradient.

The channel deposits consist of moderately sorted, well-rounded cobbles and pebbles in a course sand matrix. The gravel clasts are composed primarily of metaquartzite, tuffaceous and porphyritic rhyolite, andesite and intermediate volcanic rocks, and lesser amounts of gneiss, granite, vein quartz, limestone, and silica-cemented sandstone. These resistant clasts are derived from the San Juan

Mountains, the Gunnison Uplift, Cimarron Ridge, and the Uncompahgre Plateau to the south. The clasts are typically shades of pale red, purple, green, yellowish brown, and bluish gray (**Figure 3**). Overbank deposits that cap the flood plain and older terraces consist of pebbly sand and silt. The silt may be alluvial or eolian in origin.

Qau_1 **Alluvium one of the Uncompahgre River (Holocene) –** Gravel, sand, silt, and clay in the modern stream channel, active flood plain, and low side-terraces of the Uncompahgre River. The unit is partially incised into and may be underlain by unit **Qau_2**. Soil development is absent. There are two levels of low terraces. The high terrace reaches a height of 6 ft above current stream level. The younger group of terraces, with heights of up to 3 ft, has formed since 1987 when the river flows were first regulated by the Ridgway Dam, located 40 miles upstream. The terraces are comprised of overbank deposits. During that time period, the stream has mostly coalesced into a single channel. Maximum exposed thickness locally exceeds 8 ft; the thickness below current stream level is not known, but may be less than 15 ft.

Figure 3. Alluvium one of the Uncompahgre River (**Qau_1**), exposed in a modern gravel bar deposit. Compare the subtle, multi-colored nature of the gravel to the grayish Gunnison River gravel in **Figure 5**; this color difference provides a quick way to identify the different deposits in the field. Notebook is 8 inches high. [UTMX: 239,196, UTMY: 4,281,346]

Qau_2 **Alluvium two of the Uncompahgre River (Holocene to late Pleistocene) –** Gravel, sand, silt, and clay in low terraces above the Uncompahgre River geomorphic flood plain. Small boulders up to 2 ft in diameter are occasionally found within the deposit. The unit is widespread to the west of the quadrangle (Morgan and others, 2008). Sinnock (1978) interpreted it as being associated with the Pinedale glacial stage. The upper surface forms a terrace 10 ft above the modern river. The unit is poorly exposed. Thickness observed in gravel pits exceeds 20 ft. Water-well GIS files from the Colorado Department of Water Resources show that the maximum thickness may be around 40 ft.

Qau_3 **Alluvium three of the Uncompahgre River (late Pleistocene) –** Bouldery gravel and sand with minor silt and clay. The unit forms terraces that cap a series of small mesas near US Highway 50. Boulders up to 5 ft in diameter, which include rounded quartzite, conglomerate, and Dakota Sandstone boulders, are common in the lower part (**Figure 4**). Poor sorting and large clast sizes indicate that the unit was deposited, at least in part, by large-magnitude, torrential floods of glacial outwash. The unit fines upward to sand, silt, and clay. The soil profile includes poorly developed A and Bt horizons. Sinnock (1978) interpreted the unit as Pinedale in age. Terraces are up to 50 ft above current stream level. Thickness locally exceeds 20 ft.

Figure 4. Alluvium three of the Uncompahgre River (**Qau_3**), exposed in a railroad cut. Boulder-rich layers are visible in the foreground, near the base of the deposit. Sand-rich layers make up the knob in the left background, near top of the mesa. [UTMX:239,128 , UTMY: 4,283,798]

Qau **Alluvium of the Uncompahgre River, undivided (late Pleistocene)** — Gravel, sand, silt, and clay in a localized terrace along the eastern margin of the river valley. The deposit could not be correlated with other, more widespread terraces in the area. The dominant sediment is pebble-cobble gravel with a coarse sand matrix. Scattered, small boulders up to 2 ft in diameter are present. The upper part may contain fine-grained fan sediments from tributary streams in the adjacent “Adobe hills.” The terrace reaches a maximum height of 30 ft above current stream level. It occupies a stratigraphic elevation between the **Qau_2** and **Qau_3** deposits. Thickness locally exceeds 20 ft.

Alluvial Deposits of the Gunnison River

Gravel, sand, silt, and clay deposited by the ancestral Gunnison River. The modern Gunnison River valley is located to the north of the Olathe Northwest quadrangle. Several levels of older deposits are present as alluvial terraces that increase in age with increasing height above the modern river. These deposits cover extensive areas to the north and northwest of the mapped area. Two of those terrace units (**Qag_4** and **Qag_5**) and one local terrace deposit (**Qag**) are found in the quadrangle. Top-of-terrace elevation gradients are similar to the modern river gradient.

The gravel-clast compositions within these deposits consist primarily of dark vesicular basalt, gray porphyry, green-black to black hornfels, pink granite and pegmatite, and pinkish-gray gneiss, with lesser amounts of purple rhyolite, black schist and amphibolite, and gray to greenish-gray quartzite. Sources of the clasts include Grand Mesa, the West Elk and San Juan Mountains, and the Black Canyon of the Gunnison. The gravel is typically encased in a course, basalt-rich sand matrix. Overall, the sediments are light to dark gray in color (**Figure 5**).

Figure 5. Alluvium four of the Gunnison River (**Qag_4**), exposed in the wall of a gravel pit. The deposit consists of monochromatic, grayish pebbles and cobbles in a coarse-sand matrix. Compare this with the multi-colored Uncompahgre River gravel in **Figure 3**. [UTMX: 239,690, UTMY:4,293,223]

Qag_4 **Alluvium four of the Gunnison River (late middle Pleistocene) –** Gravel and sand with minor silt and clay. The unit forms dissected, remnant terraces. Clasts are sub-rounded to well rounded (**Figure 5**). The gravel contains occasional small boulders up to 2 ft in diameter. The capping soil typically consists of A/Bwk/Bky horizons (Stage I+ of Machette, 1985). Sinnock (1978) interpreted this deposit as being associated with the Bull Lake glacial stage. The terraces reach a maximum height of 180 ft above current stream level. Thickness locally exceeds 20 ft.

Qag_5 **Alluvium five of the Gunnison River (late middle Pleistocene) –** Gravel and sand with minor silt and clay. The alluvium forms a broad gravel cap on "Star Nelson Airport Mesa." The sediment is similar to that in unit **Qag_4**. However, a road cut on the southeastern side of the mesa exposes a lens of debris flow deposits overlain by stream deposits (**Figure 6**). This location may be along the southern bank of the paleo river, where episodic debris flows entered the main valley from tributary streams. Former low areas in the top surface are filled with up to 5 ft of eolian sand (not mapped separately). Sinnock (1978) gave a Bull Lake age for the unit. Terraces reach a maximum height of 270 ft above current stream level. Thickness is up to 25 ft.

Qag **Alluvium of the Gunnison River, undifferentiated (late middle Pleistocene) –** Gravel and sand in a small butte that rises above the Qag_5 terrace surface on "Star Nelson Airport Mesa." The sediment is similar to that of the other Gunnison River terrace deposits. This localized terrace could not be correlated with other, more widespread terraces in the area. Thickness is 15 ft.

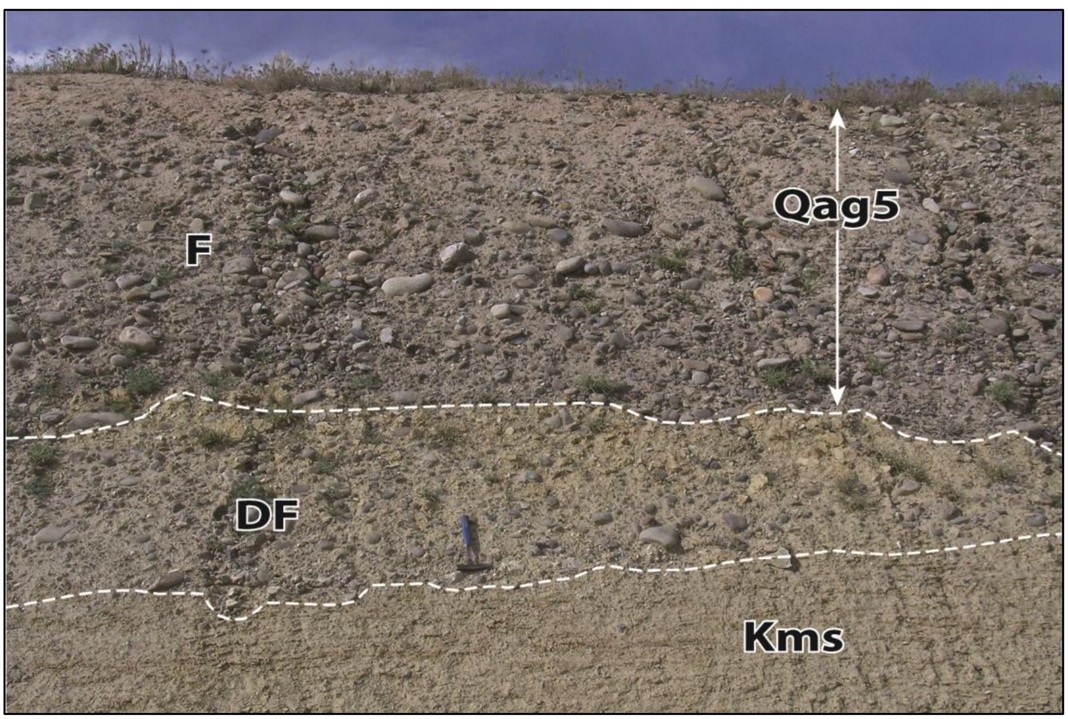

Figure 6. Alluvium five of the Gunnison River (**Qag_5**) exposed in a road cut on "Star Nelson Airport Mesa." Clast-supported, rounded, fluvial-outwash gravel (**F**) overlies a lens of mud-matrix-supported, debris-flow gravel (**DF**). The deposits overlie sandy shale of the Smoky Hill Member of the Mancos Shale (**Kms**). [UTMX: 239,938, UTMY:4,292,396]

Mud Flow and Alluvial Fan Deposits

Qamf **Alluvial, mud flow, and mud fan deposits (Holocene to late Pleistocene) –** Grayish-pink to grayish-orange to medium-gray, well to poorly sorted, poorly consolidated, locally gravel-bearing, clayey to sandy silt. The muddy sediments are mostly derived from Mancos Shale. The deposits are associated with complex alluvial and alluvial fan systems along tributary streams and in broad basins. The unit forms valley-head and valley-side alluvial fans, tributary stream valley fills, and coalescing fans in broad basins within the "Adobe hills." It forms low-gradient mud fans that cover large areas of the modern Uncompahgre River floodplain.

The deposits primarily consist of poorly defined silt layers, typically less than an inch to a few inches thick (**Figure 7a**). The layers record individual mud flow events. There are locally stringers and lenses of gravel and sand, especially in the basal deposits and in the vicinity of sand and gravel sources. Sandstone-fragment-bearing gravel deposits of Holocene age are found along the eastern side of Peach Valley, in channels that drain the base of the Dakota Sandstone dip slope. Because the gravel bodies are limited in extent and grade downstream into mud flow deposits, we map them as part of the **Qamf** mud flow map unit. Many of the mud flow deposits have been deeply dissected by stream erosion during the late Holocene, resulting in narrow arroyos that are 10 to 25 ft deep along the valley bottoms. The arroyo walls are easily eroded and often contain evidence of collapse and piping (**Figure 7b**).

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 radiocarbon dating of a bulk sample recovered near the base of a **Qamf** deposit in upper Loutsenhizer Arroyo. Thickness is 5 to 10 ft in valley-head areas and may exceed 25 ft along valley reaches and in basins and terminal fans.

Mixed Debris Flow and Alluvial Gravel Deposits

Gravel, sand, silt, and clay deposited in tributary streams along former courses of Peach Valley. Upland gravel deposits of various ages (**Qg**-series) occur mostly in the eastern part of the quadrangle. They form a series of elevated and dissected, gravel-capped mesas having linear to fan-like geometries. From younger to older, the remnants stand at progressively higher elevations. In the Orchard City quadrangle to the north, the downstream end of gravel **Qg$_3$** grades to and overlies the **Qag$_3$** Gunnison River gravel terrace (Noe and others, in prep., c). This establishes a rough age equivalence between the main stream and tributary deposits. CGS is defining associations between paired river and tributary gravels along the Gunnison River valley (Noe and others, in prep., a-b-c). We use those associations to assign ages and terrace-level equivalence for tributary gravel units in the Olathe Northwest quadrangle.

The gravel bodies contain sub-angular, very poorly sorted, poorly stratified pebbles to boulders in a mud matrix (**Figure 8a**). We interpret these to be debris flow deposits. Occasional lenses of moderately sorted, clast-supported gravel and sand are interpreted to be alluvial deposits (**Figure 8b**).

There are two, north-south belts of **Qg**-series deposits in the Peach Valley area that differ in their geometry and composition. The eastern belt lies at the foot of the Dakota dip slope. The upper and

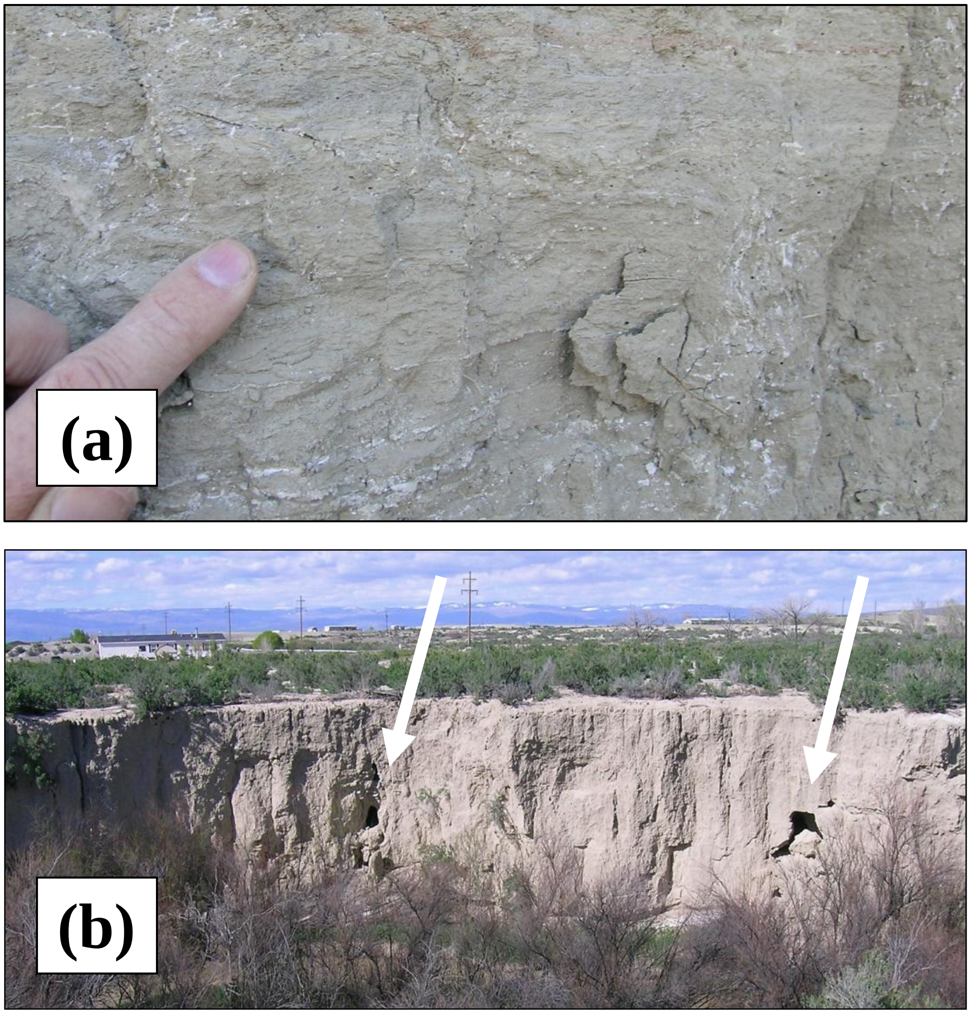

Figure 7. Mud flow deposits (**Qamf**) along incised reaches of Loutsenhizer Arroyo.
(a) Typical, faintly laminated, clayey to sandy silt beds. The deposits show abundant macro pores, sulfate accumulation along rootlets, and slightly organic paleosol horizons. [UTMX: 243,247, UTMY: 4,279,588]
(b) Two “mud caves” (arrows), caused by the piping erosion and subsequent collapse of silt-rich mud flow sediments. [UTMX: 241,653, UTMY: 4,282,082]

There are two, north-south belts of **Qg**-series deposits in the Peach Valley area that differ in their geometry and composition. The eastern belt lies at the foot of the Dakota dip slope. The upper and basal surfaces of those gravel bodies slope downward to the west, toward the valley. They appear to be former alluvial fans and fan aprons, associated with small canyons or at the foot of steeper slopes. The sediment consists of sand, mud, and granule-to-boulder sized, angular fragments of locally derived sandstone. The individual fan and fan apron deposits range from 0.2 to 0.8 miles wide.

The western belt contains deposits that are elongate in the north-south direction. They comprise a series of mesa-capping gravels or gravel benches, mostly along the western side of Peach Valley. Their upper and basal surfaces slope gently downward to the north. We interpret those linear gravel bodies

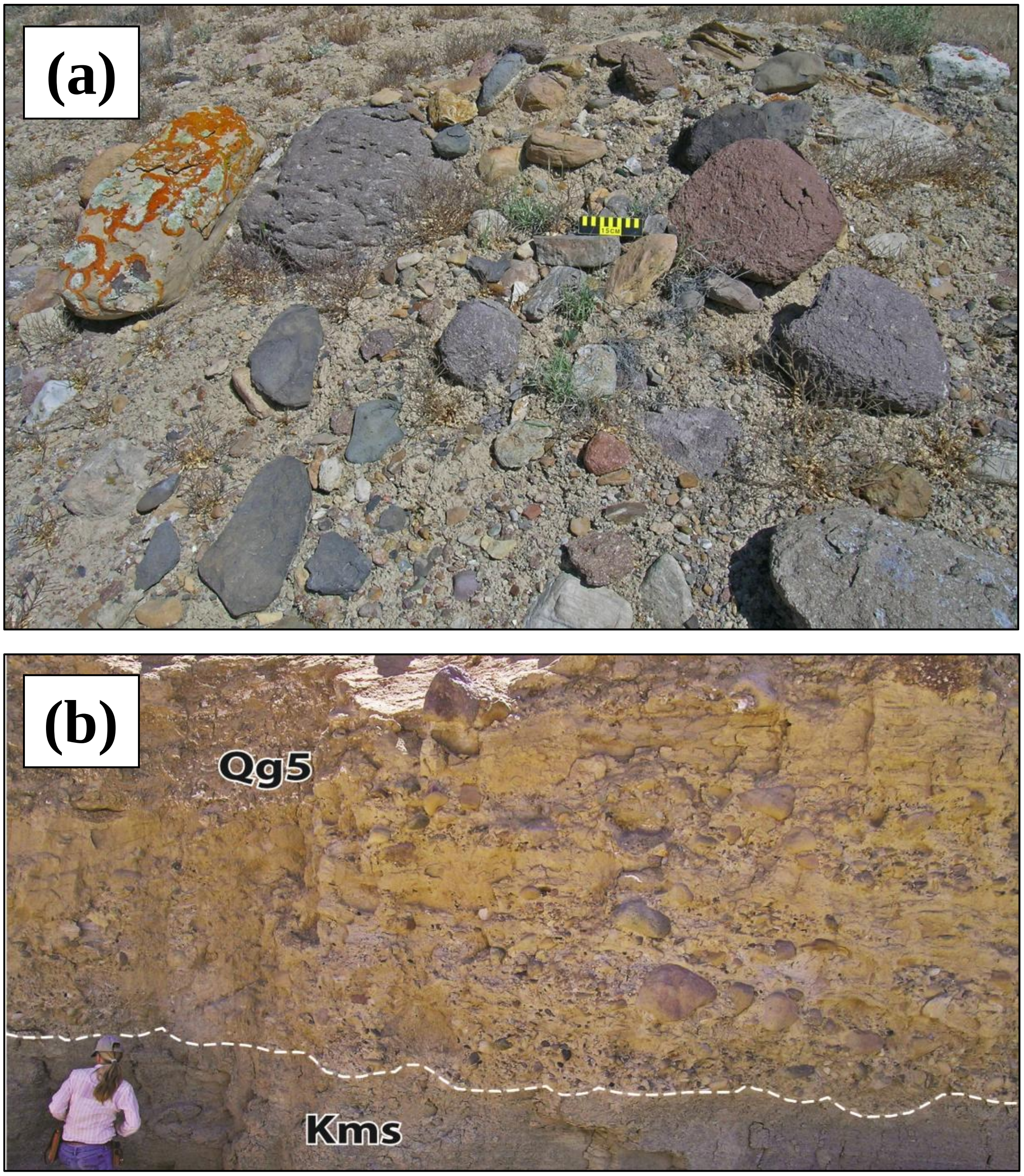

Figure 8. Mixed debris flow and alluvial gravel deposits (**Qg** series) on mesas to the west of Peach Valley. **(a)** Poorly sorted pebbles, cobbles, and small boulders of mixed composition in a mud matrix, on gravel deposit three (**Qg$_3$**). Scale is 15 cm (approximately 6 in) long. [UTMX: 246,836, UTMY: 4,279,456]
(b) Interbedded lenses of debris flow gravel and alluvial sand, in gravel deposit five (**Qg$_5$**). The basal erosion surface is visible across the lower part of the photo. It is cut into gray, sandy shale of the Smoky Hill Member of the Mancos Shale (**Kms**). [UTMX: 246,513, UTMY: 4,280,077].

to be valley fill deposits along bedrock-confined paleo streams. The valleys were up to 0.5 miles wide. The gravel mostly contains clasts of pale-red-purple to pale-purple rhyolite tuff and olive-gray andesite. Clasts of rhyolite porphyry, basalt, metaquartzite, granite, vein quartz, dark chert, and andesitic and rhyolitic breccias are present in lesser amounts. These rocks are derived from Cimarron Ridge and the

San Juan Mountains to the southeast. Most of them appear to be reworked from older gravel deposits of the Shinn Park-Bostwick Park paleo valley, of middle Pleistocene age (Dickinson, 1966; Aslan and others, 2008). Reworked, sub-rounded sandstone fragments are present in variable amounts.

We did not map a 'Gravel deposit one' (Holocene) unit. Sandy gravel deposits occur in local canyons in the Dakota dip slope and in dry washes in the Mancos Shale within a half-mile of the dip slope. Because they are generally limited in extent and grade downstream into mud flow deposits, we map those deposits as part of the alluvial mud flow map unit (**Qamf**).

Qg$_2$ **Gravel deposit two (late Pleistocene) –** Gravel, sand, silt, and clay. The unit forms small fans near local dry washes and low, dissected terraces along the flanks of modern tributary stream valleys. Most of the unit has been removed by Holocene erosion. The downstream end of its upper surfaces are 5 to 20 ft above the modern valley bottom. Thickness is 5 to 15 ft.

Qg$_3$ **Gravel deposit three (late Pleistocene) –** Gravel, clay, silt, and sand. The unit forms dissected fans and terraces along both sides of Peach Valley. It forms fan aprons in the northwestern corner of the quadrangle. It contains debris flow deposits similar to those shown in **Figure 8a**. In the southern part of the quadrangle, there are boulders of tuff (up to 3.5 ft long), sandstone (4 ft), and basalt (1.5 ft). In the northern part of the quadrangle, the deposit consists of pebbly, sandstone-clast-rich, debris flow gravel. **Qg$_3$** fan deposits along a 1.5-mile-long segment at the foot of the Dakota dip slope (Sec. 27 and 34, T 15S, R 9W) are unusual in that they are a bright, moderate to dusky red. These colors reflect a high iron content (see **Landslide** unit description and **Mineral Resources** section below for further discussions). The upper surface of the unit is 20 to 40 ft above the modern valley bottom. Thickness is 10 to 20 ft.

Qg$_4$ **Gravel deposit four (late middle Pleistocene) –** Gravel, clay, silt, and sand. The unit forms small, remnant terraces to the west of Peach Valley and small, remnant fans to the east. In addition, it caps two low hills to the west of Loutsenhizer Arroyo. Its upper surface is 25 to 60 ft above the modern valley bottoms. Thickness is 10 to 15 ft.

Qg$_5$ **Gravel deposit five (late middle Pleistocene) –** Gravel, clay, silt, and sand. The unit forms a string of elongate, dissected mesas to the west of Peach Valley. It contains mixed debris flow and sandy alluvial deposits. A sand lens in the general location of **Figure 8b** was age dated using optical dating (also known as optically-stimulated luminescence or OSL dating) methods. An age-limited result of >70 ka was obtained (see **Appendix B**). The deposits are capped by a few feet of finer-grained sand and silt that are possibly eolian in origin. The silt contains a diffuse, calcic soil horizon (Stage III). The upper surface of the unit is 80 to 90 ft above the modern valley bottom. Thickness is 15 to 20 ft.

Qg$_6$ **Gravel deposit six (middle Pleistocene) –** Gravel, clay, silt, and sand. The unit forms a single, high mesa at the southern edge of the quadrangle. (It continues to the south, into the Olathe quadrangle, where Morgan and others (2007) map it as their unit **Qg$_3$**.) Debris flows are the dominant facies, with local accumulations of tuff boulders up to 5 ft long. The deposit is capped by a few feet of finer-grained sand and silt that are possibly eolian in origin. The silt contains a red-and-white, heavily mottled, calcic soil horizon (Stage III+). The unit's upper surface is 160 ft above the modern valley bottom. Thickness is 10 to 25 ft.

EOLIAN DEPOSITS

Qes **Shale-particle dune deposits (Holocene) –** Silty clay, medium-gray to grayish-orange-pink. We mapped a single shale-particle dune. It is located near the southern edge of the map, atop a **Qg$_6$** gravel deposit (**Figure 9a**). The dune is at the mesa's edge, above a slope of Mancos Shale that

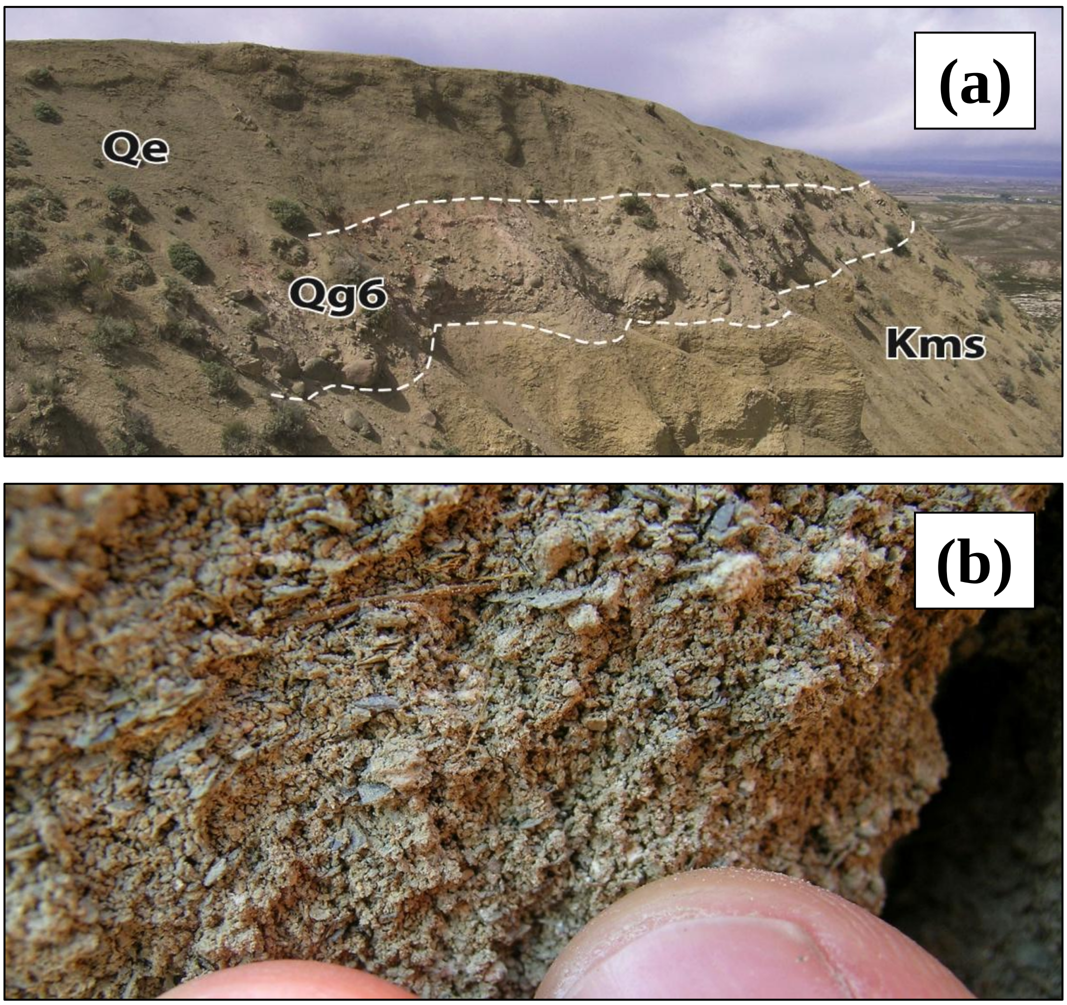

Figure 9. Shale-particle eolian dune (**Qe**) formed upon an older gravel deposit.
(a) Shale-particle dune (**Qe**) overlying gravel **Qg$_6$** and an actively eroding outcrop of Mancos Shale (Smoky Hill Member, **Kms**). Shale chips are eroded by the wind and blown up and over the lip of the cliff, forming the dune. The cliff-side face of the dune is undergoing wind erosion as well, apparently as a result of slope retreat. [UTMX: 247,479, UTMY: 4,279,358]
(b) Close-up photo of the wall of a trench dug into the dune. The sediment is a mix of fresh, gray shale chips and smaller, light-brown aggregates of clay particles. It is porous and has a disturbed texture.

is being actively eroded by the wind. It contains shale chips and smaller particles and is subtly laminated. The sediment is granular, porous, and somewhat disturbed (**Figure 9b**). This may be due to in-place swelling and shrinking of shale particles during alternating periods of wetting and drying. The dune is 10 ft thick and is 200 ft long at the cliff edge. Its upper surface gradually tapers downward and grades onto the mesa top, thinning to zero thickness within 100 ft.

MASS WASTING DEPOSITS

Qls **Landslide deposits (Holocene to middle Pleistocene) –** Unsorted to moderately sorted clay, silt, sand, gravel, and sedimentary rock fragments and blocks. The deposits record the failure of a hill slope and the down-slope movement of debris, either within an individual landslide or a larger landslide complex. The matrix and rock types, compositions, and sizes of fragments present reflect the properties of the local source area. In the Olathe Northwest quadrangle, small, rotational landslides occasionally form in mesa side slopes composed of shale. Upland gravels from the mesa edges may be incorporated into the landslide as part of the slope failure. The rotational landslides are Holocene in age. Thickness is up to 20 ft.

Block-glide landslides (**Figure 10**) are distinctive Quaternary features in the study area. They consist of masses of stratified Dakota Sandstone that have failed along weak bedding planes. The slide planes are typically within shaly zones in the middle and upper parts of the formation. The landslides occur on the gently dipping Dakota dip slope along the far eastern side of the quadrangle. They also occur on the steeply dipping, southwestern flank of the Smiths Mountain monocline in the northeastern corner. In size, the landslides range from individual small blocks

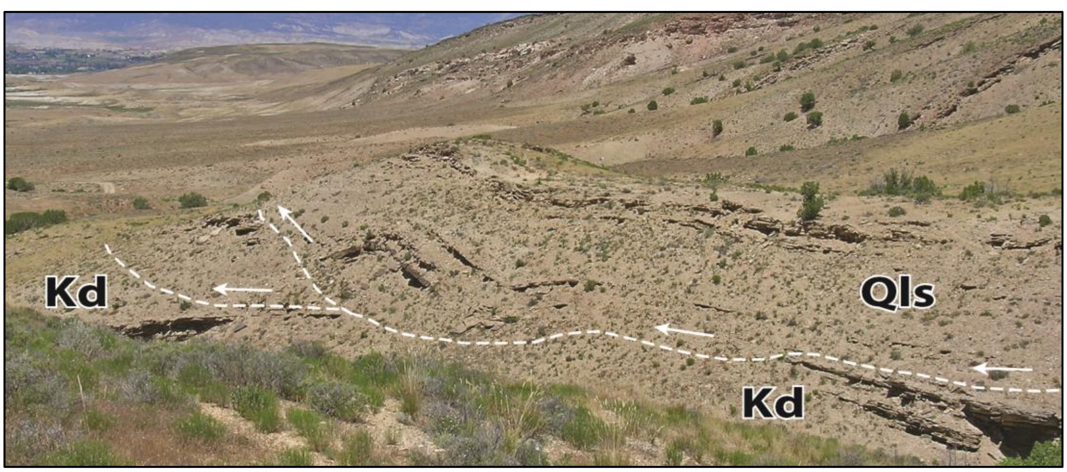

Figure 10. Block-glide landslide (**Qls**) at the base of the Smiths Mountain monocline. Here, the slide block consists of folded and kinked layers of the upper Dakota Sandstone. It slid downhill (right to left) from the steeply dipping slope in the background, overriding gently dipping, relatively undisturbed, in-place Dakota Sandstone (**Kd**). Internal thrusting within the slide toe is evidenced by a change in bedding orientation. [UTMX: 248,988, UTMY: 4,291,253]

to very large complexes that cover tens to hundreds of acres. The complexes contain numerous sub-blocks that have different movement paths. Detachment head scarps are rarely present.

The block-glide landslides appear to form uphill from places where the strata lose confining support. In particular, many of them occur uphill from small canyons that are incised obliquely across the dip slope or where several small canyons meet. Bedding within the blocks is often deformed. The deformations include internal shearing, and folding, kinking, back-tilting, and rotation of sandstone beds. The landslide surface often has randomly scattered sandstone blocks and upturned, "tombstones" that are oriented differently than the prevailing, regional strike and dip orientation. We used such features to differentiate the landslides from flanking or underlying, in-place bedrock. The compressive, lower terminus of some of the landslide bodies may feature over-thrusted sub-blocks (**Figures 10** and **11**) or large-scale folds.

A number of the landslides grade to the **Qg$_3$** gravel-fan deposits along the lower boundary of the Dakota dip slope. This establishes a late Pleistocene age for those features. Some of the landslides may be as old as middle Pleistocene, based on geomorphology and high landscape position. A few appear to be active at the present time. They show signs of slide-mass creeping and stratum-kinking at locations where Holocene canyon incision undercuts the landslide toes. At the county line on the eastern edge of the map, an active block-glide landslide grades to the modern valley level. It has advanced into and displaced irregular shale bodies of the Graneros Member of the Mancos Shale.

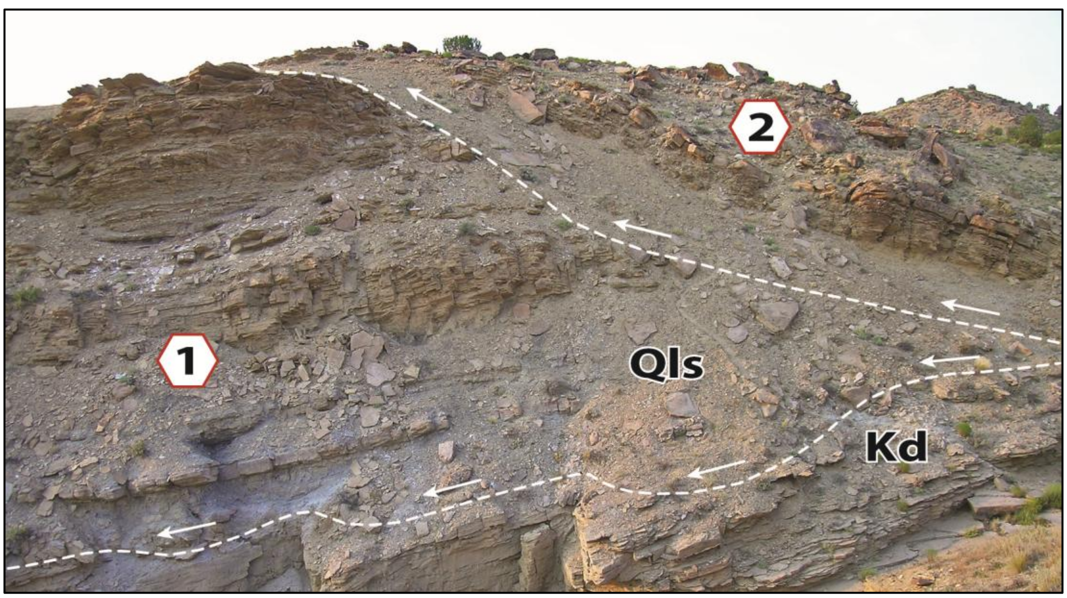

Figure 11. Deformation features in a block-glide landslide (**Qls**) formed upon the Dakota dip slope. Two landslide sub-blocks are exposed at the toe of a large block-glide landslide complex. Sub-block 2 is thrusted over the top of 1 as a result of toe compression. The sub-blocks were originally from the same stratum. Direction of sliding is right to left. Undisturbed, in-place Dakota Sandstone (**Kd**) underlies the landslide. [UTMX: 248,371, UTMY: 4,287,788]

High ground-water tables may have influenced landslide activity during Pleistocene glacial periods. Evidence for this exists at a previously mentioned location where a large block-glide landslide complex grades into **Qg_3** debris-flow fan deposits [UTMX: 248,282, UTMY: 4,288,903]. There, we found the two deposits to be laterally equivalent, with a gradational contact. It appears that the debris flows emanated from the landslide toe as it moved and fluidized. The debris flow and landslide toe deposits contain high amounts of iron. The iron occurs as a matrix cement, and at the ground surface as laminated, shield-shaped iron mounds (See **Mineral Resources** section). Ferrocrete breccias and iron mounds occur today in the nearby Gunnison River gorge (Cadigan and others, 1976; Noe and others, in prep., c). They form and aggrade where mineral springs discharge at the ground surface. Cadigan and others concluded that the springs are sourced by deeper formation waters via faults. We infer that similar, fault-sourced springs were active along the Dakota dip slope during the late Pleistocene. This would have coincided with a time of high regional ground-water levels from glacier and snow melt and outwash runoff. We found no evidence of active springs in the area at the present time.

Thickness of the block-glide landslides may vary considerably. They are typically 5 to 25 ft thick. However, they may approach 50 to 100 ft in thickness in landslide toes where the slide migrated into formerly incised and eroded areas and aggraded due to thrust stacking.

BEDROCK UNITS

A 1,600-ft-thick interval of Upper Cretaceous to Upper Jurassic sedimentary formations is exposed in the Olathe Northwest quadrangle. The oldest units are found in the Gunnison Uplift area, along the eastern side of the map. There, the main units are the Dakota Sandstone, which forms a highly resistant surface that defines the outer extent of the uplift, and the underlying Morrison Formation. The remainder of the map area lies within the outcrop belt of the Mancos Shale. The youngest strata are possibly from the middle part of the Smoky Hill Member. A generalized stratigraphic column of the mapped bedrock formations and members is shown in **Figure 12**. Thickness ranges of the bedrock units are derived from nearby oil-and-gas well logs, and from a USGS core (Ball and others, 2010) that was drilled at "Candy Lane," just to the south of the quadrangle

CGS STATEMAP geologic mapping includes the collection and cataloging of fossils. We collected marine invertebrate fossils of Late Cretaceous age from several locations in the quadrangle. The fossils are potentially useful as paleo-environmental or biostratigraphic-age indicators. **Appendix C** contains a listing of fossils found in and near to the quadrangle by CGS and previous authors.

Mancos Shale (Upper Cretaceous)

The Mancos Shale is marine in origin (Cross and Purington, 1899; McGookey and others, 1972). It consists of clayey to sandy to calcareous shale with minor limestone, sandstone, and bentonite beds. We recognize nine members of the Mancos Shale in the quadrangle. They are distinguished on the basis

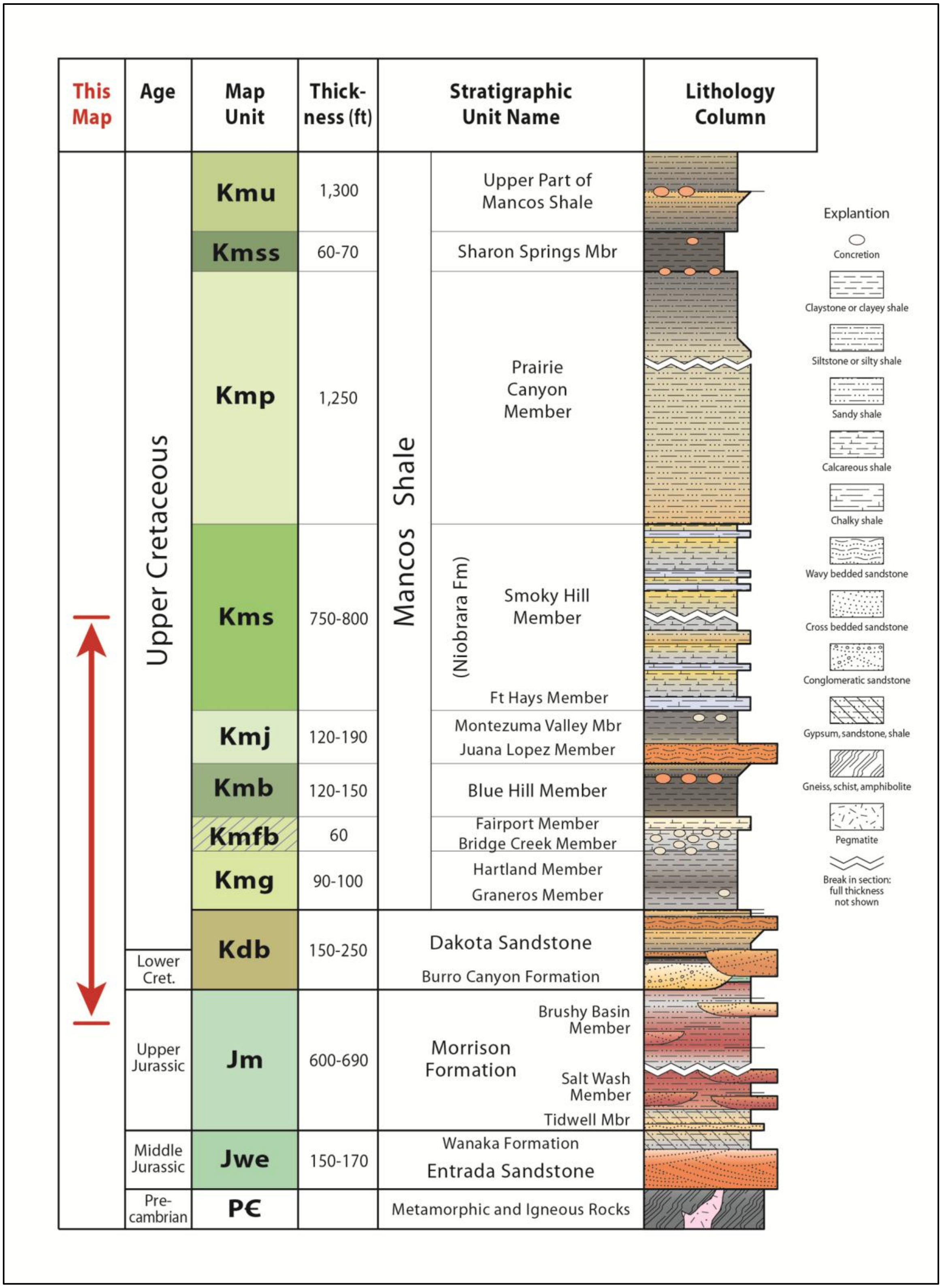

Figure 12. Generalized stratigraphic column of bedrock units for the Olathe Northwest quadrangle. Red arrow denotes bedrock units exposed in outcrops in the quadrangle and shown on the geologic map.

of composition, color, and fossil assemblages. Their contacts are conformable unless indicated. Some of the thinner members are grouped with other bedrock units on the geologic map (**Plate 1**).

Kms **Smoky Hill and Fort Hays (Niobrara) Members, undivided** — Dark-gray to light-gray, slightly calcareous to calcareous shale. Weathers to a distinctive pale yellowish orange or very pale-brown color, known locally as "Mancos blonde." The Smoky Hill Member is distinguished by the presence of thick-shelled *Inoceramus* fragments (including *I. platinus* and *Magadiceramus subquadratus*), often encrusted with *Pseudoperna congesta* oysters. Freshly exposed bedding planes are speckled with small, white, forams and coccoliths. The calcareous zones contain occasional limestone beds (peloid-rich mudstone or packstone) up to 2 ft thick. Seams of fibrous gypsum are present throughout the unit. Although widespread in outcrop, the Smoky Hill Member is often covered by thin residuum and is poorly exposed.

A 40-ft-thick, sandy shale zone, which contains *Baculites codyensis* and *B. thomi* ammonite fossils, is present in the lower middle part. It consists of light-gray to pale-yellowish-brown, silty and sandy shale that weathers grayish orange to grayish yellow (**Figure 13**). It contains rounded to irregular discs of very fine, bioturbated sandstone. The sandy shale is similar to that in the Prairie Canyon Member in its type section near Grand Junction (Cole and others, 1997) and in Montrose area outcrops (Noe and others, 2007). Morgan and others (2007) mapped this zone as the Prairie Canyon Member in the Delta quadrangle. However, basal Prairie Canyon strata

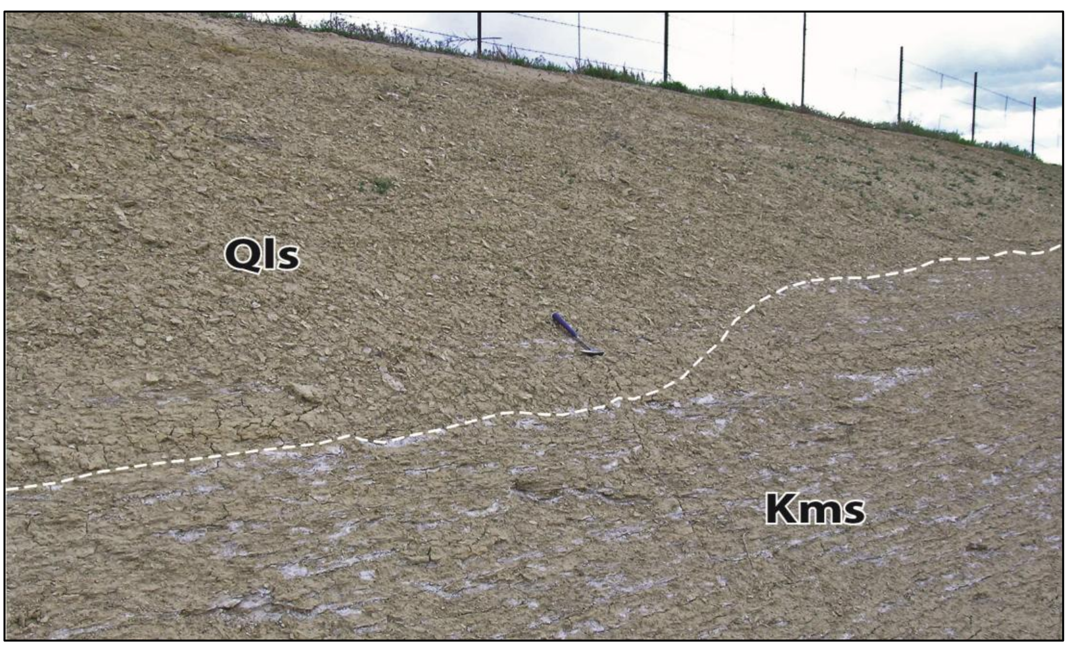

Figure 13. Sandy interval within Smoky Hill (**Kms**) Member of the Mancos Shale near Star Nelson Airport. The outcrop consists of faintly laminated, sandy shale. It is overlain by similar but disturbed strata that we interpret to be a remnant, shale-block landslide (unit **Qls**). [UTMX: 239,862, UTMY: 4,292,372]

contain *Scaphites hippocrepis* ammonite fossils in the nearby North Delta quadrangle (Noe and others, in prep., b); therefore that unit is older than the sandy zone described herein.

The Fort Hays Member forms the basal part of the Niobrara interval. It is highly calcareous and very poorly exposed. In most locations, it consists of very light gray residuum. We found a single outcrop of the Fort Hays Members in an irrigation ditch cut (**Figure 14**). The unit overlies a regional unconformity (Weimer, 1983). Thickness of the Smoky Hill Member is 700 ft. The Fort Hays Member is 60 to 90 ft thick.

Kmj **Montezuma Valley and Juana Lopez Members, undivided** — The Montezuma Valley Member is a medium-dark-gray shale. It is typically poorly exposed. The underlying Juana Lopez Member is medium gray to black; in outcrop, it weathers to light red or moderate reddish orange. It consists of 1- to 6-inch-thick interbeds of rippled calcarenite and organic-rich shale. The calcarenite beds contain shell hash and broken inoceramids (*I. Dimidius*), small oysters (*Lopha lugubris*), and coiled ammonites (*Prionocyclus macombi*). The beds are seldom in place; they are usually strewn as angular fragments across the outcrop. The Juana Lopez Member forms minor hogbacks along the eastern and western sides of Peach Valley. Thickness of the Montezuma Valley Member is 50 to 60 ft. The Juana Lopez Member is 70 to 140 ft thick.

Kmb **Blue Hill Member** — Medium-gray to black, glauconitic, pyritic, non-calcareous shale. The unit is mostly non-fossiliferous. The upper part consists of platy, silty shale with seams of gypsum along bedding planes and fractures. The bedding surfaces often contain coatings of yellow residue, presumably related to sulfide (pyrite) oxidation. Small concretions and starved, glauconitic-sand ripples occur in the uppermost 40 ft (**Figure 15**). We collected a specimen of

Figure 14. Fort Hays Member (part of unit **Kms**) of the Mancos Shale exposed in an irrigation ditch cut. This member, which is the basal part of the Niobrara interval, lies unconformably over uniform, gray shales of the Montezuma Valley Member (part of unit **Kmj**). Here, the Fort Hays consists of thin beds of gray calcareous shale, light-brown marl, and whitish limestone. [UTMX: 246,825, UTMY: 4,284,779]

the coiled ammonite, *Prionocyclus hyatti* (**Figure 25**, in **Appendix C**) and occasional juvenile *I. dimidius* shells near the top. The middle part of the unit is fissile shale with distinct bedding planes and bentonite beds. The lower part is slightly silty, wavy-bedded, fissile shale. It becomes brownish black near the base of the unit. Thickness is 120 to 150 ft.

Figure 15. Blue Hill (**Kmb**) Member of the Mancos Shale near Peach Valley.
The uppermost part of the unit is shown. It consists of well-stratified, papery black shale with starved glauconite ripples and ovoid concretions. The arrows point to a crushed ammonite specimen that we recovered for the USGS Western Interior fossil collection (locality D14793; see **Figure 25** and listing in **Appendix C**). [UTMX: 247,632, UTMY: 4,281,859]

Kmfb **Fairport and Bridge Creek Members, undivided** — The Fairport Member consists of pinkish-gray to very-pale-orange, calcareous chalky shale, calcarenite, and bentonite. The units appear as a light-colored zone within a predominantly darker shale section. Good outcrop exposures are non-existent; the zone is typically deeply weathered to residuum. Ball and others (2010) described 22 ft of Fairport strata from the USGS core at Candy Lane, just to the south of the quadrangle. The Fairport-Bridge Creek contact in western Colorado is an unconformity that is sub-regional in extent (Merewether and Cobban, 1986). The Bridge Creek Member consists of light- brownish-gray, slightly to moderately calcareous, silty shale. We collected *Pycnodonte newberryi* oysters from three locations in or near the quadrangle, at the Fairport/Bridge Creek contact. Specimens beneath the contact (in Bridge Creek) contain smaller, tightly curved upper valves. Specimens overlying the contact (in Fairport) contain larger and slightly flattened upper valves (following a discussion with W.A. Cobban, USGS, we list this larger form as "*Pycnodonte aff. P. newberryi*" in **Appendix C**). Thickness is 60 ft.

Kmg **Hartland and Graneros Members, undivided** — Light brownish gray to medium gray, non-calcareous, clayey to silty shale. The unit contains a few large, light gray concretions. We found a single, Upper Cenomanian-age bivalve fossil (*Incoceramus pictus*?). Merewether and Cobban (2006) collected fossils Middle Cenomanian-age fossils, including *Inoceramus macconnelli*, from a site within the quadrangle in 1982. Although other authors call this entire unit the Graneros Member in western Colorado (for example, Leckie and others, 1997), Merewether and Cobban (1986) indicate that its upper part is age-equivalent to the younger, Hartland Shale of eastern Colorado. We were not able to distinguish between the two units because of the weathered condition of the outcrops and the near absence of fossils. Thickness is 90 to 100 ft.

Older Bedrock Units Shown on Geologic Map

Two older sedimentary rock units are shown on the geologic map. They are the undivided Dakota Sandstone and Burro Canyon Formation and the Morrison Formation.

Kdb **Dakota Sandstone and Burro Canyon Formation, undivided (Upper and Lower Cretaceous)** — The **Dakota Sandstone** makes up most of this mapping unit. It forms the main hogbacks that comprise the Gunnison Uplift in the eastern part of the quadrangle and the Smiths Mountain monocline in the northeastern corner. It consists of interbedded sandstone, shale, and minor coal. It forms the resistant hogback slopes on the flanks of the Gunnison Uplift. There are two sub-units. The upper sub-unit consists of interbedded shale and sandstone (**Figure 16a**). The shale is grayish orange pink to light brown, sandy, and contains thin sandstone interbeds. Shale intervals are up to 10 ft thick. The sandstone is light brown to grayish red, and very fine to fine grained. It is sparsely bioturbated, locally, with *Skolithos*, *Ophiomorpha*, and *Thalassianoides* borrows. The sandstone beds are up to 5 ft thick and have rippled bedding, hummocky cross stratification, and low-angle, swaley and trough cross bedding. Occasionally, large channel-like sandstone bodies occur in upper sub-unit (**Figure 16b**). The channels are up to 15 ft thick. They contain trough cross beds that have mud-draped, rippled foresets and locally abundant mud rip-up clasts. The cross beds are up to 10's of ft long in the direction of current flow. They contain mud chips and show mostly unidirectional flow (in one case, a mean flow direction of S 27° E), with a few oriented in the opposite direction (indicating bi-directional flow).

The lower Dakota Sandstone sub-unit is variable in thickness and contains lenticular to tabular bodies of sandstone, carbonaceous shale, and coal. The sandstone is fine to coarse grained, with beds up to 15 ft thick. The sandstone lenses contain trough cross-bedding with locally common soft sediment deformation. The carbonaceous shale beds are typically less than 2 ft thick. The coal occurs as thin stringers less than 1 ft thick. Dinosaur tracks are locally abundant. The Dakota Sandstone is Upper Cretaceous (Cenomanian) in age in west-central Colorado (Merewether and Cobban, 1986). Its contact with the Burro Canyon Formation is unconformable. Thickness varies from 100 to 130 ft.

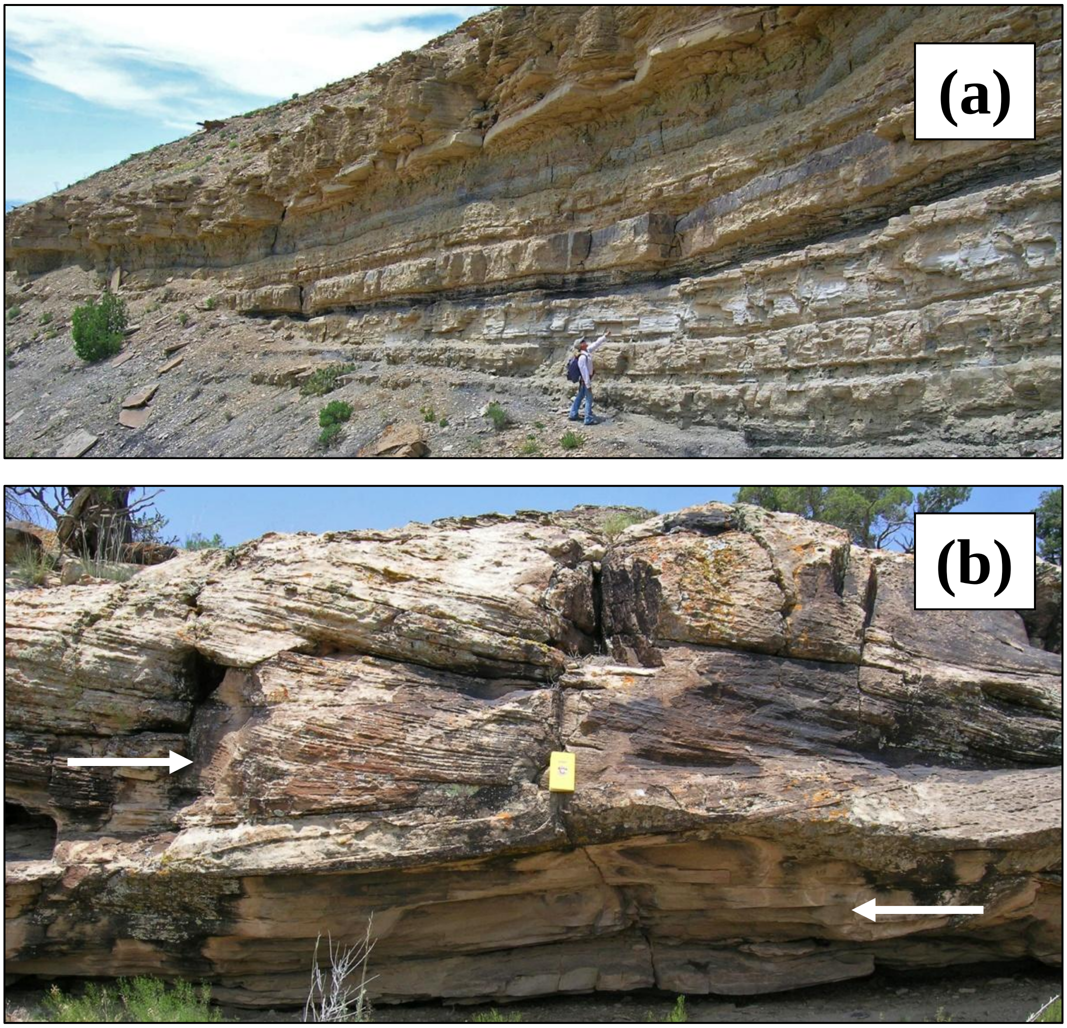

Figure 16. Dakota Sandstone (of map unit **Kdb**) exposed on the Gunnison Uplift dip slope.
(a) Dakota Sandstone exposed in a small canyon. The upper part of the cliff face contains sandy gray shale and thin-bedded, hummocky sandstone. The lower part contains carbonaceous shale and tabular sandstone beds. [UTMX: 247,757, UTMY: 4,284,044]
(b) Channel-like sandstone in upper sub-unit of the Dakota Sandstone. It contains cross beds with thin, internal mud drapes and mud chips. The cross beds are mostly unidirectional, although this photo shows bi-directional bed sets (arrows show flow directions). [UTMX: 249,442, UTMY: 4,287,612]

The **Burro Canyon Formation** contains conglomerate, sandstone, and shale. Conglomerate or conglomeratic sandstone bodies are lenticular and fill paleo lows eroded into the underlying Morrison Formation. They contain very coarse, cross-bedded sandstone and contain variable amounts of light- to medium-gray chert pebbles and granules (**Figure 17**). The chert clasts are well rounded and less than 0.5 inches in diameter. The Burro Canyon-Morrison contact is unconformable. The Burro Canyon Formation forms cliffs up to 100 ft thick. In other places it is absent, and the Dakota Sandstone rests directly upon the Morrison Formation.

Figure 17. Burro Canyon Formation (of unit **Kdb**) exposed in a small canyon on the Gunnison Uplift. This outcrop contains 40 ft of conglomeratic sandstone channel fill. The channel pinches out in the background (dashed lines). [UTMX: 249,297, UTMY: 4,280,791]

Jm **Morrison Formation (Upper Jurassic)** — The uppermost part of the Morrison Formation is exposed within small canyons in the Gunnison Uplift dip slope and in the southwestern face of the Smiths Mountain monocline. The strata represent the **Brushy Basin Member**. The unit consists of banded, light-greenish-gray to grayish-purple shale and light-brown to moderate-brown sandstone. The shale intervals are extensively disturbed by bioturbation and paleosol development. Outcrops may be covered with very-pale-orange to orange to dark-reddish-brown precipitates. The sandstone occurs as lenticular bodies and as thin, tabular beds interbedded with shale. Lateral accretion surfaces are occasionally present. The sandstone is mostly fine- to medium-grained. It often has a salt-and-pepper fabric of dark and light sand grains. In addition, many of the sandstone bodies contain knobby surfaces with cemented bodies that are orange to dark reddish brown and 1/4 to 1/2 inch in diameter. Conglomerate lenses up to 10 ft thick are occasionally present. They contain gray chert pebbles and are similar in appearance to the Burro Canyon conglomerate. The shales often contain bentonitic clays. Some of the shale and thin sandstone beds show evidence of extensive trampling and disturbance by dinosaurs (see **Archaeological and Paleontological Resources** section).

The underlying **Salt Wash** and **Tidwell Members** are exposed farther to the east in the Gunnison River gorge, but not within the Olathe Northwest quadrangle. The Salt Wash Member is similar to the Brushy Basin Member, but it contains more abundant lenticular sandstone bodies. The Tidwell Member contains beds of gray gypsiferous shale, gypsum, and tabular to lenticular sandstone (O'Sullivan, 1992a, 1992b).

Thickness of the upper part of the Morrison Formation exposed in the Olathe Northwest quadrangle is up to 100 ft. The entire formation is 600 to 690 ft thick. The entire Morrison Formation is shown as a single unit in the **Plate 2** cross sections.

Older Bedrock Units Shown on Geologic Cross Sections A-A’ and B-B' Only

Cross Section A-A’ runs east from "Star Nelson Mesa" to Peach Valley, then northeast across the Smiths Mountain monocline. **Cross Section B-B'** runs northeast from the Uncompahgre River across Loutsen-hizer Arroyo, then east across Peach Valley and onto the Gunnison Uplift. The section lines are shown on **Plate 1**. The cross sections are shown on **Plate 2**. Additional, older bedrock units are included as subsurface units on the cross sections. They do not crop out within the Olathe Northwest quadrangle but occur to the east. Reported thickness values are from outcrops in the Gunnison River gorge. The Jurassic stratigraphy in this region has undergone a revision since it was mapped by Hansen (1968, 1971). His Wanakah Formation included strata that were later redefined as the Tidwell Member of the Morrison Formation (O'Sullivan 1992a, 1992b). For this report we derive thickness values and general unit descriptions from measured sections by both authors, using O'Sullivan's formation designations.

Jwe **Wanakah Formation and Entrada Sandstone of the San Rafael Group, undivided (Middle Jurassic)** — The **Wanakah Formation** contains relatively laterally continuous beds of gray to reddish-brown shale, gypsum, thinly bedded sandstone, and minor limestone (the Pony Express Limestone Member). The **Entrada Sandstone** consists of moderate-red to grayish-pink, very fine to fine grained sandstone. Its stratification includes eolian cross bedding, horizontal planar bedding, and massive fabrics. It is the oldest sedimentary formation in the area. Since 1980, authors have assigned these formations to the Middle Jurassic (U.S. Geological Survey GEOLEX database; http://ngmdb.usgs.gov/Geolex/NewUnits/unit_11048.html, accessed January, 2012). Thickness of the Wanakah Formation is 45 to 55 ft. The Entrada Sandstone is 50 to 100 ft thick.

pC **Precambrian Rocks (Proterozoic)** — Precambrian crystalline basement rocks of the Gunnison Uplift include mica schist, quartzitic and migmatitic gneiss, amphibolite, granodiorite, and pegmatite (Hansen, 1968, 1971). The top-of-Precambrian surface is a major nonconformity that spans approximately 1.5 Ga.

STRUCTURAL GEOLOGY

The Olathe Northwest quadrangle lies within the eastern part of the Colorado Plateau physiographic province (Fenneman and Johnson, 1946). Its main structural feature is the Gunnison Uplift, located in the eastern part of the quadrangle. The uplift formed as a result of movement along basement faults during the Late Cretaceous-Eocene Laramide orogeny (Tweto, 1977). Some authors cite evidence for recent uplift in the Black Canyon of the Gunnison. Hansen (1987) postulated that cutting of the canyon began about 2 million years ago. He suggested that Quaternary uplift along major faults increased the rate of down-cutting within the canyon. Aslan and others (2008) postulate that knickpoint migration within the Black Canyon may be the result of neotectonics or modification of drainage networks.

The Dakota Sandstone forms resistant hogback slopes along the uplift that dip to the west, toward the Uncompahgre River valley, at angles of 7° to 15°. In the southeastern corner, the dips are steeper (up to 20°). An anticlinal fold there separates dip slopes having southwest and northwest dip directions. Small, curvilinear folds cross the central and northern parts of the Dakota dip slope (**Figure 18**). The fold limbs are asymmetrical. They feature a flat crest; a short, back-tilted, eastern limb with dips of 5° to 67°; and a swale at the base of the next dip slope segment. In some locations, the folds are broken by minor faults having less than 20 ft offset (**Figure 18a**). The faults appear to be high-angle reverse faults or low-angle thrust faults. In other locations, faulting is absent (**Figure 18b**). We interpret that the folds mark the margins of faulted basement sub-blocks at depth, a result of minor differential uplift and tilting. They are mapped as paired synclines and anticlines on the geologic map in **Plate 1**.

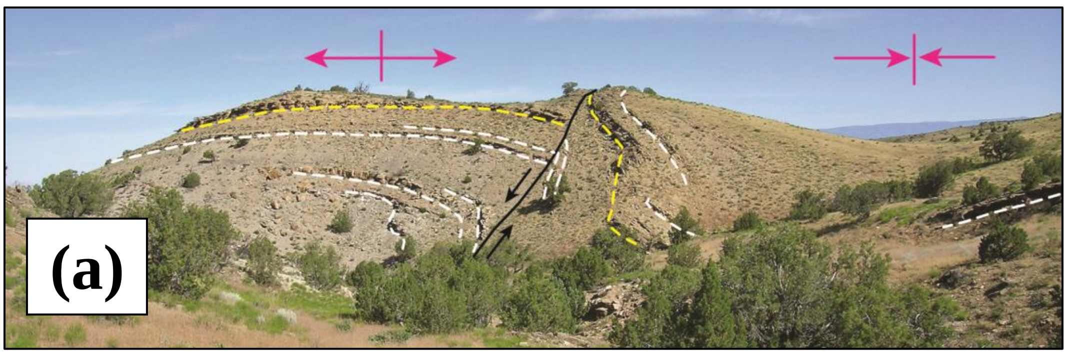

Figure 18. Small folds across the Dakota dip slope of the Gunnison Uplift.
The prevailing dip slope is at shallow angles, dipping toward the west (left) in the photos.
(a) Faulted fold crest containing a small-displacement fault. Fault movement is normal, down to west; however, it may have originally been a reverse fault based on its position relative to the fold. Anticlinal crest and synclinal swale shown, along with traces of selected beds within the Dakota Sandstone. View is somewhat oblique, looking from a low area along the synclinal axis. [UTMX: 249,589, UTMY: 4,281,362]
(b) Unfaulted, asymmetrical fold crest with steeply back-tilted limb. [UTMX: 249,682, UTMY: 4,286,431]

Mancos Shale strata to the west of the uplift generally dip westward at angles of less than 10°. The strata are folded in certain areas. The folds are not obvious in the field because the geomorphology is dominated by remnant Quaternary deposits, and not the soft shale. We mapped a well-defined anticline-syncline set in the lower Mancos Shale close to the uplift, in the southern part of Peach Valley. The anticlinal fold is an extension from one mapped in the Dakota dip slope. Elsewhere, we found evidence of gentle anticlinal and synclinal folds. Few strike and dip readings were recorded from the widespread, residuum-covered Smoky Hill Member. **Cross Section B-B'-B''** (**Plate 2**) runs from the Uncompahgre River valley eastward to the Dakota dip slope on the Gunnison Uplift.

In the northeastern corner of the quadrangle is a well-formed monocline that runs northwest to southeast, between Smiths Mountain and "Triangle Hill" (see **Figure 2**). It separates the previously described west flank of the uplift from the northern flank. To the north, the Dakota slope dips to the northeast at less than 11°. The monocline forms an abrupt escarpment with up to 500 ft of relief. It is faulted along much of its length. The fault appears to be a high-angle, reverse fault. It brings nearly flat-lying Morrison Formation into contact with steeply dipping, upper Dakota Sandstone (**Figure 19**). The maximum displacement is around 180 ft. The southwestern limb dips steeply to the southwest at angles of 30° to nearly 50°. **Cross Section A-A'-A''** (**Plate 2**) runs eastward from "Star Nelson Airport Mesa" and crosses the Smiths Mountain monocline.

MINERAL RESOURCES

The Olathe Northwest quadrangle contains sand and gravel resources and has been explored in the past for clay, iron, and oil and gas. In the following paragraphs, we outline those resources, associations with soil or bedrock units from the geologic map, and current activity.

Construction aggregates. Gravel and sand have been produced from the modern Uncompahgre River flood plain and older Uncompahgre and Gunnison River terraces (**Qau**- and **Qag**- series units). Borrow material was produced from older tributary gravels near Peach Valley (**Qg**-series) units. There are six permitted pits, and one additional pit that was permitted prior to 1981 (Schwochow, 1981; Keller and others, 2002; Guilinger and Keller, 2004). In general, alluvial gravel deposits are of limited extent within the Olathe Northwest quadrangle.

Clay. The extensive Adobe clay hills of Delta and Montrose Counties once provided raw materials for a thriving brick-manufacturing industry. Many of the region's older buildings were constructed with distinctive, yellow bricks from Delta Brick and Tile Company (Delta), which operated from 1905 to the late 1950's (Switzer, 2012). Switzer reports that other companies operated out of Montrose, North Delta, and in the North Fork area. Today, brick manufacturing in Colorado is concentrated in the Denver area. However, the many members of the Mancos Shale, varying in color, composition, clay types, and occurrence of pure clay bentonite beds, offer raw materials that could potentially be used for making kiln-fired brick and ceramic ware.

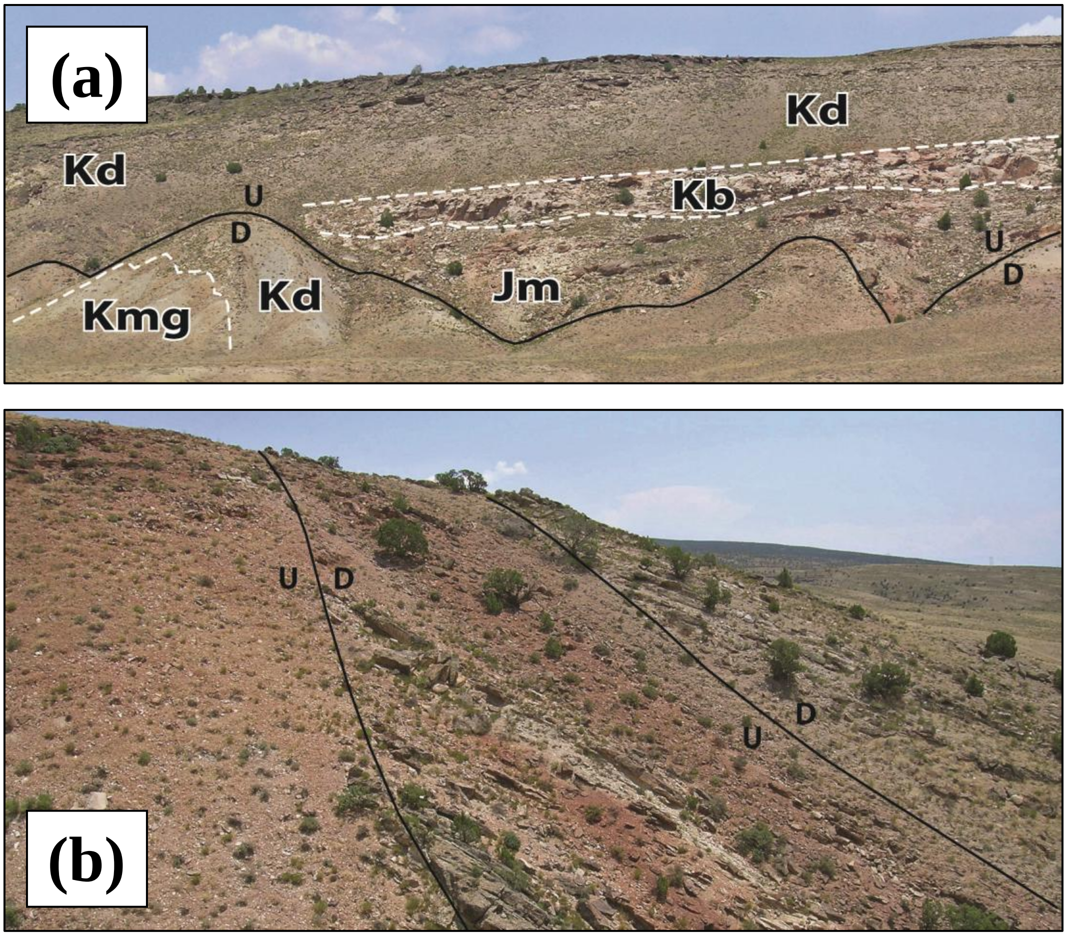

Figure 19. Faulted escarpment at the Smiths Mountain monocline on the Gunnison Uplift.
(a) The fault (black) is near-vertical. It separates steeply dipping, upper Dakota Sandstone (Kd) from flat-lying, upper Morrison Formation (Jm). Also visible are the Graneros Member of the Mancos Shale (Kmg) and the Burro Canyon Formation (Kb). Fault offset is about 180 ft. [UTMX: 248,262, UTMY: 4,292,241]
(b) Two parallel faults separating (from left to right) flat-lying Morrison, steeply dipping Morrison, and moderately dipping Dakota strata. At 1:24,000 scale, this narrow zone was mapped as a single fault. [UTMX: 249,350, UTMY: 4,291,431]

Iron. Iron-bearing deposits were mined along the eastern side of Peach Valley, at the foot of the Dakota dip slope of the Gunnison Uplift. Marshall (2000) states that the mines were worked by the Fairlamb family during the early 1900s. The ore was transported out of the valley in a string of carts pulled by a steam-powered tractor. The ore was used for pigments (Schwochow, 1981). The host deposits include iron-cemented gravels associated with block-glide landslides (**Qls**) and alluvial fans (**Qg$_3$**), and a few, iron-rich mineral spring deposits (**Figure 20**). The iron is light brown to reddish brown to dusky red in color. We postulate that the deposits formed during the late Pleistocene. Ground water, possibly circulating upward from iron-rich formations deeper within the Gunnison Uplift, may have driven the landslide failures. Cementation of the basal landslide toe and adjacent alluvial fans may have occurred contemporaneously, along with formation of the iron mineral springs.

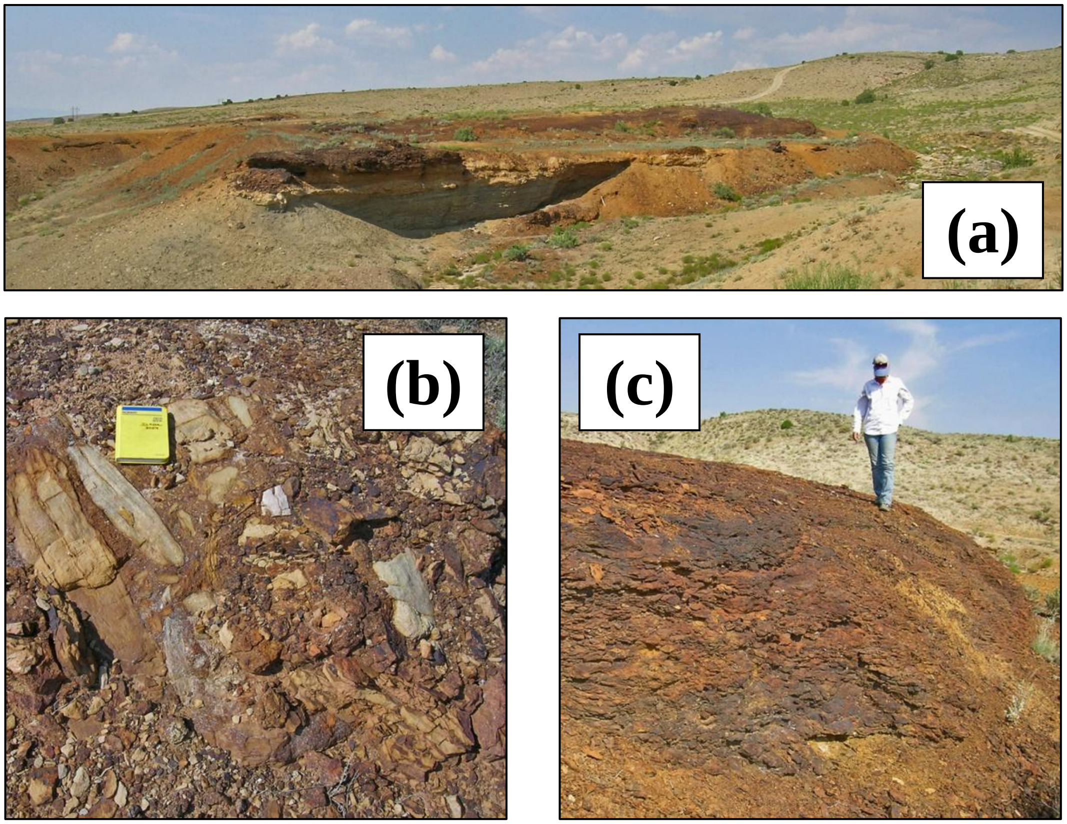

Figure 20. Iron-bearing deposits along the eastern side of Peach Valley.
(a) Distinctive brown to red alluvial fan gravel and mineral spring deposits in outcrop. The deposits are at the toe of a large block-glide landslide, forming the slope to the right. [UTMX: 248,194, UTMY: 4,289,224]
(b) Iron-cemented alluvial fan gravel from same location.
(c) Irregularly laminated mound of iron-rich, mineral spring deposits from same location.

Oil and gas. The quadrangle contains eleven inactive oil and gas wells (Milne and Watterson, 2012), all of which appear to be drilled-and-abandoned, dry holes. Nine of the wells are along the Delta-Montrose County line to the east of Peach Valley, in the Adobe hills. Two wells are in the Adobe hills farther to the north. Potential target formations in the region include the Dakota Sandstone (part of unit **Kdb**), Morrison Formation (**Jm**), and Entrada Sandstone (part of **Jwe**). There is currently oil-and-gas exploration activity in this part of western Colorado. The focus is the Niobrara-equivalent interval of the Mancos Shale. Horizontal drilling is being used to test calcareous, brittle, fractured strata. In the Olathe Northwest quadrangle, unit **Kms** represents the Niobrara interval. The principal targets are calcareous zones within the Smoky Hill Member. Unit **Kms** forms surface outcrops and is partially eroded away across most of the map area. It is entirely eroded away in the eastern part, along the flanks of the Gunnison Uplift.

GROUND-WATER RESOURCES

Ground-water resources are scarce in the Olathe Northwest quadrangle. This is because much of the area is underlain by a thick section of low-permeability Mancos Shale. The modern valley of the Uncompahgre River contains an alluvial aquifer that is charged by annual runoff from snow melt in the nearby mountains and surface water through-flow. The small, isolated Uncompahgre and Gunnison alluvial terraces are separated geomorphically from upland ground-water sources. They do not contain appreciable ground water. There are 2 ground-water wells in the quadrangle, according to GIS data from the Colorado Division of Water Resources. The wells, located along Peach Valley, are permitted for domestic use. They are 421 and 553 ft deep and produce at rates of 10 to 15 gpm. Their target formations include the Dakota-Burro Canyon-Morrison interval. Four other well locations in the Adobe hills are shown as permitted, with no completion status.

ARCHAEOLOGICAL AND PALEONTOLOGICAL RESOURCES

During the course of our mapping investigations, we found evidence of Native American tool-making at some widely scattered sites. Generally, the sites contain one or more of the following: lithic flakes, scrapers, core stones, and hammer stones. Local materials used for tool-making include silica-cemented Dakota Sandstone, metaquartzite, rhyolite tuff, and dark-gray banded rock. We documented one site of interest for the USBLM. We found occasional dinosaur tracks while mapping in the Gunnison Uplift area. They include individual tracks, trackways, and beds having extensive trampling disturbance ("dinoturbation"). Most exist in cross-sectional view, as pendulous bodies that extend downward from a sandstone bed. Some of the tracks are seen in three dimensions if the underlying mudstone is eroded away. The tracks were found in the Dakota Sandstone and Burro Canyon Formation (unit **Kdb**) and in the Morrison Formation (unit **Jm**). Examples are shown in **Figure 21**. CGS documented sites of interest for the USBLM. Those data will be used as part of BLM's natural-resource inventory for management of the Gunnison Gorge National Conservation Area.

GEOLOGIC HAZARDS

We recognize several potential geologic hazards in the Olathe Northwest quadrangle. The hazards arise when naturally occurring geologic processes affect constructed facilities such as buildings and roads. Human activities may greatly increase the rate of process activity and level of hazard. Geologic hazards are detrimental to the financial well-being, and sometimes the safety, of individual property owners and owners of public and private facilities.

Landslides (unit **Qls**) are found in several places within the quadrangle. They mostly consist of block-glide landslide complexes on the Dakota dip slope. Those landslides are confined to BLM land in the eastern part of the quadrangle. Few landslides were mapped elsewhere. However, there is a potential for landslides on shale slopes that are capped by gravel deposits. Saturated shale in the

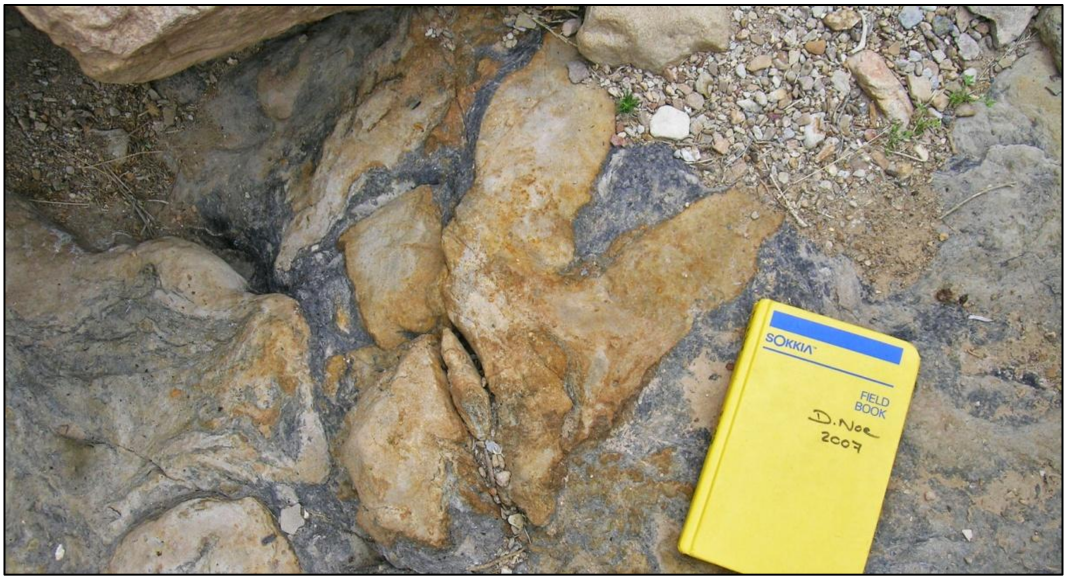

Figure 21. Examples of dinosaur tracks found in the Gunnison Uplift area.
(a) Three-toed track in carbonaceous shale, from the lower part of the Dakota Sandstone (unit **Kdb**). It was exposed in the floor of a dry-wash canyon. Flash flooding in 2010 covered it with sediment.
(b) Multi-story trackway in cross section, from the upper Brushy Basin Member of the Morrison Formation (unit **Jm**). The tracks appear as bulbous sandstone and shale bodies that extend into and deform the underlying bedding. Large and small sauropod dinosaurs made piston-like tracks that disrupted and deformed several successive layers of mud and sand.

vicinity of ditches and canals may be prone to landsliding. Modifications such as loading or cutting into hill slopes, or increases in ground-water levels and pore pressures could reinitiate existing landslides or create new landslides. Potential landslide areas should be avoided where possible, or the site should undergo geotechnical engineering investigations and mitigation. Mitigation may be expensive, but not as much as the costs of damage and repairs to structures and facilities from landslide movements.

Debris flow and **mud flow** hazards occur in hilly areas along confined stream reaches and in alluvial and mud flow fans (unit **Qamf**). These flows are produced by large rainfall events. Debris flows are dense, heterogeneous mixtures of mud, rock fragments, and plant materials (Varnes, 1978). They can form in shale-and-sandstone terrain on the Gunnison Uplift, and below gravel-capped upland terraces. The moving flows present life-and-limb safety hazards and can cause damage to roads and buildings. Mud flow valley fills and fans are typically gravel poor. They occur in or at the margins of the Adobe hills areas. Mud flows deposits are prevalent along Peach Valley and Loutzenhiser Arroyo. However, their modern arroyos are highly incised. The potential for mudflows is greatest along the smaller tributary drainages that have not been incised. All areas meeting the above descriptions should be considered at risk. Construction in those areas should be carefully considered or, in some cases, avoided.

Rockfall hazards are present at the base of arroyos that are eroded into mixed shale and sandstone. We observed several places where arroyo walls had recently collapsed. Boulders up to several ft in diameter are known to fall from the edges of mesa-capping gravel bodies (**Qag**- and **Qg**-series units). The best mitigation is to avoid rockfall-prone slopes and roll-out zones.

Expansive soil and bedrock hazards occur in clay-rich materials. These materials are relatively dry under natural climate conditions. Upon wetting, water is drawn into crystal lattices. The clay particles swell to accommodate the added water molecules (Noe, 2007). Resultant ground heaving may cause damage to buildings, roads, and underground utilities and pipelines. The clay particles lose water and shrink upon drying. This shrink-swell behavior may continue over numerous wetting and drying cycles. Potentially expansive soil and bedrock is found in the Mancos Shales (particularly in units **Kms**, **Kmb**, and **Kmg**), the Dakota Sandstone (unit **Kdb**), the Morrison Formation (unit **Jm**), and clay-rich surficial deposits derived from those units. Ground-heave movements may be significantly reduced if proper geotechnical engineering studies and designs are employed at potentially affected construction sites.

Collapsible soil hazards occur in silt-rich sediments that are relatively quickly deposited and have high internal porosity (White and Greenman, 2008). Such deposits include tributary stream alluvium and mud flow valley fills and fans (unit **Qamf**). Serious ground-collapse hazards may exist along Peach Valley and Loutsenhizer Arroyo. Streams have incised deeply along those drainages. Subsequent piping and erosion of the soft, dispersive soil resulted in the collapse of large soil blocks and isolated sinkholes (**Figure 22**). Areas containing **Qamf** deposits should be considered at risk for collapsible soil conditions. Ground-collapse hazards may be reduced if proper geotechnical engineering studies and designs are employed at potentially affected sites.

Erodible soil susceptibility is moderately high for the Mancos Shale and its surficial derivative deposits (unit **Qamf**). The Natural Resources Conservation Service (2006) estimates that 86 tons per acre per year of soil erosion is possible from those units. The NRCS found that least susceptible areas of erosion correspond to the gravel-capped mesas (**Qag** and **Qg** series) and Dakota Sandstone (unit **Kdb**).

Selenium and salt mobilization potential is high for the Mancos Shale and its surficial derivative deposits (unit **Qamf**) (**Figure 23**). Dissolution of selenium and salts, particularly from irrigated lands, negatively impacts stream water quality and causes reproductive impairment in fish and aquatic birds. Thomas and others (2008) found that the largest selenium loads in the lower Gunnison River basin are from Lousenhizer Arroyo. Based on CGS geologic mapping (this study; Morgan and others, 2007), the arroyo is mostly underlain by the Smoky Hill Member of the Mancos Shale (unit **Kms**). Other members of the Mancos Shale may contain concentrations of selenium. The Juana Lopez Member (unit **Kmj**) hosted dense growths of prince's plume (*Stanleya pinnata* and *S. albescends*), a selenium indicator

Figure 22. Fresh collapse of dispersive, silty mud flow deposits (unit **Qamf**) along Loutsenhizer Arroyo. Active ground collapse is taking place in areas where the arroyo is deeply incised. Piping erosion of the silty soil results in formation of "mud caves" (as in Figure 7b), and ground failure in sinkholes and along the stream-bank walls. Photo by Jonathan White, CGS. [UTMX: 241,791, UTMY: 4,281,966]

Figure 23. Sulfate and other salt precipitates in a seep area near Loutsenhizer Arroyo.
This extensive seep is formed on mud flow deposits (**Qamf**, flat area in foreground), and on the Smoky Hill Member of the Mancos Shale (**Kms**, low hill in background). Ground water from uphill sources may flow and discharge along perched zones associated with permeable strata within the shale. Alternatively, the water may perch upon clayey strata having low permeability. [UTMX: 241,851, UTMY: 4,283,632]

plant genera, during the wet spring of 2007 (**Figure 24**). Sulfate salts in Mancos Shale and derived deposits may be corrosive to buried infrastructure. Corrosion-resistant concrete mixes and protective coatings for buried metal items may be necessary.

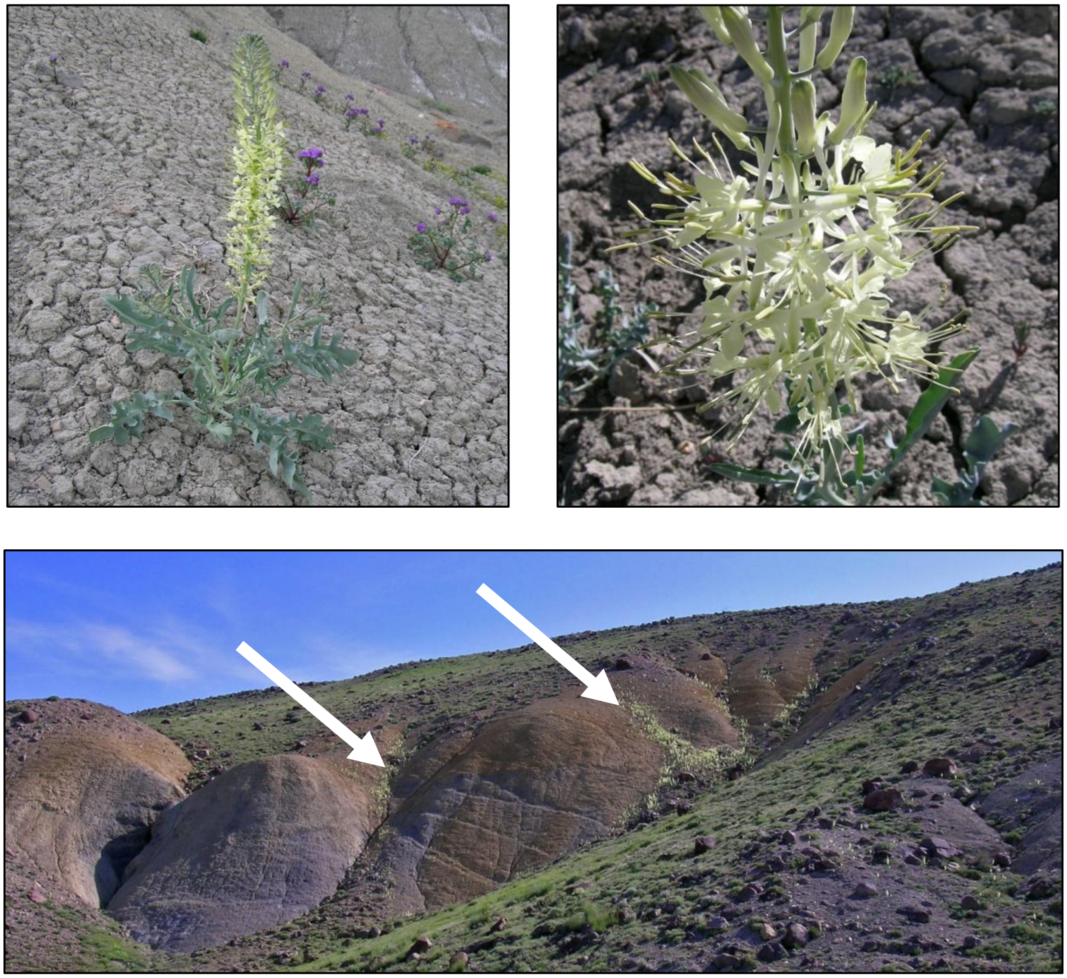

Figure 24. Prince's plume plants growing in the Adobe hills near Peach Valley.
(Top row) White prince's plume (*Stanleya albescens*) growing on the Smoky Hill Member of the Mancos Shale (unit **Kms**). Detail of flower spike at top right.
(Bottom) Profuse growths of white prince's plume (in gullies, marked by arrows) on the Juana Lopez Member of the Mancos Shale (unit **Kmj**). [UTMX: 248,247, UTMY: 4,280,910]

Seismicity and earthquake hazards are generally difficult to assess. We did not see evidence of younger faulting or offsets of Quaternary-age deposits while mapping. No historical earthquakes are shown within the quadrangle in the CGS *Colorado Earthquake Map Server* (Kirkham and others, 2004). The largest instrumentally recorded earthquake in Colorado history occurred on October 11, 1960. It was measured at magnitude 5.5 with an epicenter 15 miles southeast of Montrose (Kirkham and others, 2004). The nearest faults suspected of having Quaternary movement are located south of the Black

Canyon of the Gunnison River (6.5 miles to the southeast) and in the Uncompahgre Uplift (5.5 miles to the southwest) (Morgan, 2007). An updated, online version of the Kirkham-Morgan maps is available at http://geosurvey.state.co.us/hazards/Earthquakes/Pages/Maps.aspx (Morgan and others, 2012).

Stream flooding hazards and associated high water tables exist within the modern Uncompahgre River flood plain (unit **Qau**$_1$) and the valleys of tributary streams (unit **Qamf**). Flooding may be due to annual snow melt and occasional, large rainfall events. Residences and critical facilities in those areas should be avoided. FEMA Flood Insurance Rate Maps (FIRMs) are available for this particular area of western Colorado. FEMA's Flood Map Viewer (https://hazards.fema.gov/wps/portal/mapviewer) shows that unit **Qau**$_1$ is in a high risk area (zone AE, 1-percent-annual-chance base flood floodplain). Notable floods of the Uncompahgre River occurred in the early-to-mid 1800s (by oral account of the Ute Tribe), as well as in 1884 and 1921 (Follansbee and Sawyer, 1948). The highest recorded flow was 5,800 cfs in 1984 (Uncompahgre Watershed Partnership, 2012). Since 1987, flooding on the main branch of the Uncompahgre River has been at least partially mitigated by the Ridgway Dam, located 40 miles upstream.

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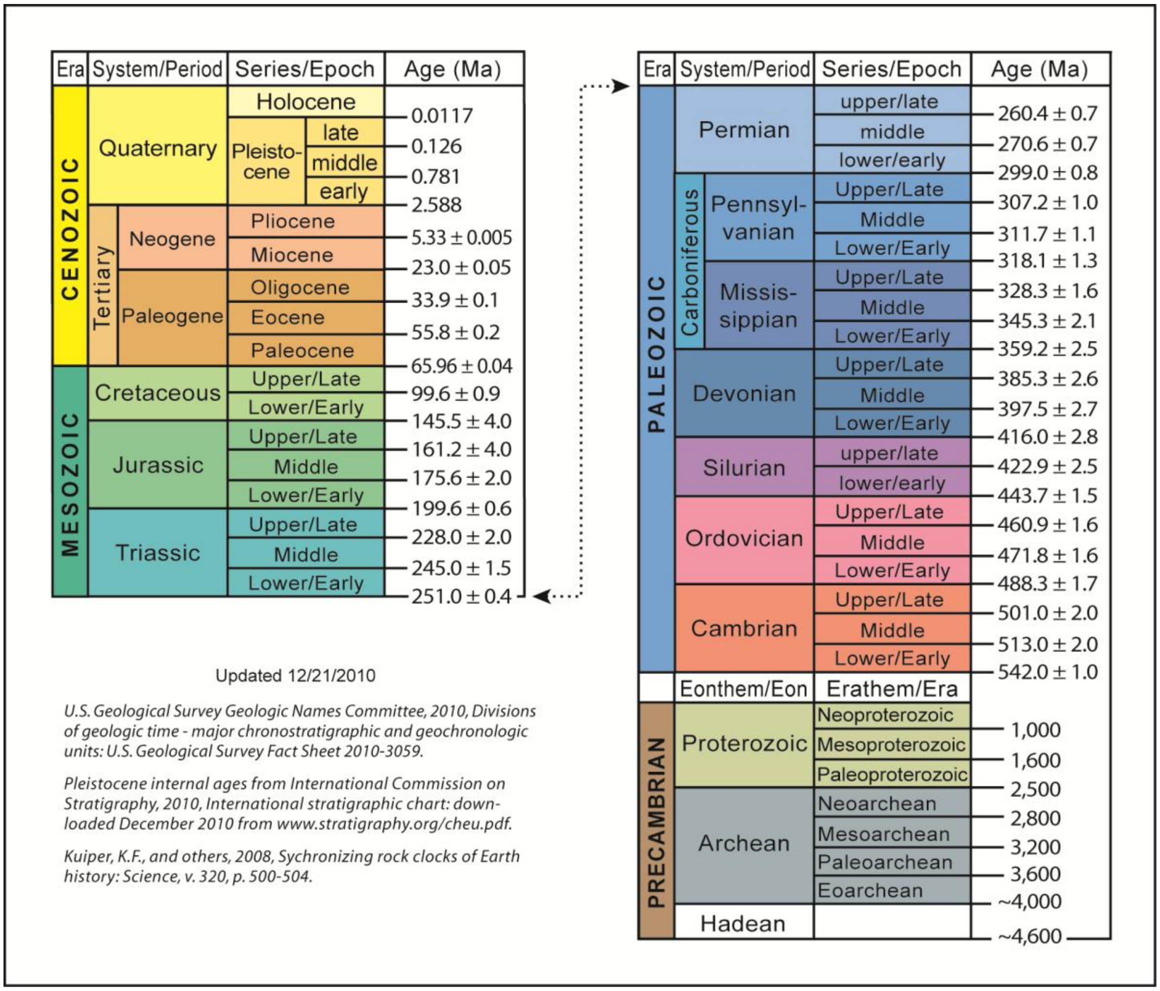
APPENDIX A

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



APPENDIX B

Appendix B. Age dates of material samples collected from the Olathe Northwest quadrangle

Optically Stimulated Luminescence (OSL) Dates

OSL dating was performed by Dr. Paul Hanson, University of Nebraska-Lincoln. His results are shown in the table below. Optical ages were computed for an estimated value of in-situ water content. The single aliquot IRSL protocol was used.

Sample ONW-106 is from a sand lens in unit **Qg$_5$**, a mixed debris flow and alluvial gravel deposit. The sampling site is in an erosional cliff, near to the photo shown in Figure 8b [UTMX: 246,513, UTMY: 4,280,077]. From geomorphic relationships we expect this unit to be middle Pleistocene in age (our estimate: early Bull Lake age, or about 190 to 150 ka; see **Table 1** in text). The results are age limited, meaning that the optical age could not be determined. As shown below, it is more than 70 ka.

Field #	UNL Lab #	Depth (m)	U (ppm)	Th (ppm)	$K_2$0 (wt %)	In Situ $H_2$0 (%)[a]	Dose Rate (Gy/ka)	D_e (Gy) ± 1 Std. Err.	Aliquots (n)	Optical Age ± 1 σ
ONW-106	UNL-1896	3	3.5	8.3	1.7	0.6	3.0 ± 0.1	>200		>70,000

[a]assumes 100% error in measurement

Dave, we finished up our work on your sample a couple of weeks back and just received the chemistry this morning. Unfortunately, this sample was too old to date. With this sample I am confident in giving it a minimum age estimate, and I am sure the sample is greater than 70,000 years old. Hopefully that helps you in some way. Please feel free to ask for clarification with anything above. Cheers. Paul [e-mail received 2/14/08]

APPENDIX C

Appendix C. Fossils collected from the Olathe Northwest quadrangle and vicinity

The table inserted at the end of this document contains a listing of marine invertebrate fossils collected within or near to the Olathe Northwest quadrangle by the CGS mapping crew during the 2007 field season. The fossils were donated to the U.S. Geological Survey (USGS) for their Cretaceous Western Interior Seaway (CWIS) collection. USGS collection numbers (beginning with a "D" for Denver collection) were assigned and are shown on the geologic map. Dr. William Cobban, USGS, provided identification of the fossils species and catalogued the specimens into the CWIS collection. In addition, where possible, we add fossils collected by other investigators. The table includes ages and guide-fossil zones from Cobban and others (2006). All of the specimens are Late Cretaceous in age. One example of our collection is shown in **Figure 25**.

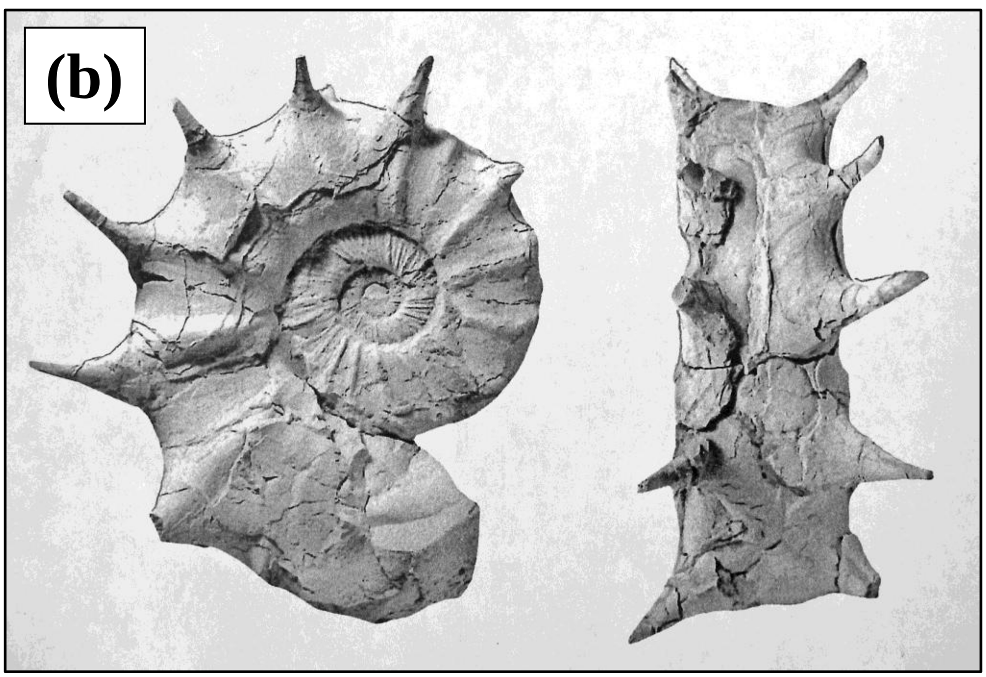
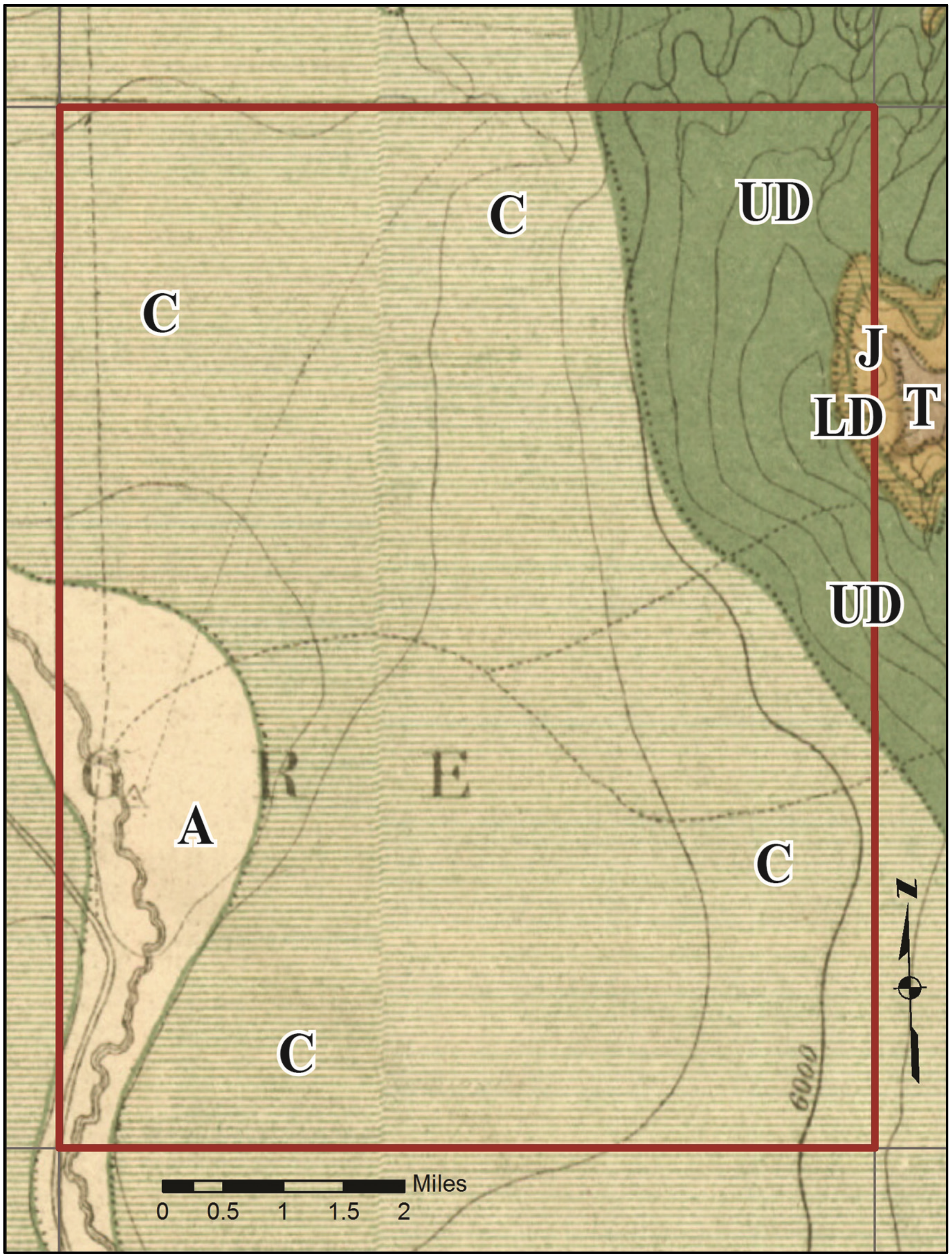


Figure 25. *Prionocyclus hyatti* ammonite fossil recovered from Olathe Northwest quadrangle.
(a) Fossil fragments recovered from the Blue Hill Member of the Mancos Shale by D. Noe, CGS. Flank ribs and a finger-like protrusion are visible. USGS collection D14793.
(b) Photograph, for comparison, of an intact specimen of *P. hyatti* from Blue Hill Shale Member of the Carlile Shale in Kansas. Courtesy of William Cobban, USGS.



Back Cover. The first geologic map of the Olathe Northwest area, published by F.V. Hayden (1877). Fieldwork for the map was conducted during the 1874-1876 Geological and Geographical Survey of the Territories (a precursor to the U.S. Geological Survey) under Professor Hayden. A portion of the map is shown, with a red box around the Olathe Northwest quadrangle. The map units are as follows:

A	Alluvium (Quaternary)	**UD**	Upper Dakota (Cretaceous)
C	Colorado (Niobrara-Fort Benton) (Cretaceous)	**LD**	Lower Dakota (Cretaceous)
		J	Morrison (Jurassic)
		T	Red beds (Jurassic-Triassic)

Appendix C. Fossils Collected From the Olathe Northwest Quadrangle and Vicinity

CGS Locality Number	USGS Locality Number	Fossils Collected and Identified	Ammonite or Mollusc Guide Fossil Zone	Age	Formation or Mancos Shale Member	Quadrangle	County	State	Land Survey Location	Collected by	Date
ONW-149	(no #)	*Baculites thomi?; Baculites sp.* (smooth)	*Desmoscaphites bassleri; Sphenoceramus lundbreckensis*	Upper Santonian	Smoky Hill Mbr	Olathe NW	Delta	CO	31-15S-94W	David C. Noe	06/13/07
ONW-48	D14652	*Magadiceramus crenulatus; Platyceramus sp.*	*Scaphites depressus; Magadiceramus crenulatus*	Upper Coniacian	Smoky Hill Mbr	Olathe NW	Montrose	CO	5-50N-9W	D.C. Noe and S.M. Townley	05/01/07
ONW-261	D14670	*Baculites codyensis?, Scaphites ventricosus?; Inoceramus sp.*	*Scaphites ventricosus*	Middle Coniacian	Smoky Hill Mbr	Olathe NW	Delta	CO	31-15S-94W	David C. Noe	07/14/07
ONW-2a	D14655	*Baculites codyensis; Inoceramus sp.; "Ostrea" sp.; Neocrioceras sp.*	*Scaphites depressus*	Upper Coniacian	Smoky Hill Mbr	Olathe NW	Montrose	CO	5-50N-9W	David C. Noe	04/26/07
ONW-107	D14661	*Inoceramus sp.* (thin shelled); *Pseudoperna congesta;* fish scales	(can't tell)	Upper Coniacian?	Smoky Hill Mbr	Olathe NW	Montrose	CO	31-51N-9W	D.C. Noe and S.M. Townley	05/29/07
ONW-2b	D14654	*Platyceramus sp.; Pseudoperna congesta*	(can't tell)	Coniacian or Santonian	Smoky Hill Mbr	Olathe NW	Montrose	CO	5-50N-9W	David C. Noe	04/26/07
ONW-2c	D14653	*Volviceramus sp.; Pseudoperna congesta*	(can't tell)	Coniacian or Santonian	Smoky Hill Mbr	Olathe NW	Montrose	CO	5-50N-9W	David C. Noe	04/26/07
ONW-111	D14662	*Baculites sp.; "Inoceramus" sp.; Pseudoperna congesta*	(can't tell)	Coniacian or Santonian	Smoky Hill Mbr	Olathe NW	Montrose	CO	30-51N-9W	D.C. Noe and S.M. Townley	05/29/07
ONW-35	D14663	*Platyceramus sp.; Pseudoperna congesta*	(can't tell)	Coniacian or Santonian	Smoky Hill Mbr	Olathe NW	Montrose	CO	24-51N-10W	David C. Noe	05/30/07
---	D14210	*Magadiceramus subquadratus, Pseudoperna congesta*	*Scaphites depressus; M. subquadratus*	Upper Coniacian	Smoky Hill Mbr	Olathe	Montrose	CO	8-50N-9W	R. Grauch and E.A. Merewether	05/11/04
---	D14211	*Magadiceramus stantoni, Pseudoperna congesta*	*Scaphites depressus; M. subquadratus*	Upper Coniacian	Smoky Hill Mbr	Olathe	Montrose	CO	8-50N-9W	E.A. Merewether	05/11/04
---	D14212	*Magadiceramus stantoni, Pseudoperna congesta*	*Scaphites depressus; M. subquadratus*	Upper Coniacian	Smoky Hill Mbr	Olathe	Montrose	CO	8-50N-9W	E.A. Merewether	05/11/04
ONW-100	D14658	*Prionocyclus macombi; Inoceramus dimidius; Lopha lugubris*	*Prionocyclus macombi; Inoceramus dimidius*	Middle Turonian	Juana Lopez Mbr	Olathe NW	Montrose	CO	33-51N-9W	David C. Noe	05/16/07
ONW-146	D14668	*Prionocyclus macombi*	*Prionocyclus macombi; Inoceramus dimidius*	Middle Turonian	Juana Lopez Mbr	Olathe NW	Delta	CO	17-51N-9W	David C. Noe	06/13/07
---	D11893	*Inoceramus dimidius; Lopha lugubris*	*Prionocyclus macombi; Inoceramus dimidius*	Middle Turonian	Juana Lopez Mbr	Olathe NW	Delta	CO	33-15S-94W	E.A. Merewether and W.A. Cobban	1982
---	D11894	*Inoceramus dimidius*	*Prionocyclus macombi; Inoceramus dimidius*	Middle Turonian	Juana Lopez Mbr	Olathe NW	Delta	CO	33-15S-94W	E.A. Merewether and W.A. Cobban	1982
ONW-168	D14667	*Prionocyclus macombi; Inoceramus dimidius; Lopha lugubris*	*Prionocyclus macombi; Inoceramus dimidius*	Middle Turonian	Juana Lopez - Blue Hill	Olathe NW	Delta	CO	20-51N-9W	David C. Noe	07/09/07
ONW-50	(no #)	*Prionocyclus macombi* (juveniles); *Scaphites sp.; Inoceramus sp.*	*Prionocyclus macombi; Inoceramus dimidius*	Middle Turonian	Blue Hill Mbr	Olathe NW	Montrose	CO	4-50N-9W	D.C. Noe and S.M. Townley	05/01/07
---	D11892	*Prionocyclus macombi; Inoceramus dimidius*	*Prionocyclus macombi; Inoceramus dimidius*	Middle Turonian	Blue Hill Mbr	Olathe NW	Delta	CO	33-15S-94W	E.A. Merewether and W.A. Cobban	1982
---	D11890	*Inoceramus dimidius; Lopha lugubris*	*Prionocyclus macombi; Inoceramus dimidius*	Middle Turonian	Blue Hill Mbr	Olathe NW	Delta	CO	33-15S-94W	E.A. Merewether and W.A. Cobban	1982
---	D11891	*Prionocyclus hyatti*	*Prionocyclus hyatti; Inoceramus howelli*	Middle Turonian	Blue Hill Mbr	Olathe NW	Delta	CO	33-15S-94W	E.A. Merewether and W.A. Cobban	1982
ONW-103	D14793	*Prionocyclus hyatti*	*Prionocyclus hyatti; Inoceramus howelli*	Middle Turonian	Blue Hill Mbr	Olathe NW	Montrose	CO	29-51N-9W	David C. Noe	05/16/07
ONW-51	D14657	Shark tooth	(can't tell)	Middle Turonian	Blue Hill Mbr	Olathe NW	Montrose	CO	33-51N-9W	D.C. Noe and S.M. Townley	05/01/07
ONW-336	D14666	*"Pycnodonte aff. P. newberryi"* *	*Collignoniceras woollgari*	Middle Turonian	Fairport Mbr	Olathe NW	Delta	CO	21-51N-9W	D.C. Noe and S.M. Townley	07/01/07
---	D14208	*"Pycnodonte aff. P. newberryi"* *	*Collignoniceras woollgari*	Middle Turonian	Fairport Mbr	Olathe NW	Delta	CO	21-15S-94W	E.A. Merewether and D.A. Sawyer	2004
ONW-98	D14659	*Pycnodonte newberryi; Mytiloides hattini; M. c.f. hattini*	*Mytiloides hattini to Mytiloides kossmati*	Upper Cenomanian to Lower Turonian	Bridge Creek Mbr	Olathe NW	Montrose	CO	33-51N-9W	David C. Noe	05/16/07
ONW-55	D14656	*Pycnodonte newberryi*	*Mytiloides hattini to Mytiloides kossmati*	Upper Cenomanian to Lower Turonian	Bridge Creek Mbr	Olathe NW	Montrose	CO	4-50N9W	D.C. Noe and S.M. Townley	05/02/07
ONW-101	D14660	*Pycnodonte newberryi*	*Mytiloides hattini to Mytiloides kossmati*	Upper Cenomanian to Lower Turonian	Bridge Creek Mbr	Olathe NW	Montrose	CO	32-51N-9W	David C. Noe	05/16/07
ONW-128	D14664	*Pycnodonte newberryi; Pseudoperna bentonense?*	*Mytiloides hattini to Mytiloides kossmati*	Upper Cenomanian to Lower Turonian	Bridge Creek Mbr	Olathe NW	Montrose	CO	20-51N-9W	D.C. Noe and S.M. Townley	06/01/07
---	D11889	*Pycnodonte newberryi*	*Mytiloides hattini to Mytiloides kossmati*	Upper Cenomanian to Lower Turonian	Bridge Creek Mbr	Olathe NW	Delta	CO	33-15S-94W	E.A. Merewether and W.A. Cobban	1982
ONW-173	(no #)	*Inoceramus pictus(?)* or older?	*Inoceramus ginterensis to Inoceramus pictus*	Upper Cenomanian?	Hartland Mbr?	Olathe NW	Delta	CO	28-15S-94W	David C. Noe	07/09/07
---	D11888	*Johnsonites sulcatus; Borissiakoceras compressum; I. macconnelli*	*Inoceramus macconnelli*	Middle Cenomanian	Graneros Mbr.	Olathe NW	Delta	CO	33-15S-94W	E.A. Merewether and W.A. Cobban	1982

Includes collection sites in and within one mile of the Olathe NW quadrangle. Sources of information for fossils collected previous to this study include Merewether and others (2006), and unpublished USGS databases for Denver and Washington D.C. collections.

Land Survey Locations are reported in terms of Section-Township-Range. CGS does not include more-detailed location information on account of Federal regulations for protection of paleontological resources.

Note by W. Cobban: Fragments of large, thick-shelled Inoceremids in Smoky Hill Member are referred to as "*Inoceramus sp.,*" and may include *Magadiceramus*, *Volviceramus*, *Platyceramus, I. Platinus,* or other Inoceramid species.

* Initially identified as *Pycnodonte aff. P. kellumi* by W. Cobban, but later amended because the strata at the collection location are younger. The amended name, recommended by Cobban, represents a larger, flattened form that occurs just above *P. newberryi* in Bridge Creek/Fairport-age strata (most likely in the basal Fairport Mbr).