Orchard City Quadrangle Geologic Map, Delta County, Colorado

Authors' Notes

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FOREWORD

The purpose of Colorado Geological Survey's (CGS) *Orchard City Quadrangle Geologic Map,Delta County, Colorado* is to describe the geology, mineral and ground-water resource potential, and geologic hazards of this 7.5-minute quadrangle located west of Delta in western Colorado. CGS staff geologist David Noe and field assistant Michael Zawaski completed the field work on this project during the summer of 2009. The geologic map plates and the Authors' Notes report were created using field maps, structural measurements, photographs, and field notes generated by the investigators.

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 G09AC00192, 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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INTRODUCTION

The Orchard City 7.5-minute quadrangle is located in Delta County, Colorado (**Figure 1**). The town of Orchard City lies within the quadrangle. It incorporates three former settlements: Austin, Cory, and Eckert (for community history, see http://www.orchardcityco.org/). Delta, the largest town and county seat of Delta County, lies 4 miles to the southwest. The area is known for its orchards and agriculture.

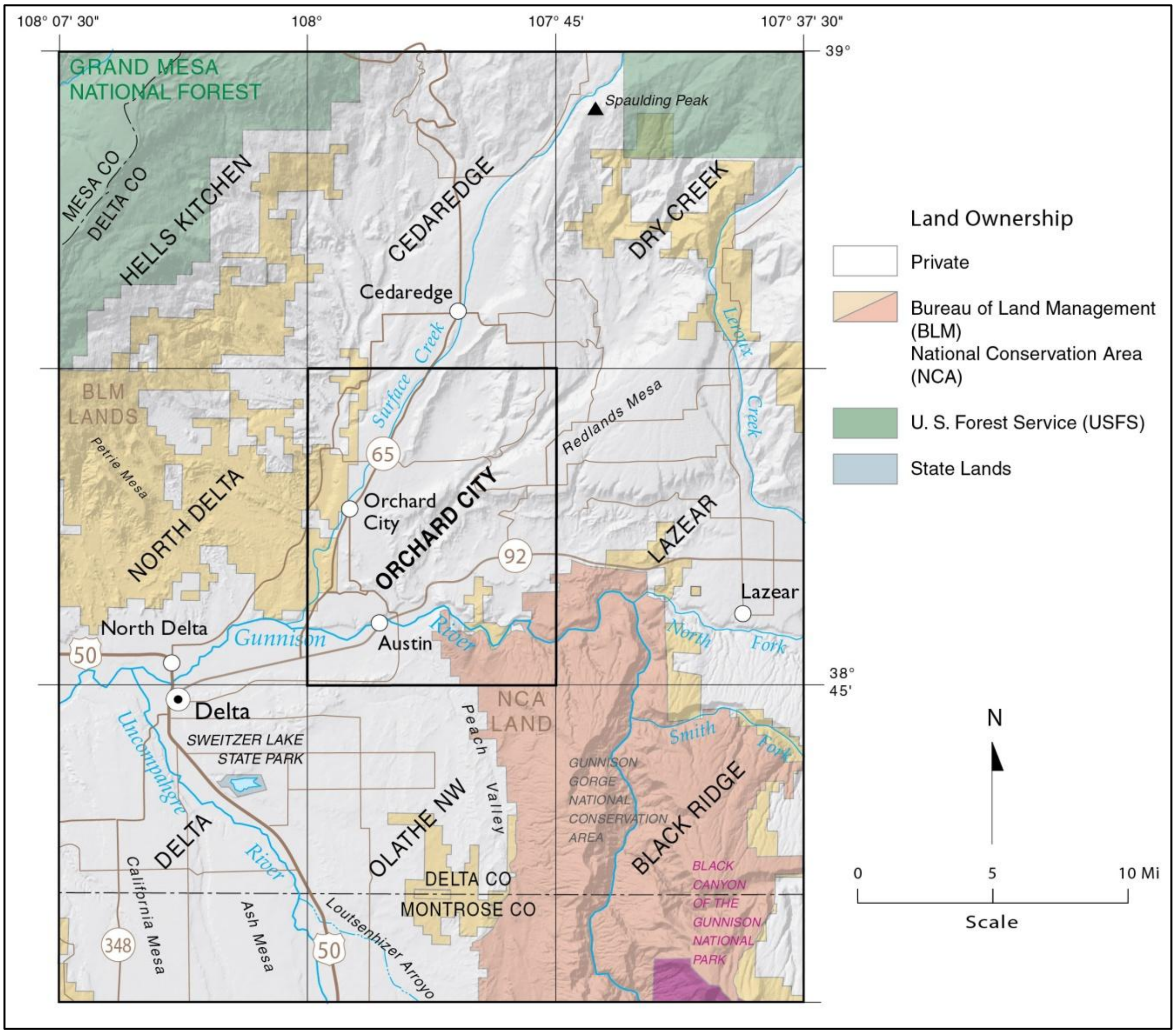

Figure 1. Index map of the Orchard City quadrangle in western Colorado.
Most of the quadrangle consists of private land parcels; the remainder is BLM-administered public land.

Figure 2 shows the major physiographic features of the quadrangle. The highest elevation is on Cedar Mesa at the northeastern corner (6,370 ft). The lowest elevation (4,975 ft) is where the Gunnison River exits at the western edge. Four geomorphic areas comprise the quadrangle: (1) The Gunnison Uplift, in the southeastern corner is, where the Gunnison River carves a 500-ft deep gorge. (2) The broad, Gunnison River valley near Austin, in the southwestern part. (3) The southern flank of 11,200 ft

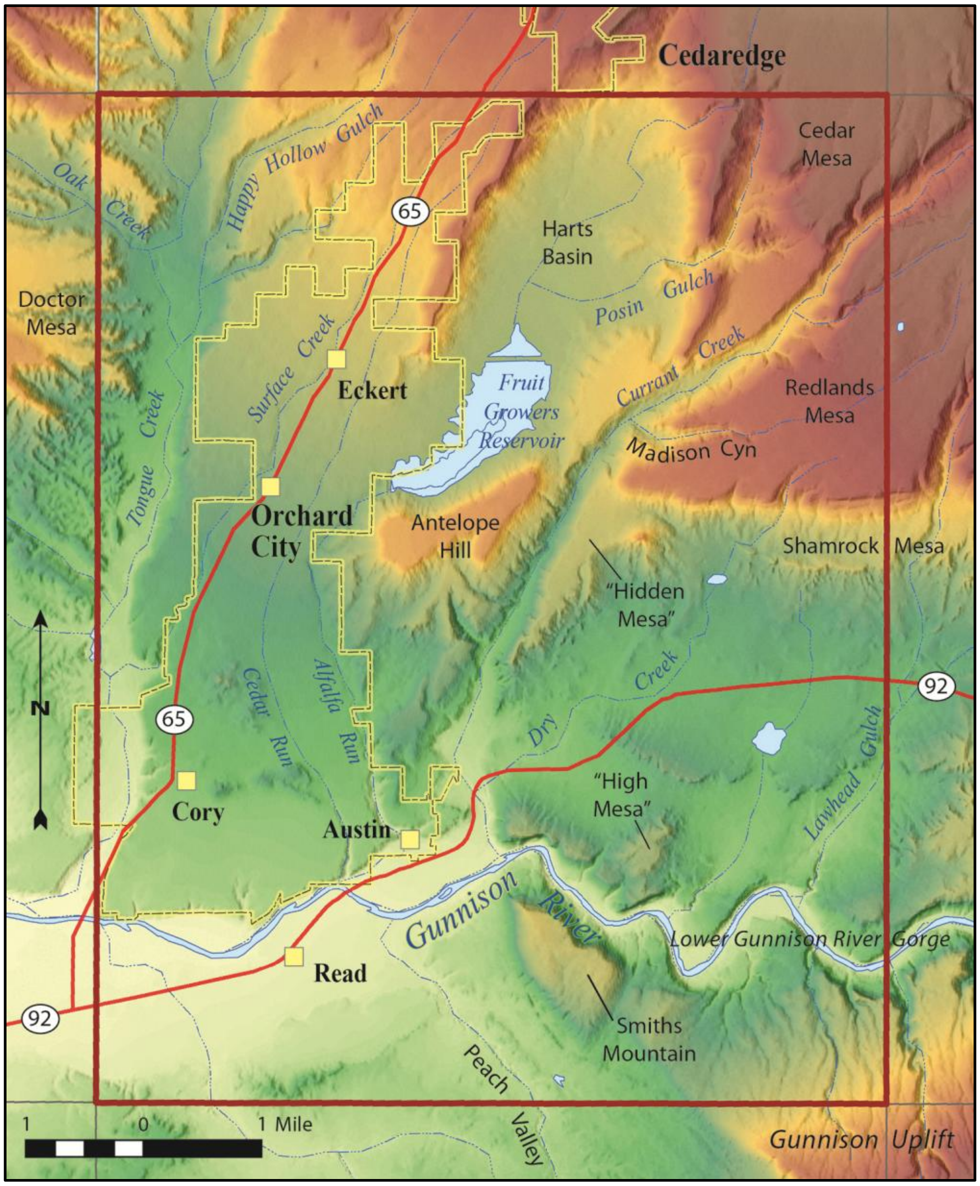

Figure 2. Shaded-relief index map of the Orchard City quadrangle, showing major physiographic features. Also shown are the population centers that comprise the Town of Orchard City. The town corporate boundaries are marked by a yellow-and-black dashed line.

Grand Mesa, in the northern and central part. This area contains tributary streams such as Tongue, Surface, and Currant Creeks. The tributary valleys are separated by gravel-capped mesas that include Cedar and Redlands Mesas, the "Surface Creek Surface" that extends from Cedaredge to south of Cory, and numerous smaller mesas. (4) Finally, shale badlands known locally as the "Adobe hills," or simply, "the Adobes," occur in the east-central part along State Highway 92, in the southern part around Peach Valley, and in the western part near the valley of Tongue Creek. Adobe hills flank many of the tributary valleys and mesas throughout the quadrangle.

PREVIOUS MAPPING STUDIES

Previous geologic mapping in the area was done by the U.S. Geological Survey (USGS). The earliest regional geological map was made 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 geologic maps by Ellis and others (1987) (1:100,000) and Hail (1972) (1:48,000). A one-mile swath at the northern end was mapped as part of a coal investigation by Dunrud (1989) (1:50,000). Hansen (1968) mapped the 1:24,000-scale Black Ridge quadrangle to the southeast.

The Orchard City quadrangle geologic map is part 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 by CGS include the Delta quadrangle (Morgan and others, 2008) and the Lazear, Olathe Northwest, and North Delta quadrangles (Noe and others, in prep., a, b, and c).

Geologic mapping of the Orchard City 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 learn about 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 Orchard City quadrangle geologic map is shown on **Plate 1**. The geologic interpretations are based on (1) CGS field investigations conducted from July to September, 2009; (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. Mapping from the aerial photos was digitized into GIS using ESRI ArcMap. The GIS point, linear, and polygonal shapefiles were created by digitizing onto a computer screen. The air-photo mapping was visually matched and digitized onto semi-transparent topographic map, NAIP orthophoto, and shaded DEM images. We used ERDAS IMAGINE 2010 to create the 3-D 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.

SURFICIAL DEPOSITS

The surficial deposits in the Orchard City 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.

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.

dr **Disturbed and reclaimed land (late Holocene)** – Disturbed land includes areas such as surface gravel pits, well-drilling pads, or other large excavations. Reclaimed areas are covered with fill or overburden materials that consist of gravel, sand, silt, clay, or rock debris, similar to unit **af**.

ALLUVIAL DEPOSITS

Gravel, sand, silt, and clay deposited in major river valleys and tributary drainages, in alluvial fans, and as older terrace deposits. The older alluvial deposits formed during Pleistocene glacial periods, particularly during episodes of outwash flooding from melting glaciers. Erosion of the landscape through time has formed *inverted topography*. This occurs when streams abandon their former courses and erode downward through the soft shale in the valley walls. A newer, lower, stream valley is formed. The abandoned deposits are somewhat resistant to erosion. They are preserved as remnant, mesa-capping gravel bodies. The highest deposits are the oldest. Terrace elevation heights represent the elevation difference between the modern river level (from the USGS topographic map) and the top of the terrace gravel. Thickness represents the maximum exposed thickness of the unit. The interpreted age relationship between the gravel-terrace levels and Pleistocene glacial stages is shown in **Table 1**.

Table 1. Interpreted glaciation and age correlations of Pleistocene gravels in the Orchard City quadrangle

Gravel-Terrace Level	Glaciation, Marine Oxygen Isotope Stage (MIS), and Age Range
1b, 2, and 3	Pinedale (MIS 2, >30-11.6 ka); early Wisconsin (MIS 4, 89-50 ka)
4 and 5	Bull Lake (MIS 6; 190-130 ka)
6 and 7	Pre-Bull Lake (MIS 8-12, 700- 500 ka; MIS 14-16, 500-300 ka)
Gravel levels are regionally comparable to those of Hail (1972), Sinnock (1978), and Cole and Sexton (1981). Glaciation-age approximate ranges from Pierce (2003), Madole and others (2005), and Aber (2006).	

Qa **Alluvial deposits along tributary streams (Holocene to late Pleistocene)** – Sand, silt, clay, and gravel in and underlying the modern flood plain of tributary streams. The flood plain consists of active, low-sinuosity to meandering channels, poorly sorted sandy to gravelly channel deposits, and finer-grained overbank deposits. The unit may include colluvial deposits along valley margins. It is sometimes overlain by alluvial fan (**Qf**) and mud fan (**Qamf**) deposits.   The gravel consists of sub-angular to sub-rounded, grayish-purple basalt. It includes pebbles, cobbles, and occasional boulders up to 6 ft in length. The larger clasts are often locally derived from older gravel-capped mesas. The deposits may contain trace amounts of angular to sub-rounded sandstone fragments, as well as well-rounded pebbles and cobbles of light-gray porphyry and greenish-gray to black hornfels. Thickness is poorly known but generally less than 15 ft.

Alluvial Deposits of the Gunnison River

Gravel, sand, silt, and clay deposited by the Gunnison River. The younger deposits (**Qag$_1$**) comprise the modern Gunnison River flood plain. Several levels of older deposits (**Qau$_2$** to **Qau$_6$**) are present as alluvial terraces that increase in age with increasing height above the modern river. Top-of-terrace elevation gradients are similar to the modern river gradient.

Alluvial unit **Qag$_1$** to **Qag$_5$** deposits are narrow (0.1 to 0.25 miles wide) within the lower Gunnison River Gorge. They record progressive down-cutting of the gorge through time. Unit **Qag$_6$** is wider (at least 0.5 miles wide) and occupies the rims of the gorge. Units **Qag$_1$** to **Qag$_5$** broaden considerably downstream from the gorge, where they cross soft Mancos Shale. Gunnison River gravel terraces may be overlain by age-equivalent to slightly younger fan and outwash gravel deposits, marking paleo confluences with tributary streams. We show alluvial deposits **Qag$_3$** to **Qag$_5$** as dashed lines where they are exposed in hill slopes at the base of an overlying tributary gravel (**Qg**-series) deposit.

Gunnison River gravel deposits consist of well-rounded, discoid to oval pebbles, cobbles, and rare small boulders up to 2 ft long. The gravel clasts are typically encased in a coarse sand matrix (**Figure 3**). Overbank deposits, where present, consist of mixed sand, silt, and clay. The silt may be alluvial or eolian in origin.

Figure 3. Alluvium three of the Gunnison River (**Qag$_3$**), exposed in a gravel pit near Austin. The deposit contains well-rounded pebbles and cobbles of diverse igneous and metamorphic rocks in a coarse sand matrix, and occasional thin lenses of medium to coarse sand. Clast imbrication is weakly to moderately developed. Notebook is 8 inches high. [UTMX: 244,407, UTMY: 4,295,186]

The composition of gravel in units **Qag$_1$** to **Qag$_5$** indicates a mix of upstream source areas. Source areas include the Black Canyon of the Gunnison (gneiss, schist, amphibolite, pegmatite, granite), San Juan Mountain volcanic field (tuffs, andesite, dacite, monzonite), central and northern West Elk Mountains (monzonite and granodiorite porphyries, hornfels, quartzite), and Grand Mesa (basalt). Interpretation of source area lithologies is based on maps by Gaskill and Godwin (1966), Godwin (1968), Hansen (1968, 1971), and Tweto and others (1978). In contrast, unit **Qag$_6$** has few West Elk clasts and no Grand Mesa clasts. Nearly all of its clasts are derived from Black Canyon and San Juan sources. It appears that the North Fork Gunnison River flowed in a separate valley located north of the Gunnison River, along the base of Grand Mesa, during and prior to **Qag$_6$** time. The ancestral North Fork River (unit **Qan$_6$**) intercepted the south-flowing Grand Mesa tributaries and drained much of the West Elk Mountains. By **Qag$_5$** time, the North Fork River was captured by the ancestral Gunnison River at an upstream location, near the present-day confluence of the rivers at Pleasure Park (in the Lazear quadrangle). North Fork alluvial deposits (**Qan**-series) are described separately.

Qag_{1a} **Alluvium one-a of the Gunnison River (Holocene) –** Gravel, sand, silt, and clay in the modern stream channel and low, active flood plain of the Gunnison River. The upper flood plain surface is 3 to 6 ft above the modern river level. It is inundated during peak snow melt and summer storm flooding. This unit is partially incised into and is underlain by unit **Qag_{1b}**. Thickness is not known but may be less than 15 ft.

Qag_{1b} **Alluvium one-b of the Gunnison River (Holocene to late Pleistocene) –** Gravel, sand, silt, and clay in low terraces and elevated portions of the Gunnison River flood plain. This deposit underlies the entire, modern river valley. Its strath is below that of **Qag_{1a}** and represents the deepest level of major river-valley incision. Its oldest, deepest sediments may be Pinedale-age outwash sands and gravels. The upper gravel surface is 5 to 10 ft above the modern river. Holocene overbank deposits, 5 to 10 ft thick, are present in places. The unit is extensively farmed and poorly exposed. Water well records from the Colorado Division of Water Resources indicate that **Qag_{1b}** deposits are up to 50 ft thick.

Qag_2 **Alluvium two of the Gunnison River (late Pleistocene) –** Gravel and sand with minor silt and clay. The unit forms low terraces along the flanks of the modern river valley. It is poorly exposed. Its upper gravel surface is 20 to 30 ft above the modern river. Thickness is 15 to 25 ft.

Qag_3 **Alluvium three of the Gunnison River (late Pleistocene) –** Gravel and sand with minor silt and clay. The unit forms broad, relatively extensive terraces. Its upper gravel surface is 80 to 100 ft above the modern river. An optically stimulated luminescence (OSL) age date of 45.2 ± 4.3 ka was obtained from a sand sample collected near Austin (**Appendix B**). In places, the unit is capped by up to 5 ft of silty overbank and loess deposits. Those deposits are moderate orange pink. They have soil profiles that consist of A-Bt-Bk horizons with weak to moderate, Stage II calcic soil development in the Bk horizon. Thickness is 20 to 40 ft.

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. Its upper gravel surface is 160 to 170 ft above the modern river. A cap of loess may be present in places. Thickness is 25 to 40 ft.

Qag_5 **Alluvium five of the Gunnison River (late middle Pleistocene) –** Gravel and sand with minor silt and clay. The unit forms dissected, remnant terraces. Its upper gravel surface is 250 to 290 ft above the modern river. A cap of loess may be present in places. Thickness is 25 to 50 ft.

Qag_6 **Alluvium six of the Gunnison River (middle Pleistocene) –** Gravel and sand with minor silt and clay. The unit forms dissected, remnant terraces. Its upper gravel surface is 450 to 470 ft above the modern river. At the High Mesa gravel pit, the unit is capped by 10 to 20 ft of silty overbank and loess deposits (**Figure 4**). The reddish color and the high degree of calcic soil development within the finer-grained deposits is generally indicative of middle Pleistocene age (A-Bt-Bk, Stage III calcic soil of Machette, 1985). Thickness is 50 to 70 ft.

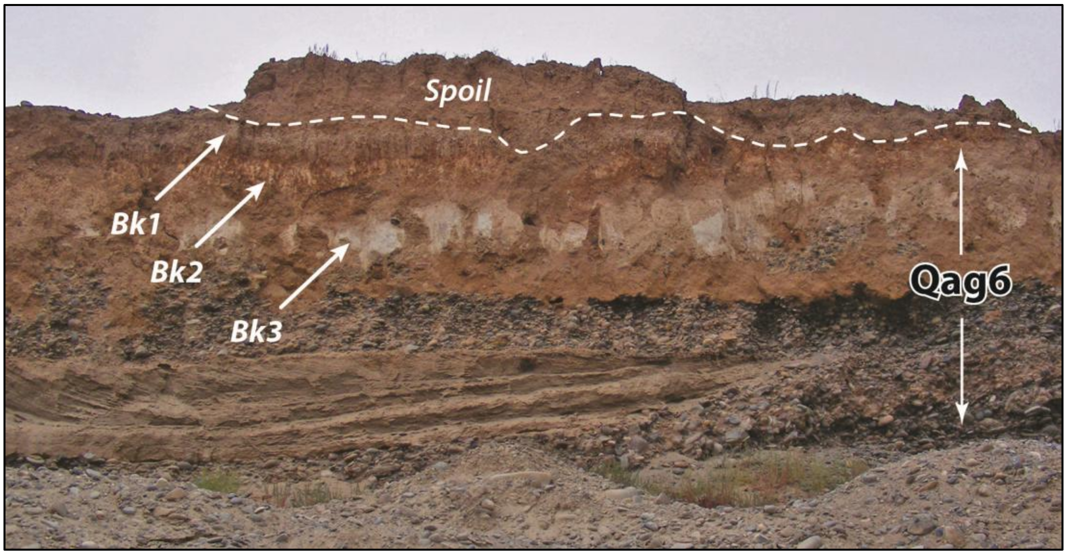

Figure 4. Alluvium six of the Gunnison River (**Qag$_6$**), exposed in high-wall of High Mesa gravel pit. Alluvial cobble-pebble gravel with large sand lens is overlain by reddish, silt-rich, overbank and loess deposits. At least three levels of diffuse to ribbon-like, white calcic soil (Bk1, Bk2, Bk3) are visible in the silt deposit. Displaced spoil material caps the exposure, which is about 15 ft high. [UTMX: 246,912, UTMY: 4,296,584]

Alluvial Deposits of the North Fork Gunnison River

Gravel, sand, silt, and clay deposited by the ancestral North Fork Gunnison River. There are two North Fork alluvial-terrace levels within the Orchard City quadrangle. **Qan$_6$** is the basal gravel at Shamrock and "Hidden" Mesas, and in an unnamed terrace on the south flank of Antelope Hill. **Qan$_7$** is the basal gravel at Redlands Mesa (southern part) and Antelope Hill. The top-of-terrace elevation gradients are steeper than those of the modern and ancestral Gunnison River. The terraces converge toward age-equivalent Gunnison River terraces in the downstream (westward) direction. No North Fork alluvial deposits are preserved west of Antelope Hill. Based on projection of converging surfaces, the confluence of the Gunnison and North Fork Rivers during middle Pleistocene time was near Delta.

North Fork terraces may be overlain by age-equivalent to somewhat younger fan and outwash gravel deposits, marking paleo confluences with tributary streams. We show alluvial deposits **Qan$_6$** and **Qan$_7$** as dashed lines where they are exposed in steep hill slopes at the base of a tributary gravel (**Qg**-series) deposit. At those locations, the North Fork gravels underlie the tributary gravels.

North Fork Gunnison River gravel deposits consist of well-rounded, discoid to oval pebbles, cobbles, and rare small boulders up to 1.5 ft in length (**Figure 5**). The gravel clasts are typically encased within a coarse sand matrix. Overbank deposits were not recognized. The gravel composition shows a mix of two upstream sources. They include the central and northern West Elk Mountains (monzonite and granodiorite porphyries, hornfels, quartzite), and Grand Mesa (basalt and trace amounts of sandstone and chert). Source-area lithologies were interpreted from maps by Gaskill and Godwin (1966), Godwin (1968), Tweto (1976), and Tweto and others (1978).

Figure 5. Alluvium six of the North Fork Gunnison River (**Qan$_6$**), exposed on a mesa near Antelope Hill. The deposit consists of pebbles and cobbles of porphyry, basalt, hornfels, and fine-grained quartzite in a coarse-sand matrix. [UTMX: 244,439, UTMY: 4,300,139]

Qan$_6$ **Alluvium six of the North Fork Gunnison River (middle Pleistocene) –** Gravel and sand. The unit forms dissected, remnant terraces (**Figure 5**). It contains coarse sand in the gravel matrix and in cross-bedded sand lenses. The basal few feet of the deposit may be well cemented by calcite. It is occasionally covered with age-equivalent or younger fan deposits (**Qg$_6$** and **Qfo**). Between Shamrock and "Hidden" Mesas, **Qan$_6$** deposits show that the ancestral North Fork River flowed through a gap between the southwestern tip of Redlands Mesa and a butte to the south. This former canyon is 0.25 miles wide, and the deposit there is mostly covered by landslides. The upper surface of the river gravel is 520 to 570 ft above the modern Gunnison River. Based on optically stimulated luminescence (OSL) age dating , a **Qan$_6$** sand sample collected near Antelope Hill was found to be older than 71 ka (**Appendix B**). The deposit is probably much older, based on its elevation and landscape position. Thickness is 20 to 40 ft.

Qan$_7$ **Alluvium seven of the North Fork Gunnison River (middle Pleistocene) –** Gravel and sand. The unit is exposed only where it is covered with very thick, age-equivalent or slightly younger fan and outwash gravel deposits (**Qg$_7$**). In map view it forms a narrow ring around the slopes of Antelope Mesa and the southern end of Redlands Mesa. We traced the deposit eastward into the Lazear quadrangle (Noe and others, in prep., a). Overall, it is about a mile wide in the north-south direction. In rare exposures, the northern and southern edges of the deposit are flanked laterally by shale, marking the edge of the paleo valley. The upper surface of the **Qan$_7$** river gravel is 730 to 860 ft above the modern Gunnison River. Thickness is 5 to 30 ft.

Mud Flow and Alluvial Fan Deposits

Qamf **Alluvial, mud flow, and mud fan deposits (Holocene to late Pleistocene) –** Grayish-pink to grayish-orange, well to occasionally poorly sorted, poorly consolidated, locally gravel-bearing, clayey to sandy silt. The deposits primarily consist of poorly defined silt layers, typically less than an inch to a few inches thick. The muddy sediments are derived from the Mancos Shale and older deposits. The gravel clasts are derived locally, eroded from older debris flow deposits and landslides. The deposits are formed by channelized to laterally unconstrained mud flows or mud-and-gravel debris flows. Alluvial floods may rework the sediments. There are occasional stringers and lenses of gravel and sand, especially in the basal deposits and in the vicinity of sand and gravel sources. The unit forms valley-head and valley-side alluvial fans and tributary stream valley fills. It forms low-gradient mud fans and coalesced fan aprons that cover large areas of the modern Gunnison River and Tongue Creek floodplains. The unit is best developed within the "Adobe hills" areas of the quadrangle. Thickness is 5 to 10 ft in valley-head areas and may exceed 20 ft along valley reaches and in terminal fans.

Qf **Alluvial fan deposits (Holocene) –** Poorly to moderately sorted sand, silt, clay, and gravel. The fan sediments are deposited by flood, debris, and sheet flow processes. Alluvial fans form at the mouths of stream valleys and arroyos where the drainage loses confinement. Fan aprons form along the base of bluffs and mesas, distal to landslide complexes. Some fans encroach onto modern floodplains. Along tributary streams, they may force the stream to migrate toward the opposite side of the valley. Large alluvial fan aprons ring Harts Basin, which lacks a through-going stream. Alluvial fan aprons cover older river terraces to the south of the Gunnison River near Read. They are thickest at the proximal apex and thin toward the distal margins. Thickness is 5 to possibly 40 ft.

Qfo **Older alluvial fan deposits (late to middle Pleistocene) –** Composition and mode of deposition is the same as for **Qf**. The unit occurs as individual, dissected fans that overlie an older river-gravel terrace or shale. The fans are inactive, incised, and are bypassed by modern streams or arroyos. Thickness is 5 to 30 ft.

Mixed Debris Flow and Alluvial Gravel Deposits

Gravel, sand, silt, and clay deposited in former valleys of tributary streams that flowed southward from Grand Mesa to the ancestral North Fork or Gunnison Rivers. Upland gravel deposits of various ages (**Qg**-series) are scattered throughout the northern and western parts 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 are found at progressively higher elevations. In many cases, the downstream end of tributary gravel bodies grade to and overlie North Fork or Gunnison river-gravel terraces, marking paleo confluences with those ancestral rivers. Because of this association between the tributary gravels and main-stem river gravels, we assume that they are roughly age equivalent, with the tributary gravel deposits possibly being slightly younger.

We interpret the linear gravel bodies to be valley-fill deposits of bedrock-confined paleo streams. The fan-like gravel bodies appear to be fan complexes that formed in local basins and/or at confluences. In some cases, the original shale valley sides still exist; in other cases, the confining walls are eroded away. The valleys ranged from 0.1 to 0.6 miles in width. The fans ranged from 0.5 to many miles wide. It appears that the ancient valleys and basins were much like the region's modern tributary valleys in terms of their distribution and morphology.

We recognize three main types of tributary gravel deposits: (1) alluvial deposits containing rounded pebbles to small boulders in a sand matrix; (2) debris flow deposits containing sub-angular, very poorly sorted pebbles to very large boulders in a mud matrix (**Figure 6a**); and (3) outwash sheet-flood deposits consisting of stratified lenses of coarse to fine gravel and sand, and lesser quantities of mud (**Figure 6b**). This subdivision of gravel deposits generally agrees with an earlier study by Cole and Sexton (1981). These authors referred to our debris flow deposits as "pediment deposits". The alluvial deposits form basal gravels within paleo tributary valleys. The debris flow deposits range from 10 to 100 ft thick. They contain single to multiple flow units, and are the most common and widespread tributary gravel type. The outwash deposits tend to form deposits along valley-side margins of larger debris-fan complexes.

The tributary gravels deposits are composed nearly entirely of basalt in most cases. The basalt is derived from late Miocene basalt flows that cap Grand Mesa. Minor amounts of sandstone, siltstone, clinker, chert, carbonate concretions, and shale and tuff rip-up clasts may be present. These are derived from Upper Cretaceous to Miocene-aged bedrock units that outcrop in the upper slopes of Grand Mesa. Minor amounts of well-rounded porphyry and hornfels clasts, originally from the West Elk Mountains, may have been eroded from older, higher, North Fork River terraces and/or Miocene alluvial deposits.

In certain locations, the tributary gravel compositions reflect other sources. Gravel deposits along Peach Valley contain tuff, andesite and volcanic breccia derived from the San Juan Mountains to the south. Those gravels appear to be reworked from older deposits of the middle Pleistocene Shinn Park-Bostwick Park paleo valley system (Dickinson, 1966; Aslan and others, 2008). Deposits along the south-western side of the Gunnison Uplift near Smiths Mountain contain angular sandstone fragments eroded from the Dakota Sandstone. Deposits beneath Shamrock Mesa are derived from the **Qan$_6$** North Fork terrace. They contain well-sorted, well-rounded river gravel clasts suspended in a mud matrix; this is an interesting case of textural inversion, where the gravel is more sorted and rounded than in typical debris flow deposits. Overall, the composition, texture, and other characteristics of **Qg**-series deposits vary considerably as a function of the different sediment sources and depositional processes.

Qg$_1$ **Gravel deposit one (Holocene) –** Gravel, clay, silt, and sand. The modern gravel deposits form at the heads of local dry washes, mostly from small slope failures. They consist of gravel clasts or rock fragments eroded from the adjacent hill, often mixed with Mancos Shale-derived mud from the lower slope. Thickness is less than 15 ft.

Qg$_2$ **Gravel deposit two (late Pleistocene) –** Gravel, clay, silt, and sand. The unit forms small fans near heads of local dry washes and low, dissected terraces flanking the modern stream valleys. Its upper surface is 20 to 40 ft above the modern valley bottoms. Thickness is 10 to 15 ft.

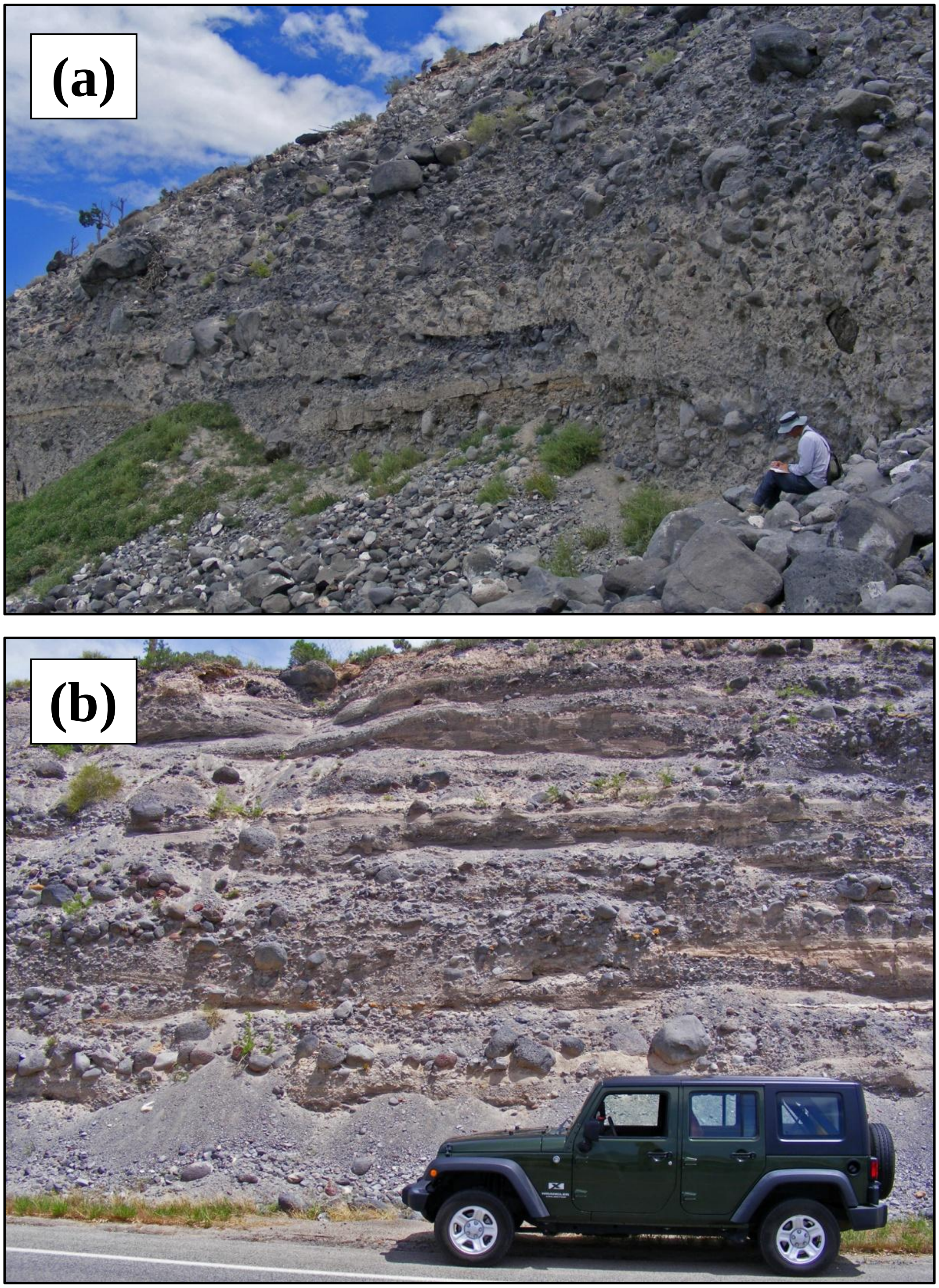

Figure 6. Examples of tributary gravels representing mixed debris flow and alluvial deposits (**Qg** series).
(a) Debris flow deposit (in **Qg$_7$**) at Cedar Mesa, just north of the map area. The lower cliff contains abundant mud-and-gravel-rich, cut-and-fill channels. The upper cliff contains poorly stratified, very poorly sorted deposits that contain very large basalt boulders. [UTMX: 248,373, UTMY: 4,307,052]
(b) Outwash sheet-flood deposit (in **Qg$_3$**) at Cory grade, State Highway 65. The deposit is highly stratified and contains relatively thin sediment lenses and minor internal erosion surfaces. It consists of alternating debris flow, mud flow, and braided stream facies. [UTMX: 239,651, UTMY: 4,296,868]

Qg_3 **Gravel deposit three (late Pleistocene) –** Gravel, clay, silt, and sand. The unit forms small fans, dissected terraces, shoestring mesas, and extensive gravel surfaces. It forms the majority of the "Surface Creek Surface," which is 2.5 miles wide near Orchard City and at its lower terminus along the Gunnison River. That deposit splits to both sides of a shale outcrop between Orchard City and Cory, and then joins again to form a contiguous terminal fan between Austin and Cory. The unit contains abundant debris flow deposits, especially in the upper layers. Outwash sheet-flood deposits are found in the western part of the fan terminus (**Figure 6b**). The upper surface is 40 to 180 ft above the modern valley bottoms. Thickness is 15 to 45 ft for the valley-fill deposits, expanding to 70 ft where the terminal fans overlap **Qag_3** Gunnison River gravels.

Qg_4 **Gravel deposit four (late middle Pleistocene) –** Gravel, clay, silt, and sand. The unit forms dissected terraces, shoestring mesas, and extensive gravel surfaces. It forms an older part of the "Surface Creek Surface" near the northern map boundary. Its upper surface is 60 to 220 ft above the modern valley bottoms. Thickness is 15 to 50 ft.

Qg_5 **Gravel deposit five (late middle Pleistocene) –** Gravel, sand, silt, and clay. The unit forms dissected terraces and shoestring mesas. Just north of Austin, the unit overlies a Gunnison River gravel terrace (**Qag_5**) and consists of 20 ft of pale-red, sandy silt (possibly loess) overlain by 20 ft of basalt debris flow gravel. This is the only location where we observed a fine-grained interval preserved within the unit. The upper surface of the unit is 100 to 360 ft above the modern valley bottoms. Thickness is 40 to 100 ft.

Qg_6 **Gravel deposit six (middle Pleistocene) –** Gravel, sand, silt, and clay. The unit forms dissected shoestring mesas and fans. Most notable is the string of three remnant fans in paleo basins along a former course of Currant Creek, between Cedar Mesa and "Hidden Mesa." Each of the fans thins to the southwest, in the downstream direction, resulting in wedge-shaped sediment bodies. Debris flows are the dominant facies, with basalt boulders up to 7 ft in length. The unit's upper surface is 100 to 350 ft above the modern valley bottoms. Thickness is 10 to 60 ft.

Qg_7 **Gravel deposit seven (early middle Pleistocene) –** Gravel, sand, silt, and clay. The unit forms dissected shoestring mesas, and extensive fans. Thick, aggraded debris flow deposits are found in the Cedar and Redlands Mesa fan complexes (**Figure 6a**). They contain abundant, large basalt boulders 5 to 10 ft long. A 30-ft long block of sandstone was found by Dr. A. Aslan (Colorado Mesa University, personal communication, 2008). Outwash deposits are present in Redlands Mesa, particularly in the western part of the fan and in the lower part of the unit. In southern Redland Mesa and Antelope Hill, **Qg_7** deposits overlie **Qan_7** North Fork river gravels. It appears that the Redlands Mesa fan prograded into and filled the entire paleo North Fork River valley. Some of the fan sediments were deposited down-valley to the west, at today's Antelope Hill. Shoestring mesas that flank Harts Basin contain basal alluvial gravels overlain by stratified debris flow deposits. The top of the **Qg_7** unit consists of up to 7 ft of silty to sandy, pale- to weak-red loess. A heavy, Stage III+ calcic Bk soil is developed in the loess. The unit is at about the same elevation as Petrie Mesa (Aslan and others, 2008), which contains the Lava Creek B ash (640 ka; Lanphere and others, 2002). We did not encounter the ash in the map area. The upper surface of the unit is 200 to 300 ft above the modern valley bottoms. Thickness is 60 to 100 ft.

Qg **Gravel deposits, undivided (Pleistocene) –** Gravel, sand, silt, and clay. The unit forms small, dissected terraces along the flanks of modern tributary stream valleys. These are stray gravel remnants that do not correlate with terrace levels 1 to 7. Thickness is 10 to 15 ft.

ʘ **Isolated gravel pod or lag (Holocene to Pleistocene) –** Black-and-red "bulls' eyes" mark the locations of small, thin, relict gravel deposits in the Adobe hills. They occupy the tops of hills and points and appear to be in place. Most of the deposits consist of rounded pebbles and cobbles of Gunnison or North Fork River origin. A few contain sub-angular basalt gravels. The deposits are small remnants of older gravel bodies, or they are remnants of younger arroyo fill deposits that formed during erosion and redeposition of older gravels. Thickness is 5 to 10 ft.

MASS WASTING DEPOSITS

Qls **Landslide deposits (Holocene to middle Pleistocene) –** Unsorted to moderately sorted clay, silt, sand, and gravel. 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. Landslide debris may contain bodies of relatively undisturbed rock or soil. In the Orchard City quadrangle, landslides form in mesa side slopes composed of clay-rich bedrock (Mancos Shale or Morrison Formation). Upland gravels may be incorporated into the landslide, either as part of the primary slope failure, or later during erosion and retreat of the head scarp. Some of the landslides within the quadrangle are clearly active. Others appear to be inactive, although they may be metastable and potentially capable of reactivation. The landslide scarps are mapped as separate features **–** some are fresh, while others are mostly healed and retain the arcuate shape of the failure surface. Thickness is 5 to possibly greater than 100 ft.

MINERAL SPRING DEPOSITS

***** **Travertine deposits (Holocene to late Pleistocene) –** Blue asterisks on the map mark mineral spring deposits, formed by precipitation of calcium carbonate and other soluble minerals. The deposits vary in color from grayish orange pink to dark reddish brown. They form mound-like, active or relict features at the mouth of and within the lower Gunnison River Gorge, and at the southern corner of Smiths Mountain. The largest concentration occurs just east of Austin, in a fault zone along the edge of the Gunnison Uplift. The active springs produce algal-populated water that smells of sulphur (**Figure 7**). The older deposits may be eroded and dissected. The sediments contain parallel, convoluted, or botryoidal laminations. Bodies of breccia, consisting of carbonate and sandstone fragments in a cemented groundmass, are present. The deposits are slightly to highly porous. Cadigan and others (1976) found that the Austin deposits contain calcium carbonate, salt and sulphur precipitates, and minor sodium, lithium, boron, mercury, and molybdenum. They describe two travertine deposits within the gorge, deposited by carbon-dioxide-charged geysers. Those contain calcium carbonate, iron precipitates, and minor arsenic, molybdenum, beryllium, and boron. Thickness is not known, but may be up to 20 ft.

Figure 7. Travertine deposit (*) near the mouth of the lower Gunnison River Gorge.
Active spring forming an algal-encrusted travertine mound. The mound is partially covered by sandstone debris that were deposited during flash floods. [UTMX: 244,795, UTMY: 4,296,855]

BEDROCK UNITS

A 3,300-ft-thick interval of Upper Cretaceous to Upper Jurassic sedimentary formations is exposed in the Orchard City quadrangle. The oldest units are found in the Gunnison Uplift area, in the southeastern corner of the map. There, the main units are the Morrison Formation, which makes up the canyon walls within the lower Gunnison River Gorge, and the Dakota Sandstone, which forms a highly resistant surface that defines the outer extent of the uplift. The remainder of the map area lies within the outcrop belt of the Mancos Shale. Approximately the lowermost two-thirds of the 4,000-ft thick shale occurs within the quadrangle. The youngest part of the Mancos Shale is in the northeastern corner. A generalized stratigraphic column of the mapped bedrock units and sub-units is shown in **Figure 8**. Thickness ranges of the bedrock units are derived from nearby oil-and-gas well logs.

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.

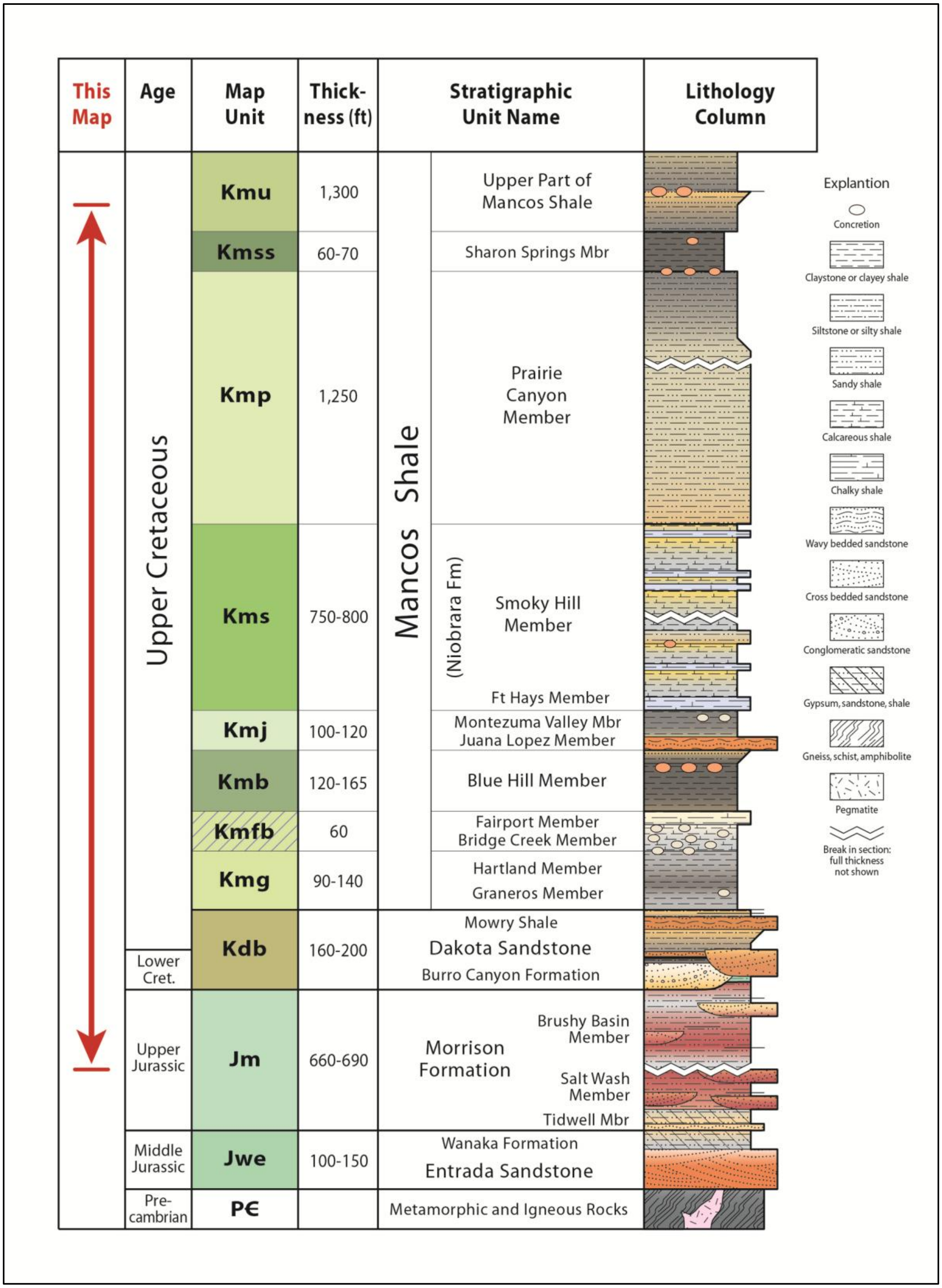

Figure 8. Generalized stratigraphic column of bedrock units for the Orchard City quadrangle. Red arrow denotes bedrock units exposed in outcrops in the quadrangle and shown on the geologic map.

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 twelve members of the Mancos Shale in the quadrangle. They are distinguished on the basis of composition, color, and fossil assemblages. Their contacts are conformable unless indicated. Some of the thinner members are grouped together on the geologic map (**Plate 1**).

Kmu **Mancos Shale, upper part** — Olive-gray to pale-yellowish-brown, non-calcareous, silty to sandy shale. Only the lowest 140 ft of the unit is present on the side of Cedar Mesa, in the north-eastern part of the map. It is mostly covered. Overall thickness is around 1,300 ft.

Kmss **Sharon Springs Member** — Dark-gray to black, organic-rich, clay shale. Weathers to mottled pale to moderate red to grayish red. This thin unit is poorly exposed along the sides of two finger mesas in the northern part of the map. It is mostly covered by landslides. Freshly exposed surfaces are rare and contain abundant healed fractures. Elsewhere in the region, this unit contains a number of white to orange bentonite beds. The bentonite beds are 0.5 to 6 inches thick. The unit is 60 to 70 ft in outcrop and in nearby oil and gas well logs, where it forms a prominent, widespread marker that is used for making subsurface well log correlations.

Kmp **Prairie Canyon Member** — Light-gray to pale-yellowish-brown, sandy shale. Weathers grayish orange to grayish yellow. This thick unit underlies most of the northeastern part of the map but is mostly covered by Quaternary deposits. It is better exposed to the northeast of Cory in some small hills, and to the east of Eckert at the southern tip of a shoestring mesa. In outcrops it occasionally contains small, rounded discs of very fine, bioturbated sandstone. The discs appear to be individual sand ripples that weather out of the shale. A few sandstone beds of up to 1 ft thick are present. The uppermost 200 ft of the unit becomes less sandy. Overall, the unit is less sandy than in the Grand Junction and Montrose areas (Cole and others, 1997; Noe and others, 2007). Fossils are sparse and consist of thin *Inoceramus* fragments. Thickness is 1,250 ft.

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. There are occasional limestone beds (peloid-rich mudstone or packstone) up to 1 ft thick. A 50-ft-thick, sandy shale zone is present in the lower middle part. Seams of fibrous gypsum are present throughout the unit. It is well exposed in cliffs along the western side of Tongue Creek and southern side of Shamrock Mesa (**Figure 9**). Although widespread in outcrop, the Smoky Hill Member is often covered by thin residuum and is poorly exposed. The Fort Hays Member forms the basal strata of the Niobrara interval. It is highly calcareous and very poorly exposed. In outcrop, it consists of very light gray residuum. The unit overlies a regional unconformity (Weimer, 1983). Thickness of the Smoky Hill Member is 650 to 720 ft. The Fort Hays Member is 75 to 90 ft thick.

Figure 9. Smoky Hill Member of the Mancos Shale (**Kms**) exposed along Shamrock Mesa. The outcrop consists of slightly calcareous shale. The pale-yellowish-orange upper part is a weathered zone where ground water infiltrated and oxidized the shale. Thin, chalky limestone beds (arrows) are seen in the weathered zone. North Fork river gravels cap the mesa. [UTMX: 249,370, UTMY: 4,300,184]

Kmj **Montezuma Valley and Juana Lopez Members, undivided** — The Montezuma Valley Member is a medium-dark-gray shale. The sub-unit is poorly exposed, except at the southern tip of "Hidden Mesa." Abundant seams of fibrous gypsum are present. Light-gray limestone concretions are found in the upper 15 ft. We found a thin bed of calcarenite shell hash containing specimens of *Mytiloides cf. M. scupini*. The underlying Juana Lopez Member is medium gray to black. In outcrop, it may weather to light red to moderate reddish orange (**Figure 10**). It consists of 1- to 6-inch thick interbeds of rippled calcarenite and organic-rich shale. The calcarenite beds contain shell hash and broken pieces of 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 northern and southwestern sides of the Gunnison Uplift. Thickness of the Montezuma Valley Member is 50 to 60 ft. The Juana Lopez Member is 40 to 60 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. Disc-shaped septarian concretions and starved glauconitic-sand ripples occur in the uppermost 40 ft. We collected several partial specimens of a coiled ammonite, *Prionocyclus hyatti*, near the top (see photo in **Appendix C**).

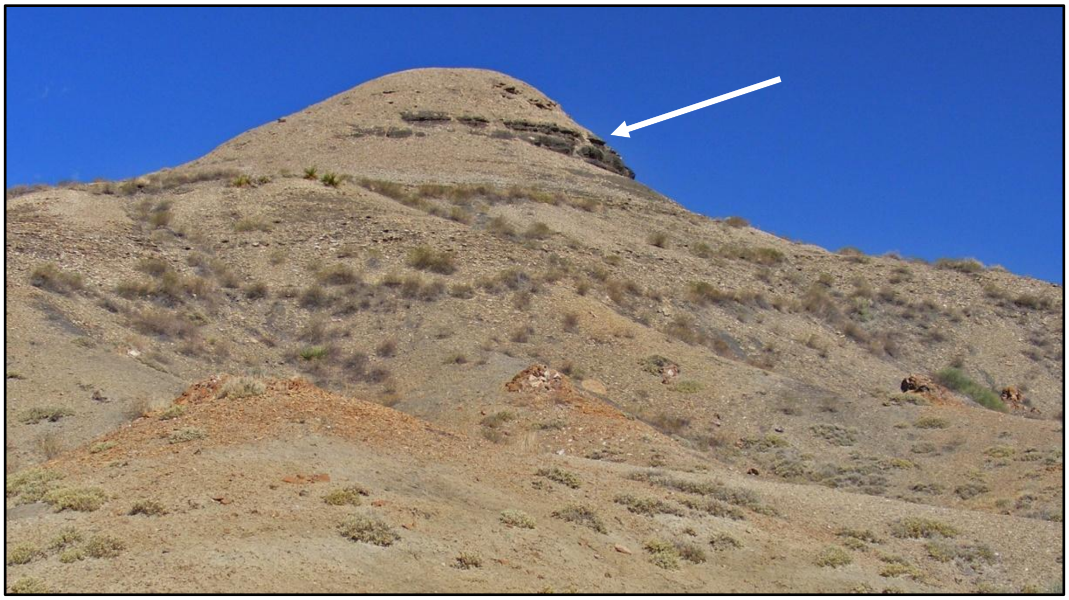

Figure 10. Juana Lopez (**Kmj**) and Blue Hill (**Kmb**) Members of the Mancos Shale near Lawhead Gulch. An arrow marks the contact between the reddish-orange Juana Lopez Member, which caps the hill, and the underlying Blue Hill Member, which forms black to gray cliffs and slopes. In the foreground is a horizon that contains large, moderate-red concretions. This horizon is widespread across much of west-central Colorado. [UTMX: 248,829, UTMY: 4,297,171]

The middle part is fissile shale with distinct bedding planes. The contact between the upper and middle parts contains a zone of abundant, moderate-red concretions up to 6 ft in diameter (**Figure 10**). The concretions have septarian structure and cloudy white calcite crystals at their cores, surrounded by outward-radiating carbonate material (possibly siderite?) with cone-in-cone structure. The lower part of the Blue Hill Member is slightly silty, wavy-bedded, fissile shale. It becomes brownish black near the base of the unit. Thickness is 120 to 165 ft.

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 a USGS core at Candy Lane, about 9 miles south of the quadrangle. They indicate that the Fairport/Bridge Creek contact 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. It contains a number of concretion zones. The concretions are pale red purple and up to 2 ft in diameter. We collected *Pycnodonte aff. P. newberryi* oysters from three locations in or near the quadrangle. The undivided Fairport and Bridge Creek Members are 50 to 60 ft thick.

Kmg **Hartland and Graneros Members, undivided** — Light brownish gray to medium gray, non-calcareous, clayey to silty shale. The unit contains a few zones with thin siltstone discs that weather out of the shale. We found a single, non-age-diagnostic fossil (*Mytiloides? sp.*). Although other authors call this 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. Thickness is 90 to 140 ft.

Older Bedrock Units Shown on Geologic Map

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

Kdb **Mowry Shale, 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 southeastern corner of the quadrangle.

The **Mowry Shale** consists of dark gray, clayey to silty shale and thin interbeds of light gray to light brown siltstone and very fine-grained sandstone. Bedding thickness is on the scale of millimeters to a few inches. The siltstone and sandstone beds contain starved ripples, ripples, and graded beds. Bioturbation is generally lacking. Elongate limestone concretions are present but rare. A new (2009) highway cut along State Highway 92 provides excellent exposures of the unit and its internal bedding. The Mowry Shale is a transitional unit between the Dakota Sandstone and Mancos Shale. Its upper contact (called the "Dakota Silt" marker by the oil and gas industry) is conformable, and its lower contact is unconformable (Currie and others, 2008). It forms a thin, partially eroded and broken cover on top of the Dakota Sandstone on gently dipping hogback slopes. Along the northern rim of the Gunnison River gorge, it forms rounded slopes capping the Dakota Sandstone cliffs. Thickness is 10 to 25 ft, thickening to the northeast.

The **Dakota Sandstone** consists of interbedded sandstone, shale, and minor coal. It forms the uppermost cliffs of the Gunnison River gorge (**Figure 11**) and resistant hogback slopes elsewhere. There are two sub-units. The upper sub-unit consists of interbedded shale and sandstone. 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 locally sparsely bioturbated with *Skolithos*, *Ophiomorpha*, and *Thalassianoides* borrows. The sandstone beds are up to 5 ft thick and have rippled bedding and hummocky cross stratification. Some of the beds have a siliceous cement; they are light gray and translucent in fresh exposures. Occasionally, large channel-like sandstone bodies occur in the lower part of the upper sub-unit. The channels are up to 50 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 10s of ft long in the direction of current flow (in one case, generally N 80° W). We found *Teridolites* borings, indicating a brackish-water depositional environment, near the base of one channel.

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

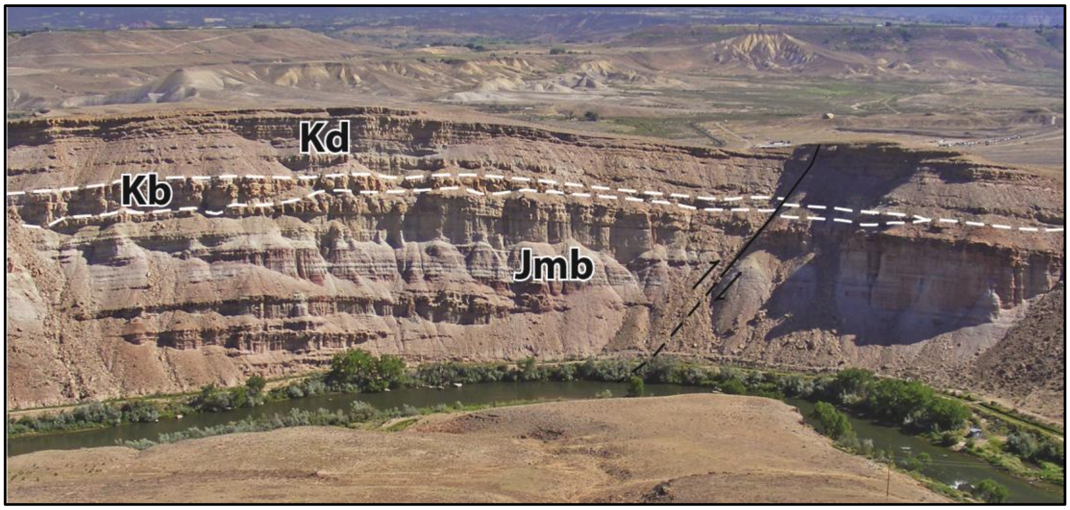

Figure 11. Cretaceous and Jurassic bedrock formations exposed in the lower Gunnison River gorge. The formations include the Dakota Sandstone (**Kd**), Burro Canyon Formation (**Kb**), and the Brushy Basin Member of the Morrison Formation (**Jmb**). Note the lenticular nature of the Burro Canyon Formation above an erosion surface that cuts into the Morrison Formation. [UTMX: 245,315, UTMY: 4,295,742]

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. There are a few distinctive sandstone beds near the base. They are 2 to 3 ft thick, moderate red, coarse grained, tabular in geometry, extensively bioturbated (including abundant *Skolithos* burrows), and have soil-like textures. The Dakota Sandstone is Upper Cretaceous (Cenomanian) in age in west-central Colorado (Merewether and Cobban, 1986). The Dakota-Burro Canyon contact is unconformable. Thickness varies from 100 to 130 ft.

The **Burro Canyon Formation** contains conglomerate, sandstone, and minor 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 variable amounts of light- to medium-gray chert pebbles and granules. The chert clasts are well rounded and less than 0.5 inches in diameter. There are other, non-conglomeratic sandstone bodies that are fine- to medium-grained and interbedded with sandy shale. Those lithologies are generally lenticular and are poorly exposed, even in cliffs, due to paleosol development. The beds often have distinctive pale-yellowish-green to pale-yellowish-orange colors. We found rounded, polished chert pebbles up to 3.5 inches in diameter at the base of non-conglomeratic sandstone bodies in two locations. We interpret these to be dinosaur gizzard stones. The Burro Canyon Formation forms cliffs up to 80 ft thick along some segments of the Gunnison River gorge where the paleo-low-filling conglomeratic sandstone bodies are present (**Figure 11**) . In other places it is absent, and the Dakota Sandstone rests directly upon the Morrison Formation.

Jm **Morrison Formation (Upper Jurassic)** — The uppermost part of the Morrison Formation is exposed in the walls of the lower Gunnison River gorge (**Figure 11**). The strata are from the

Brushy Basin Member. It 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 within the sandstone lenses and in lenses of interbedded sandstone and shale. 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 have knobby surfaces with cemented bodies that are orange to dark reddish brown and 1/4 to 1/2 inch in diameter. Some of the sandstone channels are amalgamated and up to 60 ft thick. Conglomerate lenses up to 10 ft thick are occasionally present. They contain gray chert pebbles and are similar in appearance to the Burro Canyon conglomerates. The shales often contain bentonitic clays. Many 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 up the Gunnison River gorge, but not within the Orchard City 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 Orchard City quadrangle is up to 400 ft. The entire formation is 660 to 690 ft thick. The entire Morrison Formation is shown as a single unit in the **Plate 2** cross section.

Older Bedrock Units Shown on Geologic Cross Section A-A' Only

Cross Section A-A' runs northeast from Peach Valley across Smith Mountain and the Gunnison Uplift, then north to Redlands and Cedar Mesas. The section line is shown on **Plate 1**. The cross section is shown on **Plate 2**. Additional, older bedrock units are included as subsurface units on the cross section. They do not crop out within the Orchard City quadrangle but occur to the southeast. Reported thickness values are from outcrops farther upstream 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)** — The 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 Orchard City quadrangle lies within the eastern part of the Colorado Plateau physiographic province (Fenneman and Johnson, 1946). Its main structural feature is the Gunnison Uplift. It is best expressed in the southeastern corner of the quadrangle. There, the Dakota Sandstone forms resistant hogbacks that dip generally north-northeast to north-northwest, toward the Piceance Basin, at shallow angles of 10° or less. This hogback surface is broken by a series of minor folds (mapped in **Plate 1** as paired synclines and anticlines). The folds are unfaulted in outcrop, except for one fold broken by a minor fault (less than 20 ft offset) along the eastern side of Smiths Mountain. The fold axes have east-west or northeast-southwest orientations. The fold limbs vary in degrees of steepness, with bedding dips ranging from 3° to greater than 30°. We interpret that the folds mark the margins of faulted basement blocks at depth, a result of minor differential uplift and tilting.

The southwestern and western edges of the Gunnison Uplift are rather abrupt. Those boundaries are marked by a pair of large, well-defined monoclinal folds (**Plate 1**). The folds are parallel and en echelon to the south and southeast of Smiths Mountain. The eastern fold becomes larger to the southeast. It extends into the Olathe Northwest quadrangle, where it becomes a faulted monocline (Noe and others, in prep., b). The western fold, also a faulted monocline, wraps around the western side of Smiths Mountain. It forms the escarpment at the western end of the lower Gunnison River gorge. The fault appears to be a high-angle, reverse fault. It brings nearly flat-lying Morrison Formation into contact with steeply dipping Graneros Member of the Mancos Shale (**Figure 12**). The maximum displacement is around 200 ft. The fault trace is coincident with several mineral spring deposits that were described in a previous section (**Surficial Deposits**). The monocline limb dips steeply to the west and southwest at angles of 30° to over 80°.

Mancos Shale strata to the north of the Gunnison Uplift mimic the Dakota Sandstone dip slope. The strata dip northwest to northeast at angles of less than 10°. Few strike and dip readings were recorded in the northeastern and north-central parts of the quadrangle, where Quaternary gravels and colluvial cover are prevalent. Mancos Shale strata dip steeply along the flank of the uplift-boundary monocline at Smiths Mountain. To the west of the monocline, the strata dip to the west and northwest at angles of 11° or less. **Cross Section A-A'** (**Plate 2**) crosses the Gunnison Uplift and shows its abrupt western margin and gentle northern limb.

Figure 12. High-angle reverse fault along the southwestern escarpment of Smiths Mountain. The fault is in the center of the photo (arrow). It separates steeply dipping Mancos shales in the limb of the monocline (left) from folded Dakota and Morrison sandstones near the crest of the monocline (right). In this location, the uppermost Graneros Member is faulted against the uppermost Morrison Formation. About 200 ft of strata are faulted out. [UTMX: 245,487, UTMY: 4,294,571]

Our field measurements of bedding strikes and dips revealed a zone of steeply dipping Mancos Shale strata from the mouth of the lower Gunnison River gorge northwest to the Tongue Creek valley (**Plate 1**). This zone is 0.5 miles wide near Austin and increases to 1 mile wide near Tongue Creek. It contains shale strata that dip toward the southwest at angles of up to 31°. After crossing the Tongue Creek valley, the zone bends and continues northward toward Grand Mesa. Noe and others (in prep., c) recognized this steeply dipping zone in the adjacent North Delta quadrangle. There, it is associated with a carbon-dioxide producing field in the valley of Oak Creek. We interpret this structural feature as a monoclinal fold. It is a northwestern extension of the monocline that forms the western edge of the Gunnison Uplift at Smiths Mountain. The monocline widens and flattens in its surface expression as the hard, rigid Dakota Sandstone becomes progressively deeper and is overlain by soft, plastic shale layers.

The Gunnison 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.

MINERAL RESOURCES

The Orchard City quadrangle contains abundant sand and gravel resources. The area was explored in the past for clay, oil and gas, and uranium. 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 are produced from a number of commercial and government-owned pits in the southern half of the quadrangle. The modern Gunnison River floodplain and older Gunnison and North Fork terraces (**Qag**- and **Qan**-series units) are mined for their alluvial gravel deposits. Those pebble-cobble gravels contain rounded and smooth, hard clasts from mixed igneous and metamorphic origins. Examples are shown in **Figures 3**, **4**, and **5**. Silt and clay are present in the overbank and loess deposits that cap the alluvial gravels. Older outwash and debris flow deposits (**Qg**-series units) are mined for their basalt gravel, which tends to be bouldery and poorly sorted (well graded), such as shown in **Figure 6**. Fines are present in muddy outwash interbeds and as matrix in the debris flow deposits. In addition to thirteen active, permitted pits, there are fourteen inactive pits that were permitted prior to 1981 (Schwochow, 1981; Keller and others, 2002; Guilinger and Keller, 2004). Those older pits are scattered throughout the quadrangle.

Clay. The extensive Adobe clay hills of Delta County 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.

Oil and gas. The quadrangle contains eighteen inactive oil and gas wells (Milne and Watterson, 2012), which all appear to be drilled and abandoned as dry holes. Five are along the lower Gunnison River gorge; five are in the Mancos Shale hills to the south of Redlands Mesa; two are on Surface Creek Mesa between Orchard City and Austin; and five are in the valley of Tongue Creek. The latter wells were drilled along the trend of a monoclinal fold that crosses the valley to the west of Orchard City. Carbon dioxide (CO_2) is produced from the monocline just to the northwest of the quadrangle, in the valley of Oak Creek. Potential target formations in the region include the Dakota Sandstone (part of unit **Kdb**) and Entrada Sandstone (part of unit **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 Orchard City quadrangle, unit **Kms** represents the Niobrara interval. The principal targets are calcareous zones within the Smoky Hill Member. Unit **Kms** underlies other Mancos Shale units or forms surface outcrops across the northern half of the map area. In the northeastern part of the quadrangle, the Smoky Hill Member extends into the subsurface and is overlain by over 1,000 ft of shale strata (see **Cross Section A-A', Plate 2**).

Uranium. Smiths Mountain and many of the outer dip slopes surrounding the lower Gunnison River gorge are pockmarked with abandoned, bulldozed prospect pits. These mark the sites of uranium exploration that occurred during the 1950s to 1960s. Many of the pits are shown on the USGS topographic map of the quadrangle. The primary targets appear to have been in the upper part of the Dakota Formation (part of unit **Kdb**). To our knowledge, no discoveries of significance were made.

GROUND-WATER RESOURCES

Ground-water resources are abundant in parts of the Orchard City quadrangle, despite the area's semi-arid climate. The modern alluvial valleys of the Gunnison River and Tongue Creek contain alluvial aquifers that are charged by annual runoff from snow melt in the nearby mountains and surface water through-flow. The Surface Creek Mesa gravel body is physically connected with highlands on Grand Mesa at its upstream end and receives ground water from snow melt. Gravel bodies capping Cedar and Redlands Mesas are separated from upland ground-water sources. At those locations, ground water is recharged with surface water that is diverted onto the mesa surfaces by irrigation canals.

There are 181 ground-water wells in the quadrangle, according to GIS data from the Colorado Division of Water Resources. Most of the wells are permitted for domestic or household use. Other permitted uses include irrigation (18 wells), stock (1), commercial (1), and industrial (1). The wells are mostly located along the alluvial valleys and gravel-capped mesas from the previous paragraph. The primary aquifers are in Quaternary alluvial, debris flow, or outwash fan gravels. Two wells located along the rim of the lower Gunnison River gorge reportedly produce ground water from the upper Morrison Formation (although the Burro Canyon Formation is more likely). In the Adobe hills, a subdivision near St. George Reservoir taps ground water from a mix of deep (185 to 850 ft) and shallow (less than 10 ft) wells. Most of the deep wells appear to produce water from sandy or calcareous zones in the lower Mancos Shale, although the deepest well may produce from the Dakota Sandstone. The shallow wells appear to produce from water-filled fractures in the Smoky Hill Member of the Mancos Shale, or from saturated mud flow deposits. The ground-water source may be seepage from Shamrock and Redlands Mesas. Reported pump rates for the 181 wells in the quadrangle vary widely, from 3 to 600 gpm.

Cadigan and others (1976) reported on the geochemistry of ground water associated with mineral springs in the northern Gunnison Uplift. Their general findings for the springs within the Orchard City quadrangle, near Austin, are outlined in a previous section (see **Surficial Deposits - Mineral Spring Deposits**).

ARCHAEOLOGICAL AND PALEONTOLOGICAL RESOURCES

During the course of our mapping investigations, we found evidence of Native American tool-making at numerous sites. Generally, the sites contain lithic flakes, scrapers, and core stones. Local materials used for tool-making include cobbles of hornfels, quartzite, and porphyry, which are found in most of the alluvial gravel deposits. Additionally, in the lower Gunnison River gorge, silica-cemented Dakota Sandstone was used. The sites are relatively widespread. We documented a few sites of interest for the

USBLM. The quadrangle contains two notable petroglyph sites. One is on private land. The other, near the mouth of Lawhead Gulch, is open for public viewing. The BLM has constructed a trail to the site and erected protective fencing and an informational sign. The petroglyphs and a few pictographs are in a shelter cave formed in a point-bar sandstone body, within the Brushy Basin Member of the Morrison Formation (unit **Jm**). The site is unusual in that it contains different styles of rock art. They range from Archaic to Formative to Historic eras (Patterson and Watchman, 2006). Archaeological investigations, led by Western Wyoming Community College, are ongoing at that site.

We found numerous dinosaur tracks while mapping in the lower Gunnison River gorge. 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 13**. We also encountered possible gizzard stones, coprolites, and trampled-down dinosaur wallows(?). 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 Orchard City 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.

Debris flow and **mud flow** hazards occur in hilly areas along confined stream reaches (units **Qa** and **Qamf**) and in alluvial and mud flow fans (units **Qf** and **Qamf**). These flows are produced by large rainfall events, and are sometimes generated by failures of saturated landslides. Debris flows are dense, heterogeneous mixtures of mud, rock fragments, and plant materials (Varnes, 1978). They can form at any point along a drainage including on the sides of valleys. They may cause deep erosion in some areas and dump thick deposits in other areas (both on the order of several feet). The moving flows present life-and-limb safety hazards and can cause damage to roads and buildings. Much of the upland terrain in the quadrangle has the potential to generate debris flows. Mud flow valley fills and fans are typically gravel poor. They occur in or at the margins of the Adobe hills. Mud flows are prevalent along Peach Valley, Tongue and Currant Creeks, and in a series of large, low-gradient mud flow fans that extend onto the Gunnison River floodplain in the southwestern part of the map. They also occur in drainages that cross Harts Basin and the Adobe hills badlands in the east-central part of the map. All areas meeting the above descriptions should be considered at risk. The construction of residences and critical facilities in those areas should be carefully considered or, in some cases, avoided.

Figure 13. Examples of dinosaur tracks found in the Morrison Formation, lower Gunnison River gorge.
(a) Four three-toed tracks on a slab of tabular, crevasse splay sandstone. The slab fell out of the canyon wall and came to rest upside-down, exposing the trackway.
(b) Multi-story trackway in cross section. 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.

Landslides (unit **Qls**) are particularly common in the quadrangle where shale slopes are capped by a gravel deposit. Some of the landslides are late Pleistocene in age, but most appear to be Holocene features. 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. A spectacular example occurs near the western tip of Redlands Mesa, where Madison Canyon joins Currant Creek. The construction of an irrigation canal across the lower slopes of the mesa led to the initiation of a series of large landslides. The landslides include large masses of previously intact Mancos Shale, and the failure surfaces cut deeply into the slopes (**Figure 14**). Potential landslide areas should be avoided where possible, or the site should undergo geotechnical engineering investigations and mitigation. Mitigation may be expensive, but not nearly as much as the costs of damage and repairs to structures and facilities resulting from new or reinitiated landslide movements.

Figure 14. Large, recent landslides on Redlands Mesa along Currant Creek, near Madison Gulch. These landslides were initiated by the cutting of an irrigation canal across the lower slopes, and by subsequent wetting of the slope by water from the unlined canal. A remnant of the now-abandoned canal may be seen in the middle right. The tops of fresh head scarps are marked by white arrows. The entire lower slope is failing and moving. [UTMX: 247,511, UTMY: 4,303,250]

Stream flooding hazards and associated high water tables exist within the modern Gunnison River flood plain (unit **Qag$_{1a}$**) and the valleys of tributary streams (units **Qa** and **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. The Gunnison River flood of record was in 1884, with an estimated peak discharge of 50,000 second-ft (Follansbee and Sawyer, 1948). The Ute Tribe recalled a larger flood, ca. 1862, in which the waters extended "from bluff to bluff" (Marshall, 1996). A similar flood would inundate the low terraces (unit **Qag$_{1b}$**) that flank the modern Gunnison River floodplain. Flooding on the main branch of the Gunnison River is at least partly mitigated by three upstream dams (Crystal, Morrow Point, and Blue Mesa). The entire town of Austin was inundated by flooding on June 13, 1937. This occurred when the dam to Fruit Growers Reservoir failed, sending a wall of water down Alfalfa Run. The torrent carried along large basalt boulders that had rolled into the stream valley from adjacent, mesa-capping gravel deposits. Austin is located on the alluvial fan at the mouth of Alfalfa Run. Thick mud and boulders were deposited throughout the town, causing significant damage (**Figure 15**).

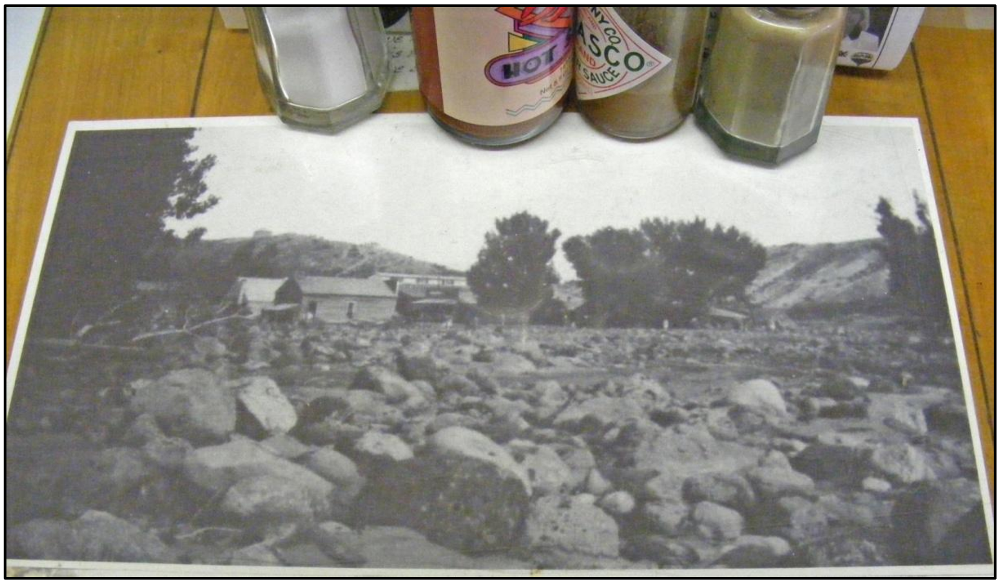

Figure 15. Historic photograph of the 1937 flood that inundated the town of Austin. This photo looks eastward across the alluvial fan. A torrent of water from a failed dam engulfed the town in mud, boulders, and woody debris. Flow was from left to right. Today, abundant basalt boulders are visible around town. This and other photos of the flood's aftermath are displayed at Faye's Cafe in Austin. Photo used with permission from proprietor Rufus Miller. [UTMX: 243,565, UTMY: 4,296,681]

Rock fall hazards are prevalent at the toes of slopes that are capped with sandstone or basalt rim rock. The size of the falling blocks is a function of bedding thickness, fracture spacing, and exposure of the slope to ground-water seepage and freeze-thaw processes. Large precipitation events may trigger rock falls, as well. We observed several boulder-sized, angular blocks of sandstone up to 20 ft in diameter within the lower Gunnison River gorge. The blocks came from outcrops of Dakota Sandstone and Morrison Formation. In the northern part of the quadrangle, large basalt boulders up to 10 ft in diameter are known to fall from the edges of mesa-capping gravel bodies (**Qg**-series units). The best mitigation is to avoid rock-fall 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 **Kmu**, **Kmss**, **Kmp**, **Kms**, **Kmb**, and **Kmg**), the Dakota Sandstone (unit **Kdb**), the Morrison Formation (unit **Jm**), and clay-rich surficial deposits derived from those units. The hazard and 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, alluvial fans, and mud flow valley fills and fans (units **Qa**, **Qf**, and **Qamf**). Collapsible soil may occur in eolian deposits that sometimes overlie alluvial terraces. All 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.

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). At least seventeen tremors of less than magnitude 3.0 and one of less than magnitude 4.0 are mapped in the Somerset area (25 miles to the east). The nearest faults suspected of having Quaternary movement are located to the south of the Black Canyon of the Gunnison River (15 miles to the south) and to the west of Delta in the Uncompahgre Uplift (19 miles to the west) (Morgan, 2007). An updated, online version of the Kirkham and Morgan maps is available at http://geosurvey.state.co.us/hazards/ Earthquakes/Pages/ Maps.aspx (Morgan and others, 2012).

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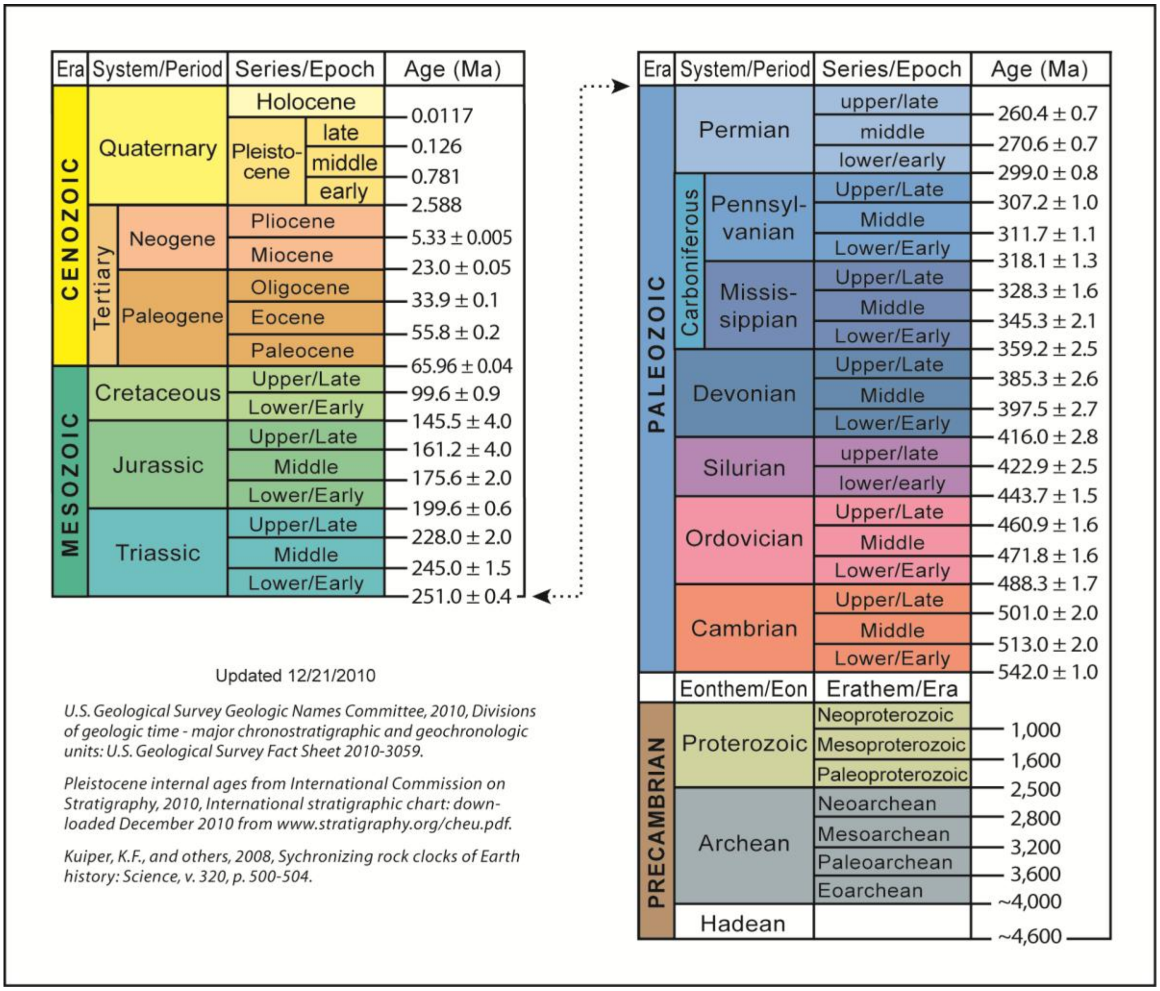
APPENDIX A

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



APPENDIX B

Appendix B. Age dates of material samples collected from the Orchard City 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 three different values of in-situ water content. The methodology is explained following the table of results.

Sample ORC-272 is from a sand lens in North Fork alluvial gravel (unit **Qan$_6$**) at the Antelope Hill gravel pit [UTMX: 244,439, UTMY: 4,300,139]. From geomorphic relationships we expect this unit to be middle Pleistocene in age (our estimate: 350 to 150 ka). This is near the limit of detection for older samples using OSL. The results are age limited, meaning that the optical age could not be determined. It is possible that the ratio of basalt sand to quartz sand is high enough to obscure the readings.

Sample ORC-358 is from a sand lens in Gunnison alluvial gravel (unit **Qag$_3$**) at the Austin gravel pit [UTMX: 244,407, UTMY: 4,295,186]. The optical age is late Pleistocene, ranging from 47.8 to 42.8 ka. The results establish that the sediment was deposited between early Wisconsin and Pinedale time (see **Table 1** in text).

Field #	UNL Lab #	Depth (m)	U (ppm)	Th (ppm)	K_2O (wt %)	In Situ H_2O (%)[a]	Dose Rate (Gy/ka)	D_e (Gy) ± 1 Std. Err.	Aliquots (n)[b]	Optical Age ± 1 σ
ORC-272	UNL-2639	2.7	4.2	13.2	2.1	0.4	3.79 ± 0.19	>220		>58
ORC-272 IR	UNL-2639 IR						4.96 ± 0.27	>350		>71
ORC-272	UNL-2639					5.0	3.60 ± 0.22	>220		>61
ORC-272	UNL-2639					10.0	3.41 ± 0.29	>220		>65
ORC-358	UNL-2640	3.6	2.9	7.4	2.4	0.3	3.30 ± 0.17	141.1 ± 7.7	27/33	42.8 ± 3.7
						5.0	3.12 ± 0.20	141.1 ± 7.7	27/33	45.2 ± 4.3
						10.0	2.95 ± 0.27	141.1 ± 7.7	27/33	47.8 ± 5.5

[a]assumes 100% error in measurement

[b]accepted disks/all disks

Optical Dating Methodology (provided by Dr. Hanson)

The multiple aliquot additive dose (MAAD) IRSL protocol was used on coarse grain sediment (90-180 μm). Potassium feldspar grains were isolated using heavy liquid separation at 2.58 g/ml. All analyses were done using a Risø DA-20 TL/OSL reader using Schott BG-39 and Kopp 7-59 detection filters. Disks were normalized using the natural normalization process. Shortshines were performed using inferred

LED stimulation at 20% for 2 sec. The dosing schedule consisted of applying an additive dose of 0, 100, 200, 300, 400, and 600 Gy to three individual disks for a total of 18 discs. All disks were preheated for 72 hours at 125° C, and left at room temperature for 24 hours before reading. Disks were analyzed using inferred stimulation at 90% power for 40 sec.

The normalized counts vs. additive dose were plotted on a scatter plot, and the sample was determined to be saturated based on the plotted data. To determine a maximum De, the same disks were bleached under natural sunlight for 1 hour, and under infrared stimulation for 120 sec. Three disks of the sample were then give doses of 50, 100, 200, 350, and 500 Gy. Again, all disks were preheated for 72 hours at 125° C, and left at room temperature for 24 hours before analysis.

Disks were analyzed using infrared stimulation at 90% power for 40 sec, and normalized counts vs. applied dose were plotted on a scatter plot. A curve was fitted to the scatter plot, and the sample was determined to saturate at ~350 Gy, based on the fitted curve. Environmental dose rates were calculated from concentrations of K, U, Th, and Rb values determined by inductively coupled plasma-mass spectrometry.

APPENDIX C

Appendix C. Fossils collected from the Orchard City 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 Orchard City quadrangle by the CGS mapping crew during the 2008 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 in the immediate area (that is, from within the quadrangle or within 1 mile of the quadrangle) by other investigators and authors. Those additions are the result of a technical-literature search. 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 16**, on the following page. *Prionocyclus hyatti*, a coiled ammonite, is a guide fossil of middle Turonian age (92.46 ± 0.57 ma from bentonite ash dating) (Cobban and others, 2006). We have found specimens of *P. hyatti* within the upper 10 to 15 ft of the Blue Hill Member in the Orchard City and other nearby quadrangles. Thus, it is a potentially useful guide fossil in western Colorado.

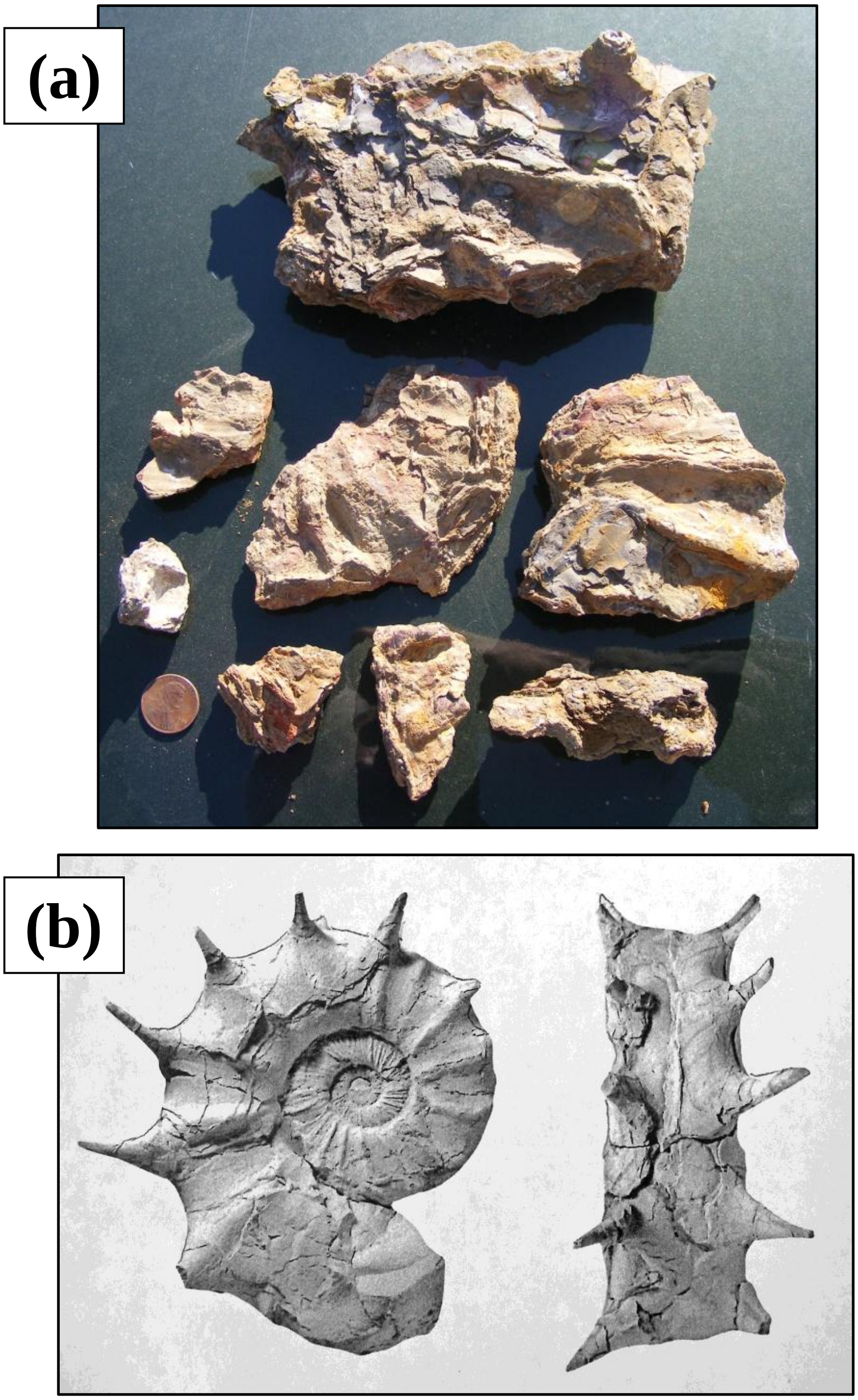
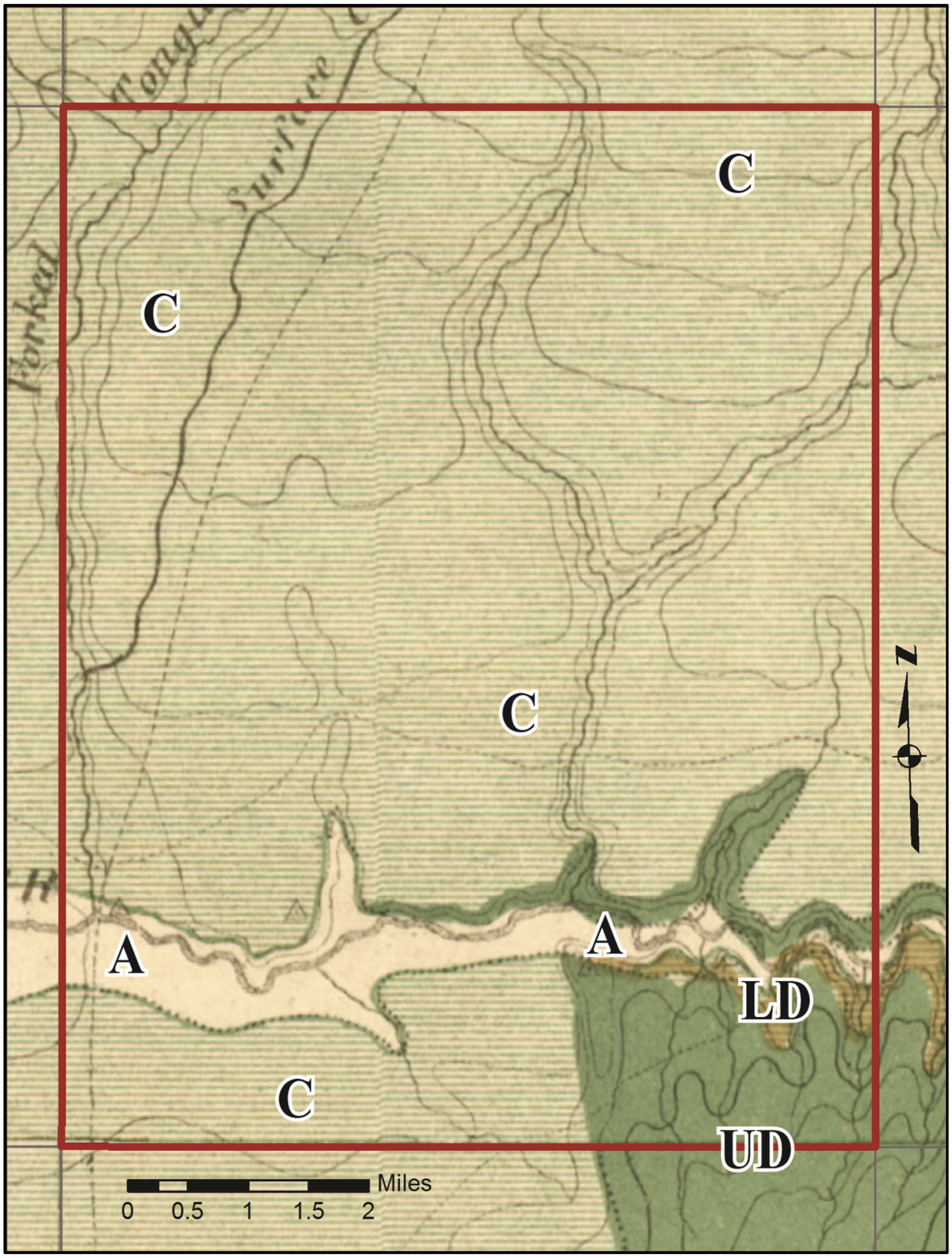


Figure 16. *Prionocyclus hyatti* ammonite fossil recovered from Orchard City quadrangle.
(a) Fossil fragments recovered from the Blue Hill Member of the Mancos Shale by D. Noe, CGS. Flank ribs and the base of a protrusion are visible. USGS collection D14880. [UTMX: 249,297, UTMY: 4,297,297]
(b) Photograph, 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 Orchard City area, published by F.V. Hayden (1877). Fieldwork for this regional 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 Orchard City quadrangle. The map units are as follows:

A	Alluvium (Quaternary)	**UD**	Upper Dakota (Cretaceous)
C	Colorado (Niobrara-Fort Benton) (Cretaceous)	**LD**	Lower Dakota (Cretaceous)

Appendix C. Fossils Collected From the Orchard City 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	UTM83-X	UTM83-Y	Collected by	Date
NDL-120	D14827	*Baculites sp.; Cataceramus subcompressus; Pseudoperna sp.*	*Cateceramus subcompressus*	Middle Campanian	Upper part of Mancos	North Delta	Delta	CO	se sw se 33-13S-95W	238405	4306969	D.C. Noe and M. Nelson	06/23/08
NDL-146	D14829	*Cataceramus balticus? **	*Scaphites hippocrepis; Cataceramus balticus*	Lower Campanian	Prairie Canyon Mbr	North Delta	Delta	CO	se se nw 15-14S-95W	238427	4303012	D.C. Noe and M. Nelson	06/28/08
NDL-17	D14819	*Scaphites hippocrepis;* fish scale; leaf imprint	*Scaphites hippocrepis; Cataceramus balticus*	Lower Campanian	Prairie Canyon Mbr	North Delta	Delta	CO	ne ne sw 28-14S-95W	237730	4299507	D.C. Noe and M. Nelson	05/22/08
LAZ-6	D15227	*Inoceramus sp.* (thin-shelled fragments)	(can't tell)	Lower Campanian	Prairie Canyon Mbr	Lazear	Delta	CO	nw ne 2, 14S, 94W	251742	4306457	David C. Noe	08/23/10
ORC-122	D14882	*Magadiceramus subquadratus?; "Inoceramus" platinus; P. congesta*	*Scaphites depressus; Magadiceramus subquadratus*	Upper Coniacian	Smoky Hill Mbr	Orchard City	Delta	CO	sw sw se 31-14S-94W	244463	4297120	D.C. Noe and M.J. Zawaski	08/06/09
ORC-6	D14887	*"Inoceramus" sp.; Pseudoperna congesta*	(can't tell)	Coniacian or Santonian	Smoky Hill Mbr	Orchard City	Delta	CO	sw ne se 3-14S-95W	239859	4305705	D.C. Noe and M.J. Zawaski	07/08/09
ORC-2	D14886	*"Inoceramus" sp.; Pseudoperna congesta*	(can't tell)	Coniacian or Santonian	Smoky Hill Mbr	Orchard City	Delta	CO	nw nw ne 3-14S-95W	240316	4306524	D.C. Noe and M.J. Zawaski	07/08/09
ORC-363	D14884	*"Inoceramus" sp.; Pseudoperna congesta*	(can't tell)	Coniacian or Santonian	Smoky Hill Mbr	Orchard City	Delta	CO	n sw nw 30-14S-94W	243866	4299691	David C. Noe	09/18/09
ORC-170	D14876	*Mytiloides cf. M. scupini*	*Prionocyclus germari; Mytiloides scupini*	Upper Turonian	Montezuma Valley Mbr	Orchard City	Delta	CO	sw ne ne 17-15S-94W	246412	4293411	Michael J. Zawaski	08/12/09
LAZ-138	D15230	*Scaphites whitfieldi; Baculites sp.; Prionocyclus sp.;* bivalves	*Scaphites whitfieldi; Inoceramus perplexus*	Upper Turonian	Montezuma Valley Mbr	Lazear	Delta	CO	sw ne 35, 14S, 94W	251258	4297689	K. McCall, G. Warden, D.C. Noe	06/03/11
---	D6022	*Scaphites ferronensis*	*Scaphites ferronensis; Inoceramus dimidius*	Middle Turonian	Juana Lopez Mbr	Orchard City	Delta	CO	se se 30-14S-94W	245015	4298736	W.A. Cobban	10/05/67
ORC-16	D14885	*Prionocyclus macombi; Inoceramus perplexus; Lopha lugubris*	*P. macombi; I. dimidius; I. perplexus*	Middle to Upper Turonian	Juana Lopez Mbr	Orchard City	Delta	CO	e ne 32-14S-94W	246616	4298123	D.C. Noe and M.J. Zawaski	07/09/09
ORC-163	D14878	*Prionocyclus sp.; Inoceramus dimidius; Lopha lugubris*	*Prionocyclus macombi; Inoceramus dimidius*	Middle Turonian	Juana Lopez Mbr	Orchard City	Delta	CO	nw sw nw 8-15S-94W	245159	4294816	D.C. Noe and M.J. Zawaski	08/12/09
ORC-247	D14880	*Prionocyclus hyatti*	*Prionocyclus hyatti; Inoceramus howelli*	Middle Turonian	Blue Hill Mbr	Orchard City	Delta	CO	c s 34-14S-94W	249295	4297310	David C. Noe	08/27/09
LAZ-142	D15206	*"Pycnodonte aff. P. newberryi" ***	*Collignoniceras woollgari*	Middle Turonian	Fairport Mbr	Lazear	Delta	CO	nw nw 2, 15S, 94W**	250488	4296670	David C. Noe	06/08/11
ORC-152	D14877	*"Pycnodonte aff. P. newberryi" ***	*Collignoniceras woollgari*	Middle Turonian	Fairport Mbr	Orchard City	Delta	CO	nw se sw 8-15S-94W	245580	4294065	D.C. Noe and M.J. Zawaski	08/11/09
ORC-263	D14881	*"Pycnodonte aff. P. newberryi" ***	*Collignoniceras woollgari*	Middle Turonian	Fairport Mbr	Lazear	Delta	CO	se sw sw 35-14S-94W	250330	4297062	David C. Noe	08/31/09
LAZ-140	D15235	*Collignoniceras woollgari*	*Collignoniceras woollgari*	Middle Turonian	Fairport/Bridge Cr Mbrs	Lazear	Delta	CO	nw nw 2, 15S, 94W**	250494	4296554	K. McCall	06/08/11
---	D10686	*"Pycnodonte aff. P. newberryi" ***	*Collignoniceras woollgari*	Middle Turonian	Fairport/Bridge Cr Mbrs	Lazear	Delta	CO	se nw 2-15S-94W	250547	4296327	E.A. Merewether and W.A. Cobban	09/13/78
ORC-243	D14879	*Pycnodonte newberryi; "Pycnodonte aff. P. newberryi" ***	*Collignoniceras woollgari*	Middle Turonian	Fairport/Bridge Cr Mbrs	Orchard City	Delta	CO	nw ne nw 3-15S-94W	248806	4296815	David C. Noe	08/24/09
LAZ-141	D15207	*Pycnodonte newberryi*	*Collignoniceras woollgari*	Middle Turonian	Bridge Creek Mbr	Lazear	Delta	CO	nw nw 2, 15S, 94W***	250404	4296664	David C. Noe	06/08/11
ORC-300	D14883	*Mytiloides? sp.*	(can't tell)	Upper Cenomanian?	Graneros Mbr	Orchard City	Delta	CO	nw se ne 31-14S-94W	244831	4298021	David C. Noe	09/09/09

Includes collection sites in and within one mile of the Orchard City 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.

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 *Cataceramus subcompressus* by W. Cobban, but amended herein because the strata at the collection location are stratigraphically older.

** 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).

*** Irregular-shaped land section