Open-File Report 14-15

Geologic Map of the Hotchkiss Quadrangle, Delta County, Colorado

Authors' Notes

COLORADO GEOLOGICAL SURVEY
COLORADO SCHOOL OF MINES

by
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FOREWORD

The purpose of Colorado Geological Survey's (CGS) *Geologic Map of the Hotchkiss Quadrangle, 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 Emma Rodgers completed the field work on this project during the summer of 2012. 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 G12AC20029, 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 Hotchkiss 7.5-minute quadrangle is located in Delta County, Colorado (**Figure 1**). It includes the town of Hotchkiss. The region is known for its orchards, vineyards, and organic agriculture. **Figure 2** shows the major physiographic features of the area. The valley of the North Fork Gunnison River (known locally as the North Fork River) bisects the quadrangle from northeast to southwest. The lowest elevation (5,210 ft) is where the river exits to the west. To the north of the river are numerous gravel-capped mesas and shale peaks, dissected by tributary streams that drain the southern slopes of Grand Mesa. The highest elevation is on Oak Mesa at the northwestern corner (7,730 ft). To the south of the river is an area of shale badlands known as the "Hotchkiss adobes," "the adobe hills," or simply, "the adobes." A number of low mesas are scattered across the eastern part of the badlands. Shale slopes flank the tributary valleys and mesas throughout the quadrangle. Scenic Mesa, at the toe of the resistant dip slope of the Gunnison Uplift, is in the far southwest corner of the quadrangle.

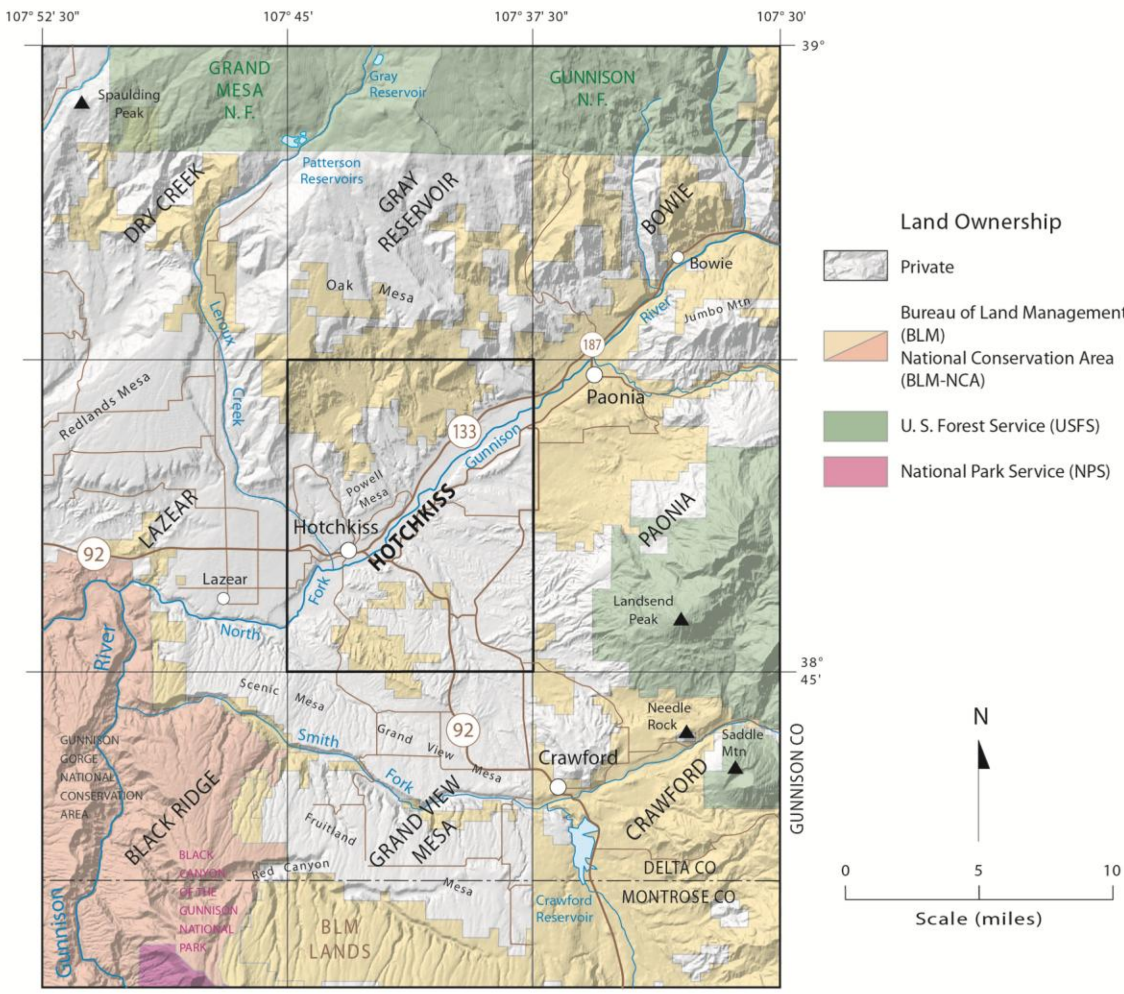

Figure 1. Index map of the Hotchkiss 7.5-minute quadrangle in western Colorado.
Most of the area consists of private land parcels; the remainder is BLM-administered public land.

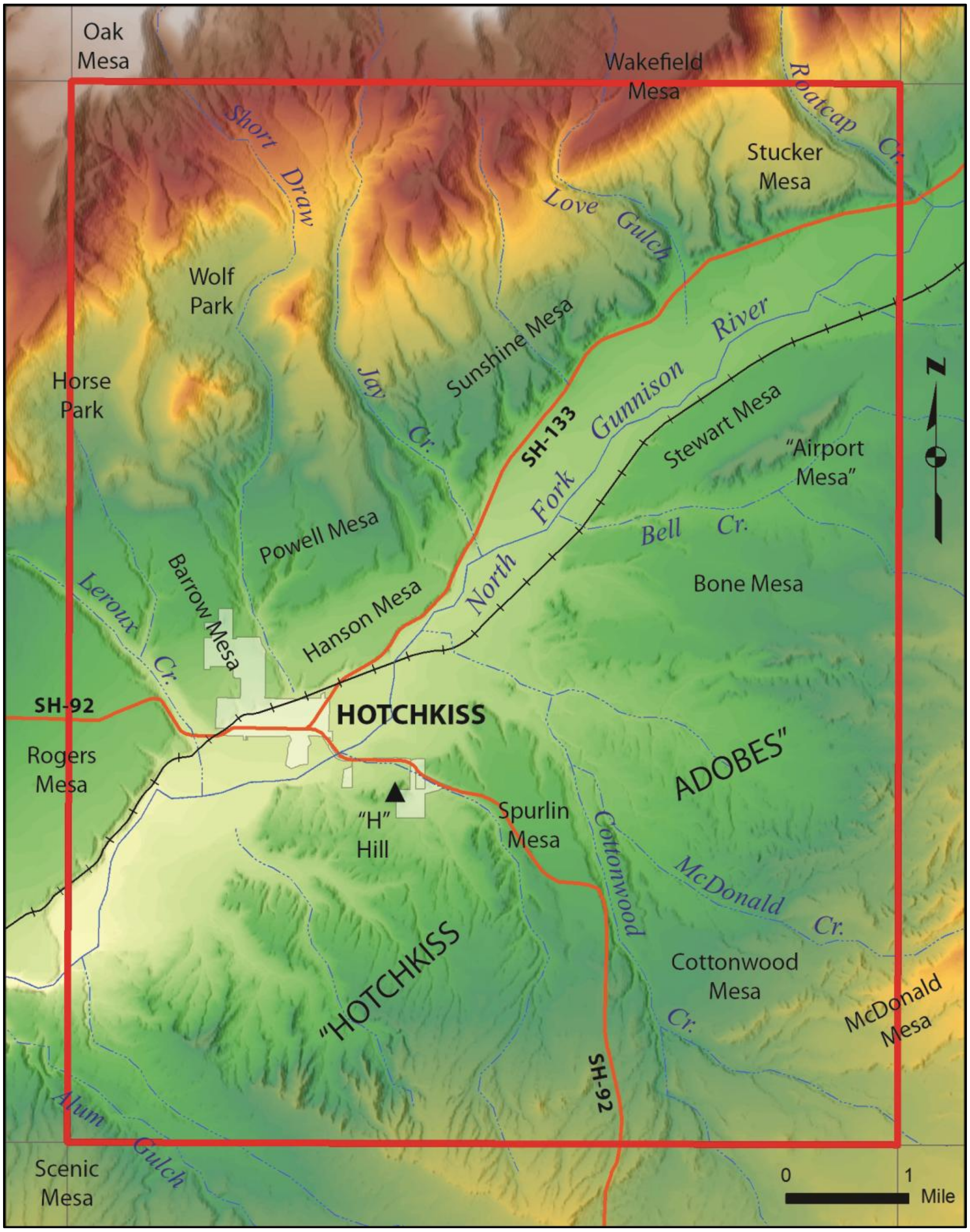

Figure 2. Shaded-relief index map of the Hotchkiss quadrangle, showing major physiographic features. There are four geomorphic areas: (1) The North Fork River valley, in which the river flows from northeast to southwest; (2) a succession of progressively higher mesas and shale peaks on the flanks of Grand Mesa, to the northwest of the valley; (3) shale badlands and low mesas of the "Hotchkiss adobes," to the southeast of the town of Hotchkiss; and (4) the toe of the sloping surface of the Gunnison Uplift at Scenic Mesa, in the far southwestern corner, to the southwest of Alum Gulch.

PREVIOUS MAPPING STUDIES

Previous geologic mapping in the area was done by the U.S. Geological Survey (USGS) and the Colorado Geological Survey (CGS). The earliest regional geological map of the area 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 and others, 1976) (1:250,000) and in intermediate-scale geologic maps by Ellis and others (1987) (1:100,000) and Hail (1972) (1:48,000). A small area at the northeastern corner was mapped as part of a coal investigation by Dunrud (1989) (1:50,000). Hansen (1968) mapped the Black Ridge 7.5-minute quadrangle to the southwest 1:24,000). Junge (1978) mapped the surficial geology of the Hotchkiss 7.5-minute quadrangle as part of a folio of 1:24,000 geologic-hazard maps in and to the north of the North Fork River valley.

The Hotchkiss 7.5-minute quadrangle geologic map is a result of an ongoing project by the CGS to conduct geologic mapping of the Uncompahgre, Gunnison, and North Fork River valleys in western Colorado. Adjacent 1:24,000-scale geologic maps by CGS include the Lazear (Noe and others, 2015) and Paonia (Noe, 2015) 7.5-minute quadrangles.

Geologic mapping of the Hotchkiss 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 for 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://coloradogeologicalsurvey.org/geologic-mapping/.

MAPPING METHODOLOGY

The Hotchkiss quadrangle geologic map is shown on **Plate 1**. The geologic interpretations are based on (1) CGS field investigations conducted from June to August, 2012; (2) other published and unpublished geologic maps and reports; and (3) interpretation of remote-sensing images. The image data include color, 1-m resolution, digital orthophotos taken in 2011 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 the orthophotos. 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 orthophotos was digitized into GIS using ESRI ArcMap. The GIS point, linear, and polygonal shapefiles were created by digitizing onto a computer screen. The field 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 oblique geologic map shown in **Plate 2**.

DESCRIPTION OF MAP UNITS

This section contains descriptions of surficial and bedrock units from the geologic map. The surficial units are organized by the dominant process of deposition and by age, and are listed from youngest to oldest in terms of latest depositional activity. The bedrock units are organized by increasing age. The geologic time divisions and nomenclature used in this report are shown in **Appendix A**. Sediment-clast sizes are based on the modified Wentworth grain-size scale (Wentworth, 1922; Ingram, 1989). For each description, 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 (abbreviated as "ft"), and miles.

SURFICIAL DEPOSITS

The surficial deposits in the Hotchkiss quadrangle are Quaternary (Holocene and Pleistocene) to early Tertiary (Pliocene) in age. The deposits shown on the map are generally more than 5 ft thick. Contacts between surficial units may be gradational, and mapped units may locally 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 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 alluvial terrace, valley fill, or fan deposits. Erosion of the landscape through time has preserved the older deposits as elevated remnants, forming what is called *inverted topography*. Topographic inversion occurs when streams abandon their former courses and erode downward through soil or rock (in this case, soft shale) that borders the valley side. As a result, the stream migrates to a new course, and a newer, lower-elevation, stream valley is formed. Remnants of the older, abandoned deposits are preserved and are recognized today as mesa-capping gravel bodies.

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

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

Map Unit	**Glaciation Episode**	**Marine Oxygen Isotope Stage (MIS)**	**Age Range** (in thousands of years)
1b and 2	Pinedale	MIS 2	11.7-30 ka
3	Late Wisconsin	MIS 4	50-89 ka
4 and 5	Bull Lake	MIS 6	130-190 ka
6	Pre-Bull Lake	MIS 10-12	340-480 ka
7	Pre-Bull Lake	MIS 16-20	620-750 ka
8	Pre-Bull Lake	MIS 22	800-850 ka
9 and 10	Late Pliocene?	not known	not known
Units and ages are regionally comparable to those of Hail (1972), Sinnock (1978), and Cole and Sexton (1981). Age ranges compiled from Porter (1989), 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 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 North Fork Gunnison River

Gravel, sand, silt, and clay deposited by the North Fork Gunnison River. The younger deposits (**Qan$_{1a,b}$**) comprise the modern river flood plain. Several levels of ancestral North Fork deposits (**Qan$_2$** to **Qan$_{10}$**) are present as alluvial terraces that increase in age with increasing height above the modern river.

The modern river valley is 0.6 to 1.0 miles wide. The deposits of alluvial units **Qan$_2$** to **Qan$_6$** and **Qan$_{10}$** typically form gravel terraces that are 0.5 miles wide or less. Units **Qag$_7$** to **Qag$_9$** form remnant gravel bodies near the tops of isolated hills and ridges. Some of the map units are made up of two or more sub-terraces that are relatively closely related in elevation and local areal extent. All of the alluvial deposits overlie erosional straths cut into soft Mancos Shale strata. **Table 2** is a summary of the map units that comprise the North Fork alluvial gravel deposits.

North Fork alluvial gravel deposits are similar in appearance, composition, and thickness, regardless of age. They consist of well-rounded, discoid to oval cobbles, pebbles, and rare small boulders up to 1.5 ft in length (**Figure 3**). The matrix is coarse sand. The bedding is well to moderately developed. The dominant sedimentary structures are trough cross bedding, particularly within sandy gravel bedforms. There are occasional lenses of fine sand up to 1.5 ft thick. Granule- and sand-sized coal particles are occasionally present as thin lenses or in the matrix. The gravel clasts are composed mostly of basalt and

Figure 3. Alluvium of the North Fork Gunnison River (**Qan$_{1b}$**), exposed in a gravel pit near Hotchkiss. The deposit consists of pebbles and cobbles of porphyry, basalt, hornfels, and fine-grained quartzite in a coarse-sand matrix. Some of the layers contain dark particles of coal within the matrix and associated, dark gravel-clast coatings. [UTMX: 266,368, UTMY: 4,299,455]

porphyritic, intrusive igneous rocks. The proportion is variable. Basalt clasts predominate along the northern margins of the deposits, at or downstream from paleo tributary confluences, and porphyritic rock clasts predominate along the southern margins. Sources of gravel include the central and northern West Elk Mountains (granodiorite and monzonite porphyries and lesser amounts of hornfels, fine-grained meta-quartzite, and other low-grade metasedimentary rocks), and Grand Mesa (basalt and trace amounts of sandstone, clinker, and chert). Source-area lithologies were interpreted using maps by Gaskill and Godwin (1966), Godwin (1968), Tweto (1977), and Tweto and others (1978).

Table 2. Summary of North Fork alluvial gravel (**Qan**-series) map units in the Hotchkiss quadrangle

Map Unit	**Age**	**Number of Sub-Terraces**	**Terrace Height** (feet)	**Deposit Thickness** (feet)	**Notes**
Qan_{1a}	Holocene	n/a	0-2	<15?	Modern river; meander-channel and overbank deposits; reworking upper part of unit **Qan_{1b}**; low overbank terraces; full thickness of unit not exposed
Qan_{1b}	Holocene to late Pleistocene	1	5-6	>25?	Partially exposed in a number of gravel pits; full thickness of unit not exposed; underlies modern river valley
Qan_2	late Pleistocene	1?	15-25	10-20	Mostly covered by mud fans; the town of Hotchkiss is built on the largest **Qan_2** terrace
Qan_3	late Pleistocene	2	130-180	10-15	Broad, loess- or fan-gravel-covered terraces to north and south of the North Fork River
Qan_4	late middle Pleistocene	1	190-250	10-15	Mostly eroded away; only a few remnant terrace deposits are preserved
Qan_5	late middle Pleistocene	3	310-380	10-15	Extensive belt of loess- or fan-gravel-covered terraces to north of North Fork River; also at "Airport Mesa" to south of river
Qan_6	middle Pleistocene	2	500-650	15-25	Extensive belt of fan-gravel-covered terraces to north of North Fork River
Qan_7	middle to early Pleistocene	2	870-1,160	10-15	Forms small, fan-gravel-covered, terrace remnants near tops of isolated hills and ridges
Qan_8	early Pleistocene	2	(1,250?)-1,430	10-15	Forms small, fan-gravel-covered, terrace remnants near the tops of isolated hills and ridges; younger sub-terrace inferred by extent of fan gravels, but no in-place deposit found
Qan_9	late Pliocene?	2	1,710-1,950	10-15	Forms small, fan-gravel-covered, terrace remnants near tops of isolated hills and ridges
Qan_{10}	late Pliocene?	1?	2,160	15-20	Single, thick deposit exposed along south face of Oak Mesa
Units and ages are regionally comparable to those of Hail (1972), Sinnock (1978), and Cole and Sexton (1981). Terrace height is height of tread surface (top of alluvial deposit) above the modern stream elevation					

North Fork terraces may be overlain by age-equivalent to somewhat younger fan-gravel deposits (**Qg**-series), marking paleo confluences with tributary streams. We map North Fork alluvial deposits as dashed lines where they are exposed in hill slopes at the base of a tributary gravel deposit. In other locations, the North Fork terraces may be overlain by eolian silt deposits (loess, unit **Qe**), which are described separately.

Mixed Debris Flow, Mud Flow, and Alluvial Gravel Deposits

Gravel, boulders, clay, silt, and sand deposited by former tributary streams that flowed to the ancestral North Fork River. Upland gravel deposits of various ages (**Qg**-series) are scattered throughout the quadrangle. They form a series of elevated and dissected, gravel-capped mesas having linear to fan-like geometries. From younger to older, the remnant deposits are found at progressively higher elevations. Gravelly mud flow deposits predominate in the Bone and Stewart Mesa areas.

We interpret the fan-shaped gravel bodies to be debris-flow fan complexes that formed in upland basins and/or as terminal fans at river confluences. The linear gravel bodies appear to be alluvial and debris-flow valley-fill deposits of paleo tributary streams. In some cases the original shale valley sides still exist; in other cases the former confining walls are eroded away. The fans deposits range from 0.4 miles to nearly one mile wide. The valley-fill deposits range from 0.1 to 0.6 miles in width. The ancient valleys and basins are related spatially and mark the paths of paleo tributary streams. They were much like the region's modern tributary valleys and basins in terms of distribution and morphology.

The terminal, tributary fan deposits may grade onto North Fork alluvial terraces. Based on such pairings, we map ten levels of **Qg**-series map units that are correlatable with the North Fork alluvial map units (**Qan**-series). In most exposures, the basal fan gravels overlie and thus are somewhat younger than the river gravels. We did find a few locations where the deposits are separated by a sheet of eolian loess (unit **Qe**); this implies that, at least locally, fan-deposition activity began a certain amount of time after the cessation of river gravel deposition. In upland basins, we could map the **Qg** deposits and assign them to different map-unit levels based on the local geomorphic succession. **Table 3** is a summary of the map units that comprise the **Qg**-series gravel deposits.

The composition and texture characteristics of **Qg**-series deposits in the Hotchkiss quadrangle vary considerably as a function of different sediment sources and depositional processes. Deposits to the north of the modern river are composed almost entirely of basalt clasts, sourced 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. Those lithologies are sourced 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 be present; these most likely eroded from older, North Fork River terraces. The basalt-gravel **Qg** deposits are mostly comprised of debris-flow facies. They contain sub-angular, very poorly sorted pebbles to very large boulders in a mud to sandy mud matrix (**Figure 4**). The boulders are commonly up to 5 to 6 ft long. The basalt-gravel deposits vary considerably in thickness, ranging from 5 to 320 ft thick, and are comprised of single to multiple flow units. Generally, their thickness increases with increasing age. In

Table 3. Summary of debris flow and alluvial gravel (**Qg**-series) map units in the Hotchkiss quadrangle

Map Unit	Age	Deposit Thickness (feet)		Notes
		Basalt*	Porphyry**	
Qg_1	Holocene	5-15?	5-15?	Scattered deposits in some modern tributary stream valleys and at base of mesa slopes; full thickness of unit not exposed
Qg_2	late Pleistocene	10-15	10-15	Generally rarely preserved; most extensive deposits are in the Bell Creek-Bone Mesa area
Qg_3	late Pleistocene	5-100	10-20	Numerous basin fan, valley fill, and terminal fan deposits to north and south of North Fork River
Qg_4	late middle Pleistocene	10-80	15	Scattered basin fan, valley fill, and terminal fan deposits to north and south of North Fork River
Qg_5	late middle Pleistocene	5-100	15	Numerous basin fan, valley fill, and terminal fan deposits to north of North Fork River; rare remnants to south of river
Qg_6	middle Pleistocene	10-140	20	Numerous basin fan, valley fill, and terminal fan deposits to north of North Fork River; rare remnants to south of river
Qg_7	middle to early Pleistocene	20-320	15	Scattered deposits capping isolated hills and ridges to north of North Fork River; one possible remnant to south of river; may contain 640-ka Lava Creek B ash in nearby quadrangles
Qg_8	early Pleistocene	30-160	(n/a)	Scattered deposits capping isolated hills and ridges to north of North Fork River; not seen or mapped south of river
Qg_9	late Pliocene?	40	(n/a)	Scattered deposits capping isolated hills and ridges to north of North Fork River; not seen or mapped south of river
Qg_{10}	late Pliocene?	320	(n/a)	Single, very thick deposit exposed along south face of Oak Mesa; not seen or mapped south of river

Units and ages are regionally comparable to those of Hail (1972), Sinnock (1978), and Cole and Sexton (1981).
* Basalt gravels are found north of modern North Fork River. ** Porphyry gravels are found south of river.

addition, clast-supported alluvial deposits of basalt gravel, marking episodic stream-flooding events, are present in some locations. These findings generally agree with those from an earlier study in the area by Cole and Sexton (1981), who refer to the debris flow deposits as "pediment deposits."

Gravel deposits to the south of the modern river are composed mainly of granodiorite porphyry and monzonite porphyry clasts, derived from Oligocene laccoliths of the West Elk Mountains to the east and southeast of the quadrangle (**Figure 5a**).   Minor amounts of hornfels and fine-grained quartzite may be present, derived from metamorphosed Mancos Shale surrounding the laccoliths. These gravel deposits are found capping Spurlin and Cottonwood Mesas, and capping many smaller, unnamed mesas along

Figure 4. Basalt-gravel fan deposit (**Qg_4**) exposed along State Highway 92 at Rogers Mesa. This outcrop is well stratified and consists of interbedded lenses of clast-supported stream gravel, mud-supported debris flow, and clast-poor mud flow deposits. The large basalt boulders in the foreground are from nearby in the outcrop. Map board case is 12 inches wide. [UTMX: 262,309, UTMY: 4,298,343]

McDonald and Cottonwood Creeks. **Qg**-series deposits in the Bone and upper Stewart Mesa areas, in the east central part of the quadrangle, are particularly mud rich. They range from gravelly mud to muddy gravel. The source area consists of a large landslide complex in Mancos Shale on the western sides of Mt. Lamborn and Landsend Peak, in the adjacent Paonia quadrangle to the east. The gravel component is derived from those two peaks. Those deposits are generally poorly exposed. In contrast to rather well-formed gravel caps elsewhere, the gravelly mud deposits form rounded mesa caps with indistinct edges (**Figure 5b**). This may be due to their relatively low resistance to erosion (as compared to the more-resistant gravel caps). The deposits appear to be comprised of mixed debris and mud flow and alluvial facies, which filled broad valleys and upland basins. These muddy deposits are much like the **Qamfo** (older alluvial, mud flow, and fan) deposits described in the next section. We have assigned **Qg**-series designations to the Bone and Stewart Mesa deposits because they contain variable amounts of gravel, and typically become gravelly at shallow depth beneath the mud-rich surface.

 **Isolated gravel pod or lag (Holocene to Pleistocene) –** Black-and-red "bulls' eyes" mark the locations of small, thin, relict gravel deposits. They occupy the tops of hills and points and appear to be in place. Some of the deposits consist of rounded pebbles and cobbles of North

Fork River origin. Other deposits consist of sub-angular basalt or porphyry gravels. The deposits are small remnants of older gravel bodies, or arroyo-fill deposits that formed during erosion and redeposition of older gravels. They are too small in extent to map as polygons at the map scale. In the GIS database, these point shapefiles are assigned to the **Qg** series of deposits. Thickness is 2 to 10 ft.

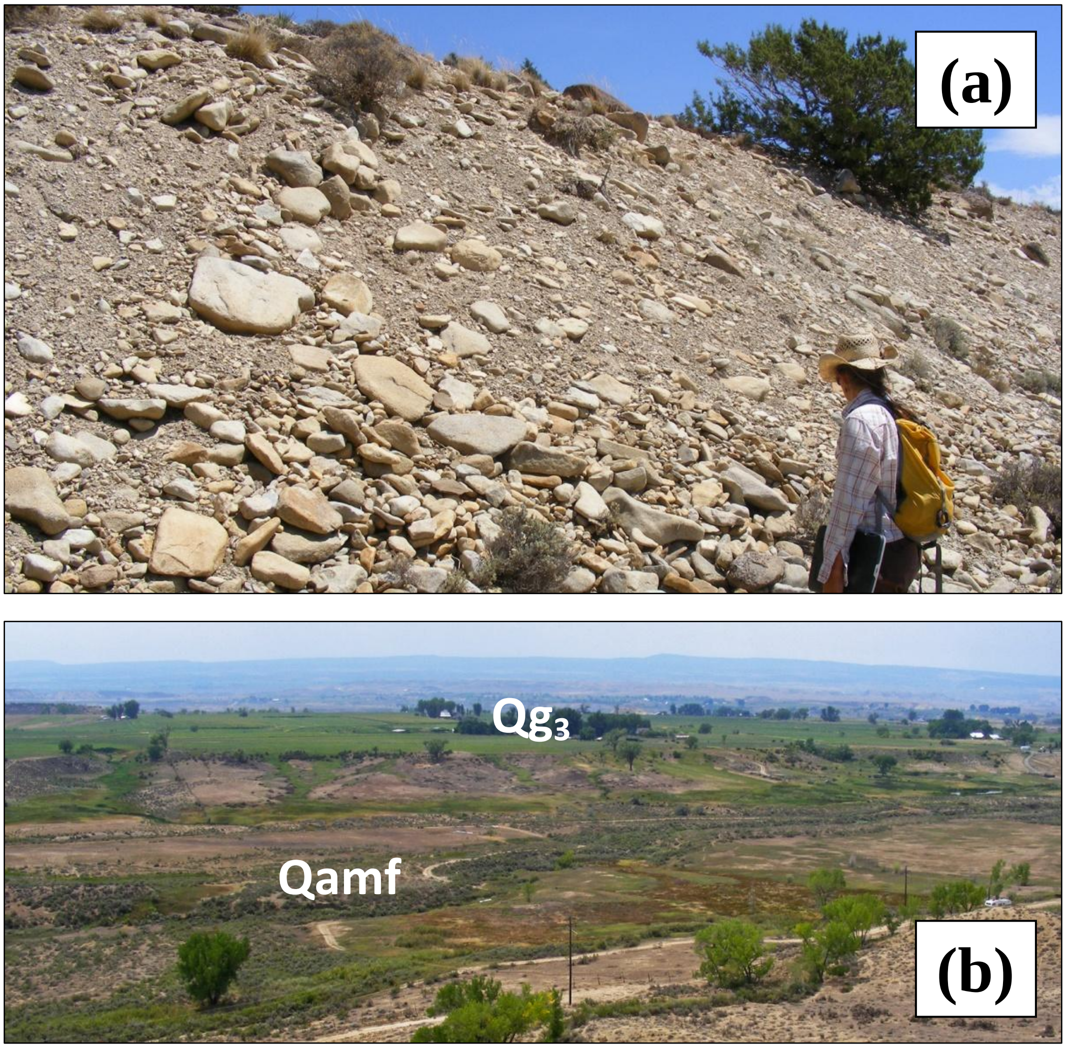

Figure 5. Porphyry-gravel and gravelly mud deposits (**Qg** series) south of the North Fork River.
(a) Gravel-rich debris flow deposit (in **Qg$_4$**) and an associated apron of colluvial gravel in a road cut on the west side of Spurlin Mesa. Porphyry boulders up to 3 ft long are scattered throughout. The deposit is poorly stratified, very poorly sorted, and has a coarse-sand matrix. [UTMX: 266,883, UTMY: 4,296,398]
(b) Gravelly mud deposit (**Qg$_3$**) at the northern side of Bone Mesa. The mesa surface is heavily irrigated for agriculture. The deposit is poorly exposed along the mesa edge, and appears to contain variable amounts of mud and gravel. The side slopes are comprised of Mancos Shale and landslides. The stream valley in the foreground is floored by modern alluvial mud flow deposits (**Qamf**). [UTMX: 270,482, UTMY: 4,301,284]

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 primarily from the Mancos Shale. The gravel is 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 (**Figure 5b**). It forms low-gradient mud fans and coalesced fan aprons that cover large areas of the modern North Fork River floodplain (**Figure 6a**). The unit is best developed within the "adobe hills" areas of the quadrangle, particularly in areas underlain by the Smoky Hill Member of the Mancos Shale (**Figure 6b**). Thickness is 5 to 10 ft in valley-head areas, and may exceed 20 ft along valley reaches and 20 to 40 ft at the heads of terminal mud fans.

Qf **Alluvial fan deposits (Holocene) –** Poorly to moderately sorted gravel, clay, silt, and sand. 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. Most of the alluvial fans in the Hotchkiss quadrangle occur along the northern edge of the North Fork River, at the apex of terminal mud fan (**Qamf**) complexes. They are thickest at the apex and contain basalt boulders and gravel. The boulders are up to 3 ft long. The deposits thin and become finer and less gravel-rich distally, where they merge contiguously into mud fan deposits. Thickness is 5 to possibly 30 ft.

Qamfo **Older alluvial, mud flow, and mud fan deposits (late Pleistocene) –** Composition and mode of deposition is the same as for **Qamf**. We mapped a string of older mud flow deposits flanking the valley of Short Draw, between Wolf Park and Powell Mesa. The deposits occupy terrace level two, about 20 ft higher than the modern stream. (Note, some older gravelly mud flow deposits that somewhat resemble **Qamfo** deposits are found on Bone and Stewart Mesas; they are described in a previous section, as **Qg**-series gravelly mud flow deposits.) Thickness is 15 ft.

Qfo **Older alluvial fan deposits (late Pleistocene) –** Composition and mode of deposition is the same as for **Qf**. We mapped one small, dissected fan at the mouth of Jay Creek. The fan is inactive, and is bypassed by the modern stream. Thickness is 5 to 20 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

Figure 6. Alluvial, mud flow, and mud fan deposits (**Qamf**).
(a) Mud flow deposits exposed in a borrow pit near Pumpkin Hollow. This is a thick, terminal mud fan that has been partially eroded by the North Fork River in a meander loop. The deposit is faintly stratified. It contains occasional, small, cut-and-fill channels with lags of basalt and porphyry gravel. (The vertical stripes are the result of digging into the deposit with a front loader.) [UTMX: 270,651, UTMY: 4,304,026]
(b) Mud-rich valley-fill deposits exposed in an incised arroyo along McDonald Creek. The deposits are easily eroded and are prone to piping, ground collapse, hydrocompaction, and sinkhole development. [UTMX: 271,487, UTMY: 4,294,917]

areas. Landslide debris may contain bodies of relatively undisturbed rock or soil. In the Hotchkiss quadrangle, landslides form in mesa side-slopes composed of clay-rich Mancos Shale. Upland gravels from the mesa caps 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 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.

Qc **Colluvial deposits (Holocene to middle Pleistocene) –** Sediments locally transported by water and gravity, found generally at the base and lower part of slopes. Deposits consist of locally derived clay, silt, sand, and boulders. Veneers (a few feet thick) of colluvium commonly cover the mesa slopes, but were too thin to map. We did map thick colluvium on the southern slopes of Wakefield and Stucker Mesas. In both cases, the slope is in the upper part of a landslide head scarp. Colluvial material has raveled onto the scarp face, sourced locally by gravel deposits (**Qg**-series) that cap the mesas. It forms a sediment wedge covering the uphill part of the landslide body. Thickness is not known, probably 5 to 30 ft.

EOLIAN DEPOSITS

Qe **Loess deposits (late Pleistocene) –** Silt or sandy silt, pale red in color, appearing massive or having weakly developed bedding or relict soil-zone development. Loess deposits are found capping alluvial gravel deposits (particularly, the **Qan_3** and **Qan_5** terraces), on several mesas to the north and south of the North Fork River. Loess deposits on Rogers Mesa were not mapped, as there are few exposures and we could not define any boundaries in the field.

The loess deposits record the accumulation of windblown silt and sand. They are similar in appearance to mud fan and valley fill deposits (**Qamf**/**Qamfo**). The two types of deposits are distinguished on the basis of color (reddish, versus light gray to yellowish brown), depositional geometry (sheet-like, versus linear or fan-shaped), and age (mainly late Pleistocene, versus mainly Holocene). The loess appears to be closely associated in time and proximity with tributary-fan gravel deposits. Both deposits locally overlie river-gravel terraces. In some cases, on Hanson and Powell Mesas for example, the loess appears to blanket the toe of the fan gravel. However, we noted a location on Sunshine Mesa where the loess forms a sheet-like deposit between the river gravel and overlying fan gravel (**Figure 7**). More work is needed to document this interrelationship. On Stewart Mesa, loess has accumulated into low mounds that are elongated in the NE-to-SW direction. Weak calcic soils (Bt-Bk, Stage I and II) are developed near the top of the loess deposits. In some cases there are internal soil horizons that are either poorly developed or partially preserved. Thickness is 5 to 20 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 are grayish-white in color. They form terrace- or mound-like features (**Figure 8**). We found active springs forming travertine in three locations in the Leroux Creek drainage. They occur in the lower slopes of hills that flank the valley, or at the junctures of small tributary

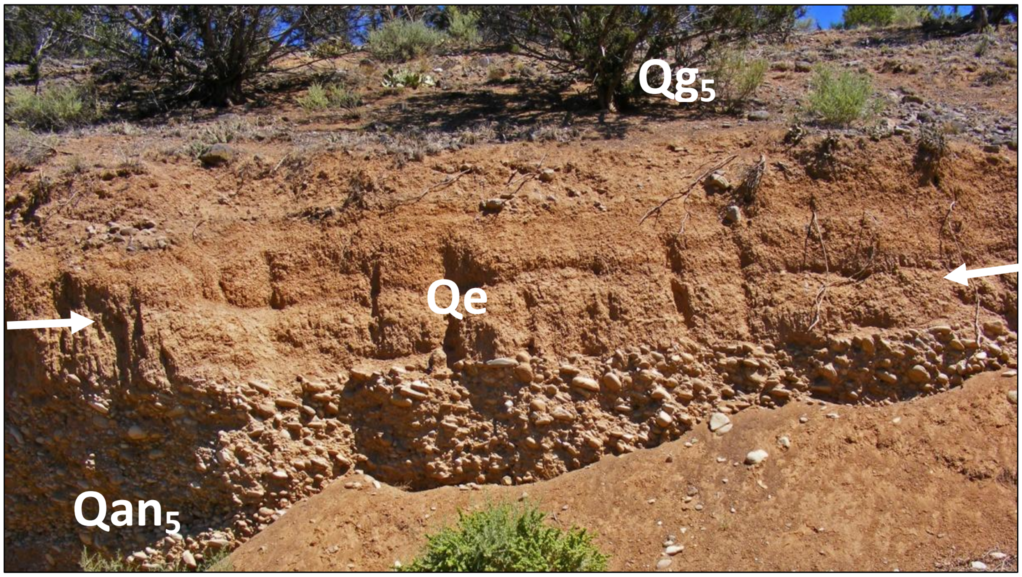

Figure 7. Eolian loess deposit (**Qe**) exposed in a road cut on Sunshine Mesa.
The loess forms a small cliff band at the center of the photo. It is pale to medium red and is comprised entirely of sandy silt. At this particular location, it contains an internal paleosol horizon, seen as a darker band or groove across the middle of the cliff face (between arrows), which divides the deposit into older and younger sub-units. The loess is underlain by ancestral North Fork River deposits (**Qan$_5$**), consisting of cobble-pebble gravels and thin sand lenses. It is overlain by colluvium from bouldery, debris-fan basalt gravels (**Qg$_5$**) that overlie the loess deposit and cap the mesa. [UTMX: 268,849, UTMY: 4,303,734]

Figure 8. Travertine deposit (*) in IX Gulch, a small tributary valley near Leroux Creek.
Active spring forming algal-encrusted, travertine terraces. It is located approximately in the middle of the Smoky Hill Member of the Mancos Shale. We interpret that calcium-rich formation waters may be flowing outward from the Piceance Basin along certain bedding zones, and discharging at the ground surface within modern stream valleys. [UTMX: 262,374, UTMY: 4,299,754]

valleys. The springs appear to be developed at the outcrops of brittle zones in Niobrara-equivalent strata of the Mancos Shale. Two springs are along the base of the Fort Hays Member, which contains thin limestone beds. The third spring is in the middle of the Smoky Hill Member, an interval in which we have recognized both sandstone and limestone zones. We also mapped a fourth, active mineral spring issuing from the Dakota Sandstone near the western edge of the quadrangle. It is located in an arroyo just to the south of the North Fork River. Its associated travertine deposit forms a single, shield-like mound beside of small sandstone cliff. The mineral spring deposits are partially covered with colluvium, algae, and other types of wetland vegetation. Cadigan and others (1976) located and described numerous mineral springs and their associated deposits in the Gunnison Gorge-North Fork region; however, they did not mention any of these four springs. To our knowledge, they are previously unrecognized and undescribed, and their geochemistry is not known. Thickness is 5 ft or greater.

BEDROCK UNITS

A 3,500-ft-thick interval of Upper Cretaceous sedimentary formations is exposed in the Hotchkiss quadrangle. The oldest units are found in the Gunnison Uplift area, in the southwestern corner of the map. There, the main unit is the Dakota Sandstone, which forms a highly resistant, dip-slope surface that defines the outer toe of the uplift. The remainder of the map area lies within the outcrop belt of the Mancos Shale. Approximately the lowermost four-fifths of the 4,000-ft thick shale occur within the quadrangle. The youngest part of the Mancos Shale is in the northwestern corner, in the slope of Oak Mesa. A generalized stratigraphic column of the mapped bedrock units and sub-units is shown in **Figure 9**. Thickness ranges of the bedrock units are derived from nearby oil-and-gas well logs.

Some of the bedrock units are combined and mapped as an undivided map unit. This occurs either because the outcrop width of one or both units is too thin to map, or if the two units are not easily distinguished in the field. In the Hotchkiss quadrangle, bedrock to the north of the North Fork River is typically obscured by colluvial cover, and the thinner units have narrow outcrop belts. However, in the "Hotchkiss adobes" to the south of the river, individual bedrock units are better exposed, more readily distinguished, and have broader outcrop widths. Accordingly, we combine some of the units to the north and map individual units to the south. This mapping convention applies specifically to the Smoky Hill and Fort Hays Members and the Montezuma Valley and Juana Lopez Members.

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.

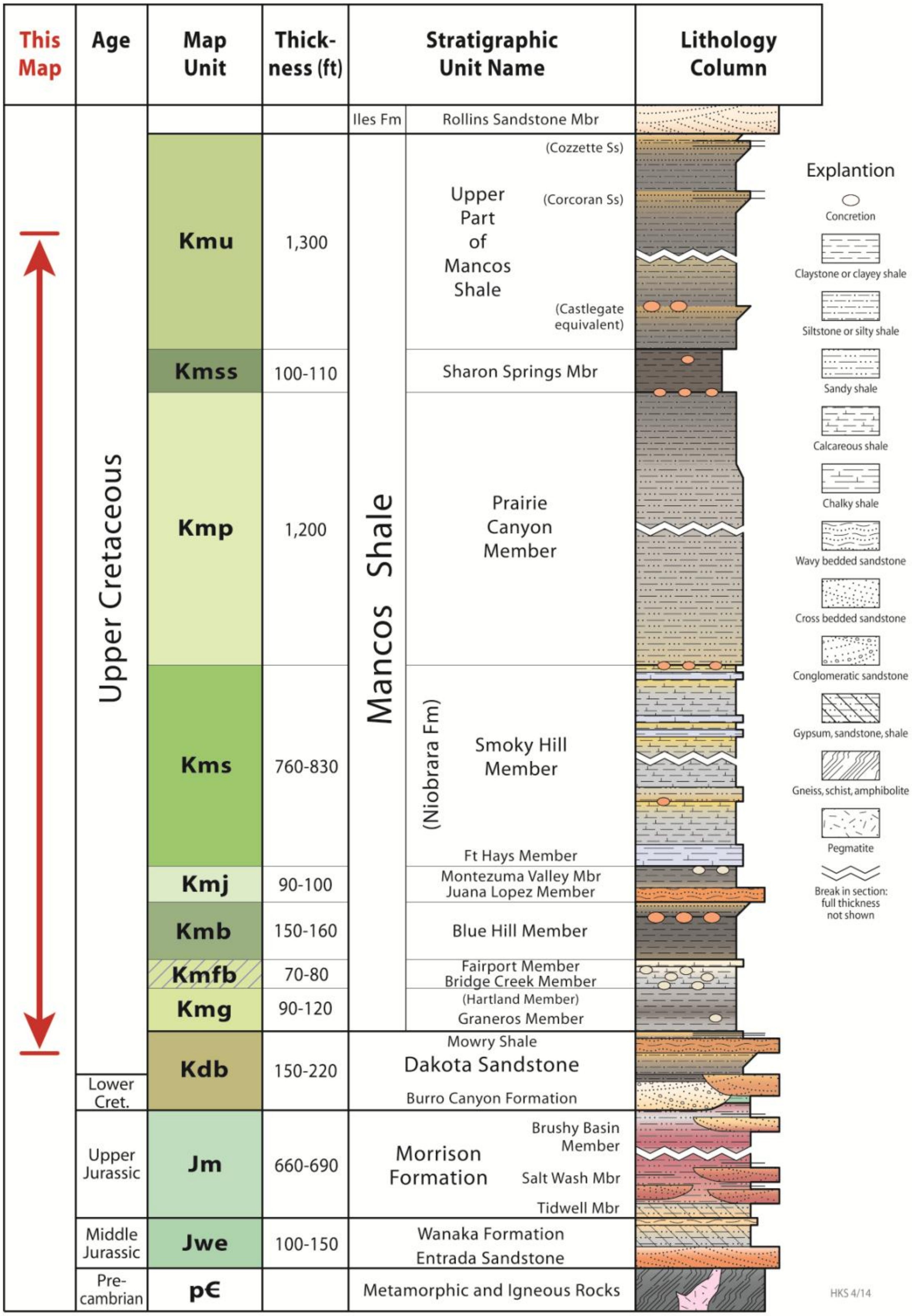

Figure 9. Generalized stratigraphic column of bedrock units for the Hotchkiss quadrangle. Red arrow, at left, denotes the bedrock units exposed in outcrops and shown on the geologic map.

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, or with other, thicker members, as undivided map units on the geologic map (**Plate 1**). The Mancos Shale is poorly exposed in the northern two-thirds of the quadrangle, where it is mostly covered by Quaternary alluvial, fan, landslide, and colluvial deposits. There, we depended on localized exposures for making observations and descriptions. In contrast, it is relatively well exposed across the "Hotchkiss adobes" area, in the southern third of the quadrangle. There, we were able to make more complete observations and descriptions of the bedrock units.

Kmu **Mancos Shale, upper part** — Olive-gray to pale-yellowish-brown, non-calcareous, silty to sandy shale. All but the uppermost ~200 ft of the unit is present across the northern part of the map area. It is mostly covered. Only one internal horizon could be distinguished, a 30-ft-thick, sandy shale zone in the lower part of the unit. It contains large concretions up to 10 ft in diameter (**Figure 10**), which contain abundant, but poorly preserved, bivalves and *Baculite* ammonites. From our mapping of other nearby quadrangles, this zone contains fossils from the *Baculites aspiriformis* and *Baculites sp.* (smooth) Taxon Range Zones, making it approximately age equivalent to the Castlegate Sandstone. We mapped this sandy concretion zone at several locations in the Hotchkiss quadrangle. Overall unit thickness is around 1,300 ft.

Figure 10. Upper part of the Mancos Shale (**Kmu**) exposed in the upper Jay Creek drainage basin. The outcrop consists of olive-gray, non-calcareous shale. The pale-yellowish-orange upper slopes comprise a weathered zone where ground water previously infiltrated and oxidized the shale. A horizon of sandy shale with very large, light-orange, limestone concretions (between arrows) occurs in the upper slope. Fossil collections made in nearby quadrangles indicate that this horizon is approximately age equivalent to the Castlegate Sandstone. [UTMX: 266,077, UTMY: 4,305,210]

Kmss **Sharon Springs Member** — Dark-gray to black, organic-rich, clay shale. In outcrop, it weathers to mottled pale to moderate red to grayish red. This relatively thin unit is locally exposed across the northern part of the map. It is mostly covered by landslides. Freshly exposed surfaces are rare and contain abundant healed fractures. The unit contains a number of white to orange bentonite beds (0.5 to 6 inches thick) and discontinuous, sometimes lenticular-shaped concretions (**Figure 11**). The bentonite beds are occasionally locally sheared and folded. The unit is 100 to 110 ft thick in outcrop and in nearby oil-and-gas well logs, where it forms a prominent, widespread marker that is used for making subsurface correlations.

Figure 11. Sharon Springs Member of the Mancos Shale (**Kmss**) exposed along Fire Mountain Canal. The outcrop consists of black, noncalcareous shale, interspersed with thin, whitish bentonite beds and ovoid to lenticular concretions. A laterally extensive, lenticular concretion occurs along a bedding horizon near the bottom of the exposure. [UTMX: 268,887, UTMY: 4,304,881]

Kmp **Prairie Canyon Member** — Light-gray to pale-yellowish-brown, silty to sandy shale. In outcrop, it weathers grayish orange to grayish yellow. This unit underlies large areas of the northern and eastern parts of the map, but is mostly covered by Quaternary deposits. 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. 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. Both the upper and lower contacts of the Prairie Canyon Member are marked by horizons of medium orange, dolomitic, iron-rich concretions, up to 3 ft in diameter. The lower-contact concretion zone is about 60 ft above the highest limestone bed in the underlying Smoky Hill Member, and can be traced for miles across the Hotchkiss “adobe hills.” Thickness is 1,200 ft.

Kms **Smoky Hill and Fort Hays (Niobrara) Members, undivided** — *mapped to north of river only*

Kms **Smoky Hill (Niobrara) Member** — *mapped to south of river only*

Kmfh **Fort Hays (Niobrara) Member** — *mapped to south of river only*

The Smoky Hill and Fort Hays Members can be distinguished to the south of the North Fork River, where they are mapped separately. They are not easily distinguished to the north of the river and are mapped there as a single, undivided unit. Together, they are age-equivalent to the Niobrara Formation of central and eastern Colorado.

The Smoky Hill Member consists mainly of dark-gray to light-gray, slightly calcareous to calcareous shale. It 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; we show the base of the sandy zone on the map. Fracture-filling seams of fibrous gypsum are present throughout the unit. Although widespread in outcrop, the Smoky Hill Member is often covered by thin residuum. It is moderately well exposed in the eastern part of the "Hotchkiss adobes" (**Figure 12**). Thickness of the Smoky Hill Member is 700 to 770 ft.

Figure 12. Smoky Hill Member of the Mancos Shale (**Kms**) exposed in the slopes of "Eagle Butte." The outcrop consists of slightly calcareous to 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. [UTMX: 269,070, UTMY: 4,298,400]

The underlying Fort Hays Member forms the basal strata of the Niobrara interval. It is highly calcareous and very poorly exposed. In outcrop, its outer surface consists of very light gray residuum. Beneath the residual cover are thinly interbedded limestone, marl, and shale beds. Each bed or bedding zone is only a few inches thick. The Fort Hays Member is best seen along the southwestern side of a group of isolated buttes near Hotchkiss High School. (These buttes include "H Hill.") The unit overlies a regional unconformity (Weimer, 1983). The Fort Hays Member is 50 to 60 ft thick.

Kmj **Montezuma Valley and Juana Lopez Members, undivided** — *mapped to north of river only*

Kmz **Montezuma Valley Member** — *mapped to south of river only*

Kmj **Juana Lopez Member** — *mapped to south of river only*

The Montezuma Valley and Juana Lopez Members can be distinguished to the south of the North Fork River, where they are mapped separately. They are not easily distinguished to the north of the river and are mapped there as a single, undivided unit.

The Montezuma Valley Member is a medium- to dark-gray, shaly mudstone. The sub-unit is poorly exposed to the north of the river. It forms extensive, hill-capping outcrops on top of the Juana Lopez hogback, to the south of the river. The outcrops are weathered and consist of brownish-gray residuum. The unit forms low, rounded, hill slopes with local drainages and drainage divides. In rare, fresh exposures, abundant seams of fibrous gypsum are present. Light-gray limestone concretions are found in the upper 15 ft. Thickness of the Montezuma Valley Member is 50 to 60 ft.

The underlying Juana Lopez Member is medium gray to black. In outcrop, it may weather to light red to moderate reddish orange (**Figure 13**). 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 a thin, colluvial cover of angular calcarenite fragments across the outcrop. The Juana Lopez Member is poorly exposed to the north of the river. To the south, however, it forms extensive, low-angle hogbacks and dip surfaces. The Juana Lopez Member is 40 to 45 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 fibrous 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. 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 13**). 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 unit is slightly silty, wavy-bedded, fissile shale. It becomes brownish black near its base. Thickness of the entire unit is 150 to 160 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 10 miles southwest of

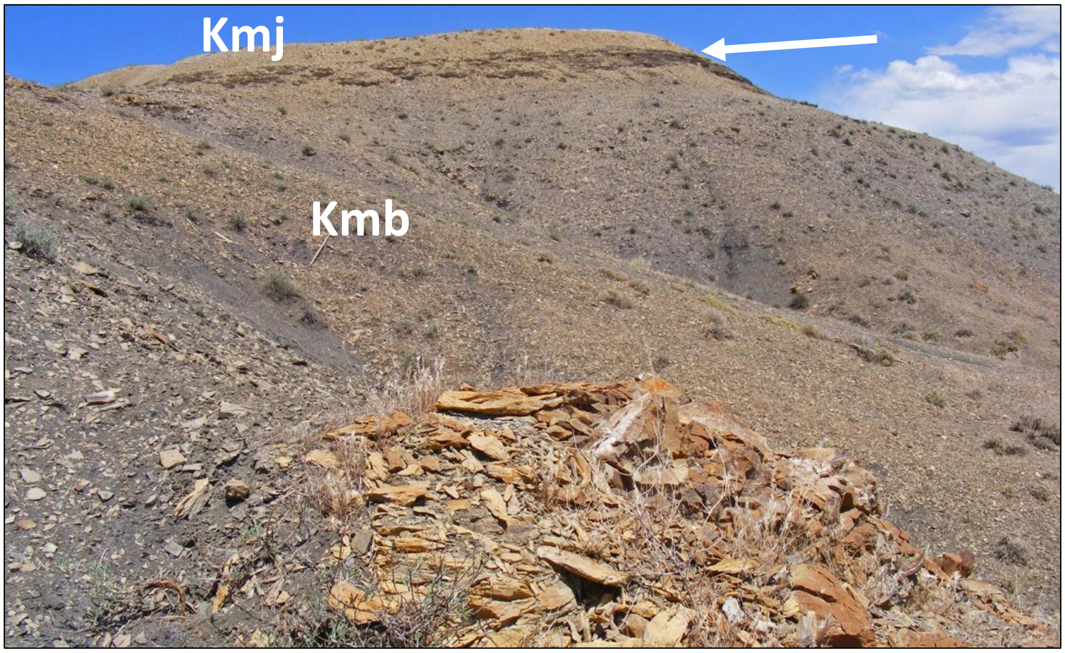

Figure 13. Juana Lopez (**Kmj**) and Blue Hill (**Kmb**) Members of the Mancos Shale, south of Hotchkiss. An arrow marks the contact between the reddish-orange Juana Lopez Member, which caps the hill, and the underlying Blue Hill Member, which forms black to gray cliffs and slopes. In the foreground is a large, moderate-red concretion, part of a widespread concretion horizon that occurs across much of west-central Colorado. [UTMX: 262,586, UTMY: 4,293,842]

the quadrangle. They indicate that the Fairport/Bridge Creek contact is an unconformity that is sub-regional in extent (Merewether and Cobban, 1986). In outcrop, 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. In the nearby Lazear quadrangle (Noe and others, in prep.), we collected *Pycnodonte aff. P. newberryi* oysters from the contact zone between the two units. The undivided Fairport and Bridge Creek Members are 70 to 80 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. 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. We could not distinguish a contact between the members in the field. Thickness is 90 to 120 ft.

Older Bedrock Units Shown on Geologic Map

Two older sedimentary rock units that underlie the Mancos Shale are shown on the geologic map. From youngest to oldest, they are the Mowry Shale and the Dakota Sandstone-Burro Canyon Formation.

Kmow **Mowry Shale (Upper Cretaceous)** — This unit consists of dark gray to reddish brown, clayey to silty shale, with interbeds of siliceous, light-gray to medium-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 (2011) erosional cut through part of the unit, resulting from flash flooding, provides excellent exposures of the unit and its internal bedding (**Figure 14**). The Mowry Shale is a transitional unit between the Dakota Sandstone and Mancos Shale. Its upper contact (which is 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 gently dipping hogback slopes, on top of the Dakota Sandstone. Thickness is 30 to 45 ft.

Figure 14. Mowry Shale (**Kmow**) exposed in a fresh erosional cut in the dip-slope face of Scenic Mesa.

The cut, eroded by a flash-flood storm event in 2011, exposes alternating beds of reddish brown, clayey to silty shale and medium brown, siliceous, rippled siltstone.

[UTMX: 261,582, UTMY: 4,294,289]

Kdb **Dakota Sandstone and Burro Canyon Formation, undivided (Upper and Lower Cretaceous)** — Only the upper part of the Dakota Sandstone is exposed in the Hotchkiss quadrangle. It forms the main hogback surface of Scenic Mesa, which comprises the toe of the Gunnison Uplift in the southwestern corner. In outcrop, it consists of interbedded shale and sandstone (**Figure 15**). 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 sandstone beds contain siliceous cement and are quite hard; these beds are light gray and translucent in fresh exposures and, when broken, form angular blocks and fragments having well-defined, sharp edges and faces.

Figure 15. Upper part of the Dakota Sandstone (**Kdb**) exposed in an arroyo on Scenic Mesa. The outcrop contains alternating zones of gray, sandy shale (slopes) and light-brown, thin-bedded sandstone with ripples and hummocky stratification (cliffs). [UTMX: 261,399, UTMY: 4,294,528]

The lower part of the Dakota Sandstone is not exposed in the quadrangle. In the nearby Gunnison Gorge, to the west, contains lenticular to tabular bodies of sandstone, carbonaceous shale, and coal, and is variable in thickness (Noe and others, in prep.). The Dakota Sandstone is Upper Cretaceous (Cenomanian) in age in west-central Colorado (Merewether and Cobban, 1986). Its lower contact with the Burro Canyon Formation is unconformable.

The Burro Canyon Formation is not exposed in the quadrangle. Nearby outcrops to the south and southwest contain chert-pebble conglomerate, conglomeratic sandstone, sandstone, and minor shale. The unit is highly variable in thickness due to the lenticular nature of the sandstone and conglomerate beds. It forms cliffs up to 80 ft thick along segments of the Gunnison River gorge (Noe and others, in prep.). In other places it is absent, and the Dakota Sandstone rests directly upon the Morrison Formation. Thickness of the undivided Dakota Sandstone and Burro Canyon Formation varies from 100 to 125 ft.

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

Cross Section *A-A'* runs northeast from the toe of the Gunnison Uplift, near the southwestern corner of the map, to Stucker Mesa and Roatcap Creek, near the northeastern corner. The cross section line is shown on **Plate 1**. The cross section is shown on **Plate 2**. Older bedrock units, which are not shown on the geologic map, are included as subsurface units on the cross section. They do not crop out within the Hotchkiss quadrangle but occur to the south and west. Reported thickness values are from outcrops in the upper Gunnison River gorge. The Jurassic stratigraphy in this region has undergone a revision since it was mapped by Hansen (1968, 1971). The Wanakah Formation from his report 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.

Jm **Morrison Formation (Upper Jurassic)** — The Morrison Formation unit consists of three members, from youngest to oldest, the Brushy Basin, Salt Wash, and Tidwell Members. The Brushy Basin Member consists of banded, light-greenish-gray to grayish-purple shale and occasional lenses of light-brown to moderate-brown sandstone (Noe and others, in prep.). 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). The Morrison Formation is 660 to 690 ft thick.

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 (Kellogg and others, 2004).

STRUCTURAL GEOLOGY

The Hotchkiss quadrangle lies within the eastern part of the Colorado Plateau physiographic province (Fenneman and Johnson, 1946). Its main structural feature is the Gunnison Uplift, which formed as a result of movement along basement faults during the Late Cretaceous-Eocene Laramide orogeny (Tweto, 1977). Its toe is expressed in the southwestern 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. Mancos Shale strata to the north of the Gunnison Uplift mimic the Dakota Sandstone dip slope. The regional dip of the shale strata is toward the northwest to northeast at angles of less than 10°.

This northeastern slope of the Gunnison Uplift is broken by a series of minor folds. One of these folds is shown on the cross section (**Plate 2**), and in outcrop is indicated by a displacement of the Juana Lopez hogback across a small strike valley. The folds appear to be unfaulted in outcrop where we noted continuous bedding layers in harder, brittle units such as the Dakota Sandstone or Juana Lopez Member of the Mancos Shale. The fold axes generally have northeast-southwest orientations. Their limbs vary in steepness, with bedding dips ranging from 2° to greater than 16° (in the adjacent Lazear quadrangle; Noe and others, 2015). We interpret that the folds mark the margins of faulted basement blocks at depth, as depicted in the cross section, as a result of minor differential uplift and tilting. We did not have access to drilling or seismic data that would confirm or disprove this interpretation.

In the east-central part of the quadrangle, we mapped two localized folds in the Mancos Shale. They are shown on the geologic map as a monocline and as a paired anticline and syncline. Because of limited exposures, we were not able to fully constrain their extent or axial orientations. The folds occur in gently-dipping shale and have steeply dipping interaxial limbs (14° to 22°).

Few strike and dip readings were recorded in the northern two-thirds of the quadrangle, particularly north of the North Fork River. This is due in part to deep weathering of the shale, resulting in thick residual-soil cover and destruction of the primary bedding planes. Also, the shale there is mostly hidden beneath Quaternary gravels, landslides, and colluvium. We were able to discern a possible, paired anticline and syncline in the Short Draw/Jay Creek area, based on changes in bedding strike. Those folds are subtle and not well constrained. They appear to be roughly parallel and north-trending.

MINERAL RESOURCES

The Hotchkiss quadrangle contains abundant sand and gravel resources. The area was explored in the past for clay, and oil and gas. In the following paragraphs, we outline those resources, associations with soil or bedrock units from the geologic map, and current activity. GIS location and permit-status data for mining operations and oil-and-gas wells are available from the Colorado Division of Reclamation Mining and Safety (http://mining.state.co.us/Reports/Pages/GISData.aspx) and the Colorado Oil and Gas Conservation Commission (http://cogcc.state.co.us/, on Maps link page).

Construction aggregates. Gravel and sand have been produced from commercial pits along the North Fork river valley. In addition to three active, permitted pits, there are fourteen inactive pits that either have terminated permits or were operated prior to 1981 (Schwochow, 1981; Keller and others, 2002; Guilinger and Keller, 2004). Most of the pits are located within the modern floodplain of the North Fork River, and a few are located atop older North Fork terraces (**Qan_3** and **Qan_5**). The mined deposits contain pebble-cobble gravels with rounded and smooth, hard clasts of basalt, porphyritic igneous rock, and hornfels, with a coarse sand matrix. An example is shown in **Figure 3**. One borrow pit is in mud fan deposits near the river (**Figure 6a**). Finally, there is one small pit in the southern part of the quadrangle near State Highway 92, atop an isolated butte, which produced porphyritic gravel from unit **Qg_7**. Gravel deposits in the quadrangle become increasingly weathered with age. The weathering produces light to heavy accumulations of calcic soil (Bk to K horizons) and may cause disintegration of some gravel clasts, particularly the basalt. The modern floodplain and younger terraces (**Qan_1** to **Qan_3**) contain the most likely potential gravel resources.

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 the North Fork area (Switzer, 2012). Today, industrial 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. We found one instance where a storage shed was recently constructed using old-fashioned, mud-and-straw adobe blocks (**Figure 16**).

Figure 16. Detail of adobe bricks used to construct a modern storage shed on Cottonwood Mesa. The bricks and the mortar are made of mud and straw. The source of the clay is believed to be the Smoky Hill Member of the Mancos Shale. A couple of flat, lenticular rock fragments, possibly rippled calcarenite from the Juana Lopez Member or starved siltstone ripples from the Blue Hill Member, are incorporated into the wall mortar. [UTMX: 269,490, UTMY: 4,294,528]

Oil and gas. The quadrangle contains four inactive oil and gas wells (Milne and Watterson, 2012), all of which appear to be drilled-and-abandoned, dry holes. One is in southern Wolf Park; one is in the "adobe hills" near 3400 Road, and two are north of Cottonwood Mesa along Crawford Road. Historic, potential target formations in the region included the Dakota Sandstone (part of unit **Kdb**) and the 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 Hotchkiss quadrangle, units **Kms** (Smoky

Hill Member) and **Kmfh** (Fort Hays Member) represent the Niobrara interval. The principal targets are calcareous zones within the Smoky Hill Member. Unit **Kms** forms surface outcrops across the central part of the map area. It is absent, eroded away from the southwestern part. In the northeastern part of the quadrangle, the Smoky Hill Member extends into the subsurface and is overlain by 0 to over 1,000 ft of shale strata (see **Cross Section A-A', Plate 2**). A study of the oil and gas potential of prospective geologic units in the area of the Hotchkiss quadrangle is beyond the scope of this mapping project.

Coal. Most of the historic coal production in the region occurs in the Upper Cretaceous Mesaverde Group. This geologic unit outcrops just to the north of the Hotchkiss quadrangle, with subsurface production extending to the north of the outcrop, into the Piceance Basin. In canyons along Scenic Mesa, to the west of the study area, we encountered a few lenses of thin (less than 2 ft thick), poorly formed coal and carbonaceous shale in the lower part of the Dakota Sandstone. We assume that such deposits underlie the upper part of the Dakota Sandstone that we mapped in the Hotchkiss quadrangle. Based on our field observations, the potential for coal resources in the formation appears to be poor.

GROUND-WATER RESOURCES

Ground-water resources exist in parts of the Hotchkiss quadrangle, despite the area's semi-arid climate. The modern alluvial valley of the North Fork River contains alluvial aquifers that are charged by annual runoff from snow melt in the nearby mountains and surface water through-flow. Gravel bodies capping the upland mesas flanking the river valley, mostly to the north and less commonly to the south, 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 162 ground-water wells in the quadrangle, according to GIS data from the Colorado Division of Water Resources (GIS data regarding water-well locations and application status are available at http://water.state.co.us/DataMaps/GISandMaps/Pages/GISDownloads.aspx). Most of the wells are permitted for domestic or household use. Other permitted uses include irrigation (1 well), stock (2), commercial (5), 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 and debris flow fan gravels. A few wells located in the “Hotchkiss adobes,” in the southwestern part of the map area, appear to produce ground water from the Dakota Sandstone. Other deep wells in the quadrangle possibly produce from sandy or calcareous zones in the lower and middle Mancos Shale.

Reported water-well depths range from 2 to 1,386 feet. A majority of the wells along the river valley are in the 30- to 70-ft depth range, while most wells in the small mesas to the north are in the 30- to 150-ft depth range. At Rogers Mesa, with its very thick fan gravels, most of the wells are 85- to 200-ft deep. The deepest water wells are widely scattered, and are often surrounded by shallower wells. Pump rates for the 162 wells in the quadrangle vary widely, from 0.2 to 100 gpm. A large number of the wells, however, produce at pump rates of 15 gpm or less.

Cadigan and others (1976) reported on the geochemistry of ground water associated with mineral springs in the northern Gunnison Uplift. They found that ground water from mineral springs located to the west of the Hotchkiss quadrangle contains elevated amounts of calcium carbonate, salt and sulphur precipitates, occasional iron precipitates, and minor sodium, lithium, boron, mercury, molybdenum, arsenic, beryllium, and boron. Their report does not mention the three travertine-producing springs that we located and mapped within the valley of Leroux Creek and the one to the south of the North Fork River near the eastern quadrangle boundary (see **Surficial Deposits - Mineral Spring Deposits**), although those springs occur within their study area.

Cadigan and others reported barium and radioactive elements, in the form of radium-226 and uranium-238, in travertine deposits and flowing water from Doughty Springs and from the Colonel Chinn artesian hot well. Doughty Springs is located just to the west of the Hotchkiss quadrangle along the North Fork Gunnison River. The Colonel Chinn well was drilled during the early 1900's on Stewart Mesa, in the quadrangle, near to the northwestern prow of "Airport Mesa." It has a total depth of 4,499 ft and produces water from a cased interval at a depth of 1,850 ft (Headden, 1909; Barrett and Pearl, 1978), at a temperature of 41° C (106° F) (Cadigan and others, 1976). **Table 4** lists temperature and geochemical data for the Colonel Chinn well.

Table 4. Temperature and geochemical data for the Colonel Chinn artesian hot well, on Stewart Mesa

Temperature	41-42° C (106°-108° F)		Alkalinity as Calcium Carbonate		896 mg/l
pH, Field	6.5		Alkalinity as Bicarbonate		764-1540 mg/l
Hardness, total	410 mg/l		Specific Conductance		3200-3560 µmohs
Water type	Na-HCO_3		Significant minor elements		Li, Ba
Aluminum (Al)	55 µg/l	Lithium (Li)	1500 µg/l	Silica (Si)	25 mg/l
Barium	4000 µg/l	Magnesium (Mg)	32-34 mg/l	Sodium (Na)	570-610 mg/l
Boron (B)	800-1700 µg/l	Manganese (Mn)	880 mg/l	Strontium (Sr)	3100 µg/l
Calcium (Ca)	110 mg/l	Nitrogen (N)	0 mg/l	Sulfate (SO_4)	58 mg/l
Chloride (Cl)	370-400 mg/l	Phosphate (Po)	0.06-0.12 mg/l	Zinc (Zn)	<1 µg/l
Fluoride (F)	2.4-2.5 mg/l	Potassium (K)	36-41 mg/l	Radium (Ra)	9.1 µµg/l
Iron (Fe)	100 mg/l	Selenium (Se)	not measured	Uranium (U)	0.03 µg/l
Data compiled from Barrett and Pearl (1976) and Cadigan and others (1976).					

Headden (1905) and Cadigan and others (1976) interpreted that the radioactive ground water is from a deeper source than mineral waters from other springs in the area, which are sourced from the adjacent (Piceance) basin by flow through Jurassic and Cretaceous sedimentary rocks. Cadigan and others speculated that the geochemistry of the radioactive ground water points to a geothermal system that intersects vein-type thorium-uranium mineral deposits in the deep subsurface. They interpret the deposits to be located in the subsurface roughly in the vicinity of Hotchkiss to Paonia.

GEOLOGIC HAZARDS

We recognize several potential geologic hazards in the Hotchkiss 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 northern part of the quadrangle has the potential to generate debris flows. Mud flow valley fills and fans are typically gravel-poor. They occur in stream valleys and basins within the “adobe hills” to the south of the river, in stream valleys to the north of the river, and in the large, low-gradient mud flow fans that extend onto the North Fork River floodplain. 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.

Landslides (unit **Qls**) are particularly common in the quadrangle where shale slopes are capped by a gravel deposit. Some of the landslides are Pleistocene in age, but others 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. Mesa edges ("view lots") and mesa side-slopes are susceptible, particularly on mesas where agricultural irrigation adds to the natural ground-water seepage at the mesa edge (**Figure 17**). 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. Due to the qualitative nature of our mapping, the potential for large, catastrophic landslide events in this area is not known.

Stream flooding hazards and associated high water tables exist within the modern North Fork River flood plain (unit **Qan_{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, and FEMA Flood Hazard Area mapping is viewable via the Delta County Interactive Mapping Resources web site (http://www.deltacounty.com/382/Delta-County-Interactive-Mapping-Resourc). The North Fork 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 in the region, ca. 1862, in which the waters extended "from bluff to bluff" (Marshall, 1996). A similar flood would inundate the low terraces (unit **Qan_{1b}**) that flank the modern North Fork River floodplain. Flooding on the North Fork River is at least partly mitigated by an upstream dam (at Paonia Reservoir, on Muddy Creek).

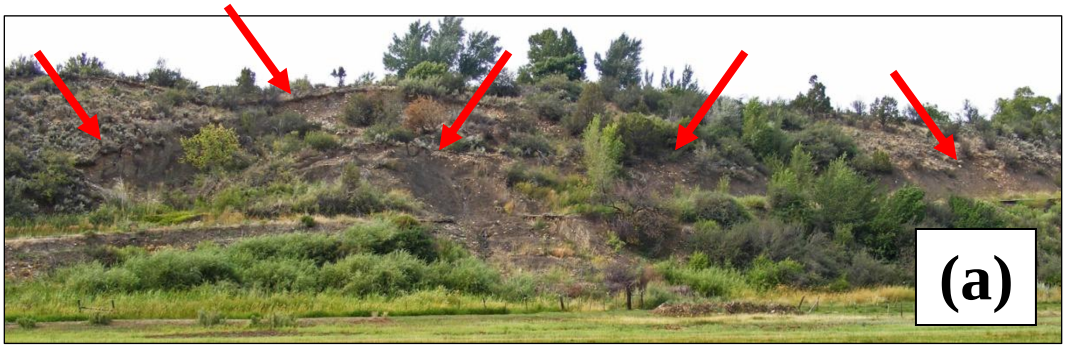

Figure 17. Extensive, active landslides (**Qls**) along the side-slopes of Stewart Mesa, near Coburn.
(a) View of the mesa side, which in this location is a laterally extensive landslide complex that consists of overlapping, active landslide deposits. The top of the mesa is agricultural land that is heavily irrigated. The mesa-capping deposit is a paleo North Fork River gravel deposit (**Qan$_3$**) that has a sand matrix and high hydraulic conductivity. It is underlain by the Prairie Canyon Member of the Mancos Shale, which has relatively low permeability. Perched ground-water flows along the shale-gravel contact until it reaches the mesa edge, where several small seeps and springs issue from the hillside. Fresh head scarps run along the mesa edge and are found down slope within the landslide, as shown by red arrows. [UTMX: 271,565, UTMY: 4,303,013]
(b) Landslide damage to Back River Road (which cuts across the hillside in **Figure 16a**). The photographer is standing on pavement in a part of the landslide that slid downhill relative to the pavement segment in the photo. After years of unsuccessful attempts to mitigate ongoing landslide movements and attendant damage along the entire grade, Delta County officially closed and vacated this section of county road in 2012. [UTMX: 271,545, UTMY: 4,302,875]

Rockfall hazards are prevalent along the faces and toes of slopes that are capped with cobbly to bouldery gravel deposits. The size of the falling rock clasts is a function of the grain-size character of the sediment deposit and the exposure of the slope to ground-water seepage and freeze-thaw processes. Large precipitation events may trigger rock falls, as well. In the northern part of the quadrangle, large basalt boulders up to 8 ft in diameter are known to fall from the edges of mesa-capping gravel bodies (**Qg**-series units). The best mitigation is to avoid rockfall-prone slopes and roll-out zones.

Expansive soil and bedrock hazards occur in clay-rich materials. These materials are relatively dry under natural climate conditions. Upon wetting, water is drawn into crystal lattices. The clay particles swell to accommodate the added water molecules (Noe, 2007). Resultant ground heaving may cause damage to buildings, roads, and underground utilities and pipelines. The clay particles lose water and shrink upon drying. This shrink-swell behavior may continue over numerous wetting and drying cycles. Potentially expansive soil and bedrock is found in the Mancos Shales (particularly in units **Kmu**, **Kmss**, **Kmp**, **Kms**, **Kmb**, and **Kmg**), the Dakota Sandstone (unit **Kdb**), 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**, **Qfo**, **Qamf**, and **Qamfo**). Ground collapse and settlement occurs as a result of wetting or loading of the soil. An example of extreme damage to a structure built on a mud flow fan is shown in **Figure 17**. 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.

Figure 18. Garage damaged by collapsible soil and ground settlement in the town of Hotchkiss. This brick structure was built upon the alluvial fan (**Qf**) and mud fan deposit (**Qamf**) that underlies the main part of the town. A geotechnical well boring from nearby encountered 17 ft of potentially collapsible mud and gravelly mud deposits. Soil collapse issues are of concern for many western Colorado towns. [UTMX: 264,360, UTMY: 4,298,379]

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. The CGS *Colorado Earthquake Map Server* (Morgan and others, 2012) shows one historical earthquake within the quadrangle, which occurred on October 7, 2008. It was located 2 mi E-NE of Hotchkiss, at an approximate depth of 1 km (3,280 ft), and had a magnitude of 2.7. At least 45 tremors of less than magnitude 4.0 and one of magnitude 4.4 are mapped in the Somerset area (8 miles to the east). Many of these are attributed to ground movements and collapses within coal mines, or "coal bumps." The nearest faults suspected of having Quaternary movement are located to the south of the Black Canyon of the Gunnison River (17 miles to the south) and to the west of Delta in the Uncompahgre Uplift (27 miles to the west). An updated, online version of the Kirkham and Morgan maps is available on the CGS web site, at http://coloradogeologicalsurvey.org/geologic-hazards/earthquakes-2/maps/.

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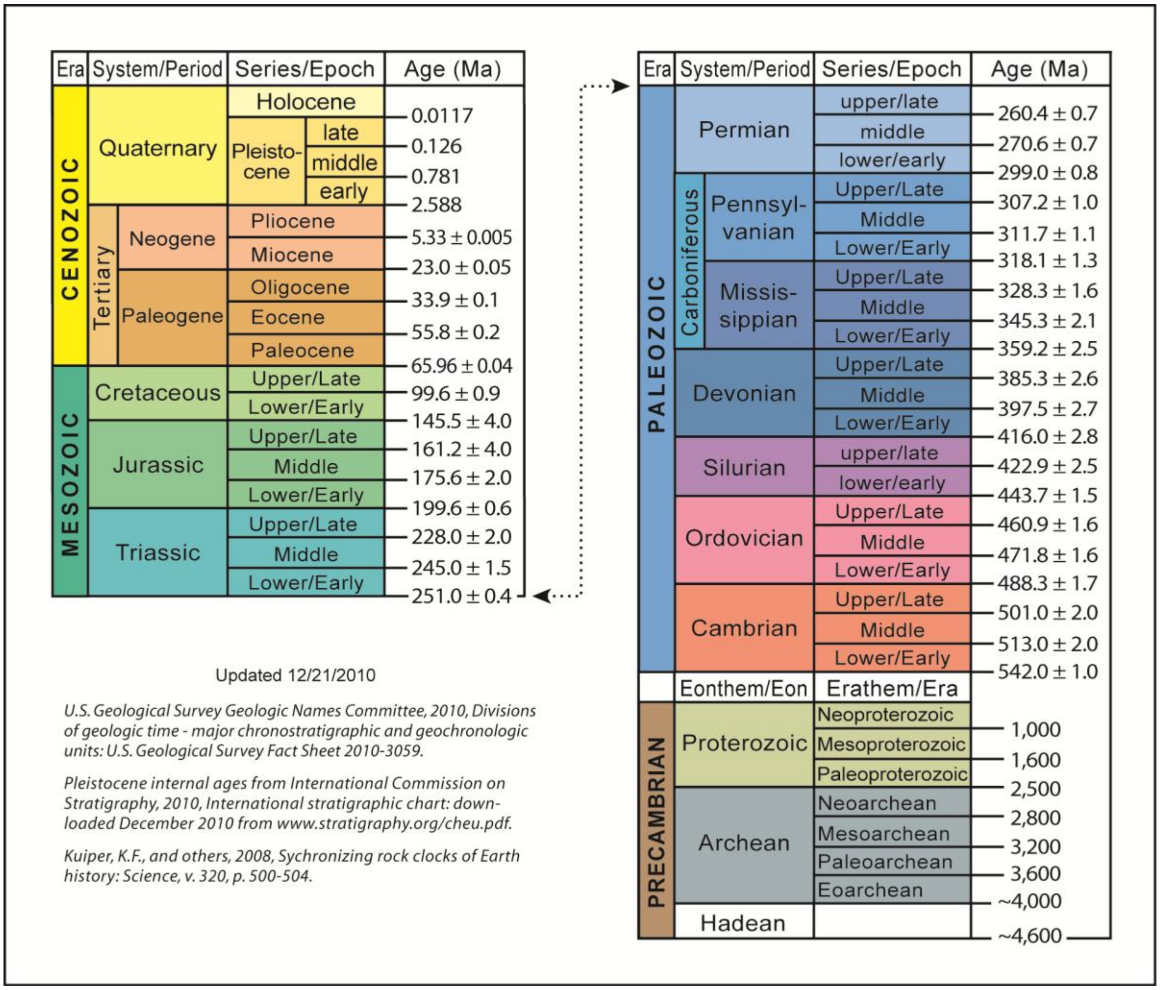
APPENDIX A

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



APPENDIX B

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

Optically Stimulated Luminescence (OSL) Dates

OSL dating was performed by Dr. Steven Forman, University of Illinois at Chicago. His results are shown in the table on the next page. The methodology is explained below the table of results. Many samples from different locations in Colorado were tested; only sample HKS-2 is from the Hotchkiss quadrangle.

Sample HKS-2 is from a sand lens in a stratified, basalt-gravel fan deposit (unit $\mathbf{Qg_4}$), located on the edge of Rogers Mesa along the Leroux Creek road grade of State Highway 92, just to the west of the town of Hotchkiss [UTMX: 262,309, UTMY: 4,298.343]. **Figure 4** is a photograph of this location. The sand lens is at the top of the dark, basal gravel unit in the exposure, and is probably fluvial in origin.

From geomorphic relationships we expect this unit to be late middle Pleistocene in age (possibly from the late Bull Lake glacial stage, around 130 ka). The result of the age dating (>64,990 ka) is 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.

Table 1: Optically stimulated luminescence (OSL) ages and associated chronologic data for fluvial sediments high country, western Colorado (10/7/2013)

Field number	Laboratory number	Quartz grain size (μm)	Equivalent dose (Grays)[a]	Uranium (ppm)[b]	Thorium (ppm)[b]	K_20 (%)[b]	H_20 (%)	Cosmic dose (mGrays/yr)[c]	Total dose rate (mGrays/yr)	OSL age (ka)[d]
CO-2059-1	UIC3345	150-250	96.70 ± 5.03	1.6 ± 0.1	4.7 ± 0.1	4.70 ± 0.05	12 ± 3	0.26 ± 0.03	3.40 ± 0.22	**28.4 ± 1.6**
HKS-2	UIC3454	100-150	>249	2.7 ± 0.1	8.9 ± 0.1	2.64 ± 0.03	5 ±3	0.18 ± 0.02		**>64,990**
LA2-178	UIC3443	150-250	>174	2.4 ± 0.1	13.7 ± 0.1	1.59 ± 0.02	10 ± 3	0.04 ± 0.004	2.82 ± 0.14	**>61,660**
LR2	UIC3346	150-250	>357	4.5 ± 0.1	37.1 ± 0.1	5.00 ± 0.05	10 ± 3	0.30± 0.03	7.24 ± 0.47	**>49**
LR8	UC3358	250-355	289.54 ± 16.49	5.5 ± 0.1	25.5 ± 0.1	4.96 ± 0.05	10 ± 3	0.30 ± 0.03	7.13 ± 0.46	**40,620 ± 2480**
PCF	UIC3348	250-355	42.29 ± 2.92	4.9 ± 0.1	25.8 ± 0.1	3.68 ± 0.04	10 ± 3	0.29 ± 0.03	5.98 ± 0.30	**~~7170 ± 540~~**[e]
PCR-1	UIC3349	250-355	31.49 ± 2.11	4.0 ± 0.1	24.8 ± 0.1	3.61± 0.04	10± 3	0.27 ± 0.03	5.16 ± 0.29	**6095 ± 355**
PCR-2	UIC3369	250-355	55.02 ± 3.05	2.4 ± 0.1	12.4 ± 0.1	4.66 ± 0.05	10 ± 3	0.28 ± 0.03	5.34 ± 0.32	**10,300 ± 750**
RS0	UIC3341	150-250	375.29 ± 20.56	2.5 ± 0.1	16.3 ± 0.1	4.63 ± 0.05	10 ± 3	0.30 ± 0.03	5.14 ± 0.33	**73.0 ± 4.7**
RSy2	UIC3340	150-250	90.75 ± 4.81	4.5 ± 0.1	22.3 ± 0.1	4.77 ± 0.05	10 ± 3	0.31 ± 0.03	6.09 ± 0.40	**14.9 ± 1.2**
S2-2	UIC3347	250-355	>523	3.3 ± 0.1	12.5 ± 0.1	3.88 ± 0.04	10 ± 3	0.16 ± 0.02	2.26 ± 0.13	**>124**
S2-1	UIC3370	250-355	Dose saturated	3.6 ± 0.1	14.9 ± 0.1	4.67 ± 0.05	10 ± 3	0.14 ± 0.01		**Incalculable**
NDL-14W	UIC3446	250-355	Dose saturated	2.2 ± 0.1	8.1 ± 0.1	2.42 ± 0.03	10 ± 3	0.16 ± 0.02		**Incalculable**
WW#6457A	UIC3421	250-355	69.15 ± 3.67	2.5 ± 0.1	5.3 ± 0.1	1.61 ± 0.02	10 ± 3	0.16 ± 0.02	2.32 ± 0.12	**29,790 ± 1840**
WW#6457B	UIC3439	150-250	90.19 ± 5.09	1.4 ± 0.1	8.2 ± 0.1	1.89 ± 0.02	10 ± 3	0.19 ± 0.02	2.62 ± 0.13	**34,490 ± 2310**

[a] Equivalent dose determined by the multiple aliquot regenerative dose method under blue (470 nm) excitation (Jain et al., 2003). Blue emissions are measured with 3-mm-thick Schott BG-39 and one, 3-mm-thick Corning 7-59 glass filters that blocks >90% luminescence emitted below 390 nm and above 490 nm in front of the photomultiplier tube.

[b]U ,Th and K_20 determined by ICP-MS, Activation Laboratory Ltd., Ontario.

[c] Cosmic dose rate component from Prescott and Hutton (1993).

[d]All errors are at one sigma and ages are calculated from AD 2010. Analyses preformed by Luminescence Dating Research Laboratory, Dept. of Earth & Environmental Sciences, Univ. of Illinois-Chicago.

[e]Sample tube 60% full; mixing of light and unlight exposed sediments; spurious younger age.

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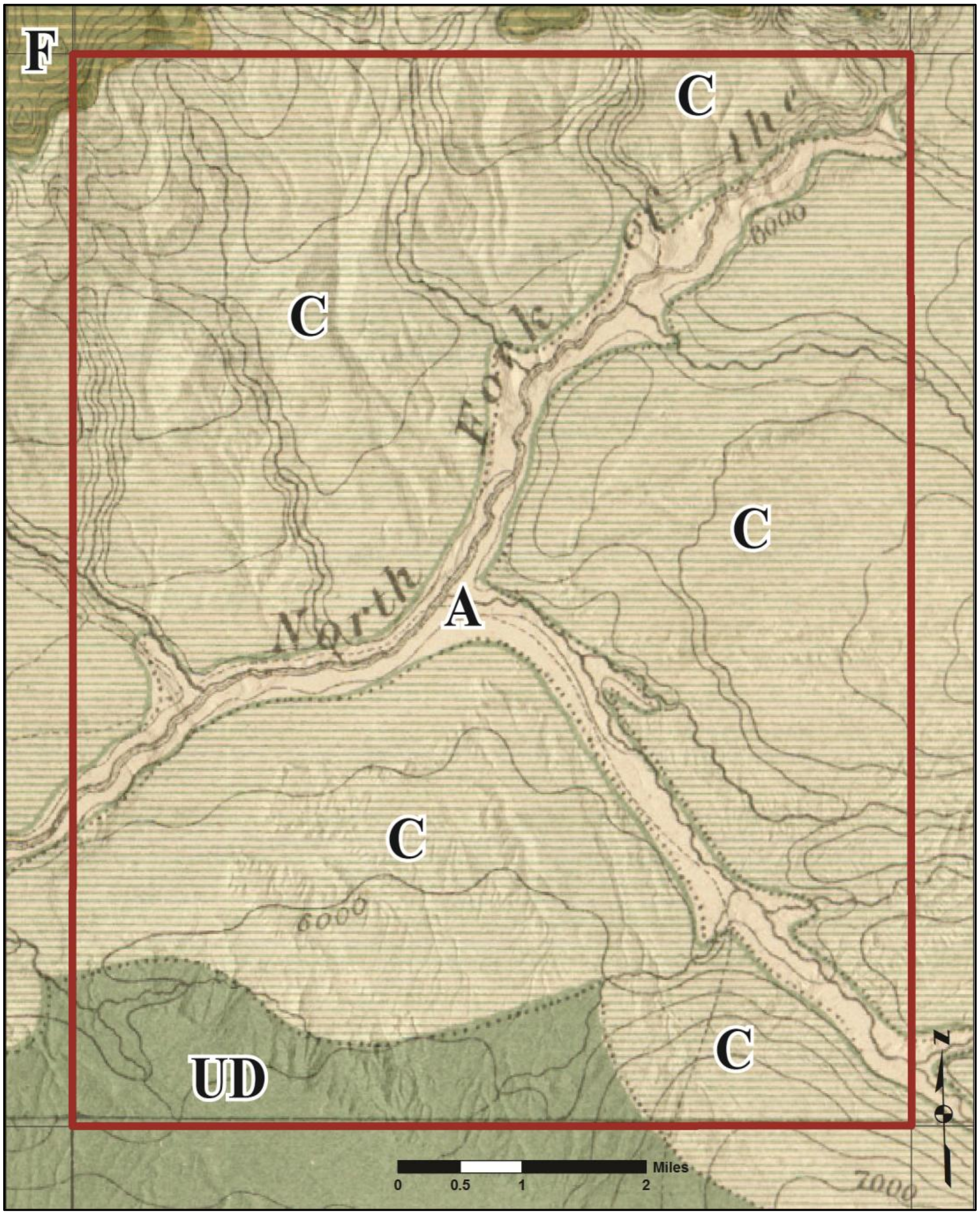
APPENDIX C

Appendix C. Fossils collected from the Hotchkiss 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 Hotchkiss quadrangle by the CGS mapping crew during the 2012 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 general identification of the fossil species, with additional identification provided by Dr. Stephen Hook, Atarque Geologic Consulting, Socorro NM, and Dr. Irek Walaszczyk, University of Warsaw. K.C. McKinney, USGS, 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.



Back Cover. The first geologic map of the Hotchkiss 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 Hotchkiss quadrangle. The map units are as follows:

A	Alluvium (Quaternary)	**C**	Colorado (Niobrara-Fort Benton) (Cretaceous)
F	Fox Hills-Fort Pierre (Cretaceous)	**UD**	Upper Dakota (Cretaceous)