Description of Map Units for Lazear Quadrangle

Accompanies Geologic Map of the Lazear Quadrangle, Delta County, Colorado
Open-File Report OF 15-08

by David C. Noe, Zachary D. Logan, Kevin J. McCall, and Geoffrey W. Warden
2015

This mapping project was funded jointly by the Colorado Geological Survey
and the U.S. Geological Survey through the National Cooperative Geologic Mapping
Program under STATEMAP agreement numbers G10AC00410 and G11AC20250

DESCRIPTION OF MAP UNITS

Note: this booklet contains abbreviated descriptions of the surficial deposits and bedrock units. For more detailed descriptions, see the booklets produced by CGS for the geologic maps of the adjacent Orchard City and Hotchkiss quadrangles (Noe and Zawaski, 2013; Noe and Rodgers, 2014).

Unit Symbol

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af **Artificial fill (late Holocene)** — Gravel, sand, silt, clay, and rock or concrete debris emplaced to construct dams, embankments, or other human-made structures. Fills may be engineered (built with controlled compaction) or completely uncontrolled. Their compositions and properties are varied. Thickness is typically less than 20 feet.

dr **Disturbed and/or reclaimed ground (late Holocene)** — Disturbed land includes areas such as surface gravel pits or other large excavations, and associated stockpiled or spoil materials. Reclaimed areas are covered with fill or overburden materials that consist of gravel, sand, silt, clay, or rock debris, similar to unit **af**. Thickness of fill, overburden, stockpiled, or spoil materials is typically less than 20 feet.

ALLUVIAL DEPOSITS

Alluvial Deposits of the Gunnison River

Qag_{1a} **Alluvium one-a of the Gunnison River (Holocene)** —
Qag_{1b} **Alluvium one-b of the Gunnison River (Holocene to late Pleistocene)** —
Qag_{2} **Alluvium two of the Gunnison River (late Pleistocene)** —
Qag_{3} **Alluvium three of the Gunnison River (late Pleistocene)** —
Qag_{4} **Alluvium four of the Gunnison River (late middle Pleistocene)** —
Qag_{5} **Alluvium five of the Gunnison River (late middle Pleistocene)** —

Qag_6 **Alluvium six of the Gunnison River (middle Pleistocene)** —
Qag_7 **Alluvium seven of the Gunnison River (early middle Pleistocene)** —
Qag_8 **Alluvium eight of the Gunnison River (early? Pleistocene)** —
Tag_9 **Alluvium nine of the Gunnison River (late Pliocene?)** —
Tag_{10} **Alluvium ten of the Gunnison River (late Pliocene?)** —
Qag **Alluvial deposits of the Gunnison River, undifferentiated (Pleistocene)** —
Gravel, sand, silt, and clay deposited by the Gunnison River. The younger deposits comprise the active flood plain (**Qag_{1a}**) and flood terrace (**Qag_{1b}**) of the modern Gunnison River. Several levels of older deposits (**Qag_2** to **Qag_{10}**) are present as alluvial terraces that increase in age with increasing height, at approximately 20 to 900 feet higher than the modern river. All of the major terraces are associated with Pleistocene glacial episodes (Sinnock, 1978). Gunnison River gravel deposits consist of well-rounded, discoid to oval pebbles, cobbles, and rare small boulders up to 2 feet long. The gravel clasts are typically encased within a coarse sand matrix. Overbank deposits, where present, consist of mixed sand, silt, and minor clay. The silt may be alluvial and/or eolian in origin. In **Qag_6** and older deposits, the gravel clasts are composed of gneiss, schist, amphibolite, and andesitic and rhyolitic tuffs, with lesser amounts of pegmatite, granite, monzonite or granodiorite porphyry, quartzite, and sandstone. Those gravels were sourced through the Black Canyon of the Gunnison River. In **Qag_5** and younger deposits that are downstream from Pleasure Park, the gravels contain a significant amount of basalt, monzonite porphyry, and minor hornfels and low-grade quartzite, in addition to the Black Canyon-sourced clasts. This change in composition marks the capture of the North Fork Gunnison River and the establishment of a new confluence of the rivers at Pleasure Park. Sandoval (2009), using cosmogenic burial dating, found the gravels in a **Qag_7** terrace to the southwest of Pleasure Park to be approximately 1 million years (ma) in age. In the **Qamf** mud fan deposit that overlies that particular terrace, we found a volcanic ash layer; age dating of the ash was not successful, but we suggest that it could be the Lava Creek B ash, which is 0.64 Ma. Thickness of the alluvial deposits in the modern flood plain and older Pleistocene terraces ranges from 15 to 100 feet.

Alluvial Deposits of the North Fork Gunnison River

Qan_{1a} **Alluvium one-a of the North Fork Gunnison River (Holocene)** —
Qan_{1b} **Alluvium one-b of the North Fork Gunnison River (Holocene to late Pleistocene)** —
Qan_2 **Alluvium two of the North Fork Gunnison River (late Pleistocene)** —
Qan_3 **Alluvium three of the North Fork Gunnison River (late Pleistocene)** —
Qan_4 **Alluvium four of the North Fork Gunnison River (late middle Pleistocene)** —
Qan_5 **Alluvium five of the North Fork Gunnison River (late middle Pleistocene)** —
Qan_6 **Alluvium six of the North Fork Gunnison River (middle Pleistocene)** —
Qan_7 **Alluvium seven of the North Fork Gunnison River (early middle Pleistocene)** —
Qan_8 **Alluvium eight of the North Fork Gunnison River (early? Pleistocene)** —
Tan_9 **Alluvium nine of the North Fork Gunnison River (late Pliocene?)** —
Tan_{10} **Alluvium ten of the North Fork Gunnison River (late Pliocene?)** —
Qan **Alluvial deposits of the North Fork Gunnison River, undifferentiated (Pleistocene)** —
Gravel, sand, silt, and clay deposited by the North Fork Gunnison River. The younger deposits comprise the active flood plain (**Qan_{1a}**) and flood terrace (**Qan_{1b}**) of the modern North Fork Gunnison River. Several levels of older deposits (**Qan_2** to **Qan_{10}**) are present as alluvial terraces that increase in age with increasing height, at approximately 20 to 2000 feet higher than the modern river. All of the major terraces are associated with Pleistocene glacial episodes (Sinnock, 1978). Many of them are overlain by thick deposits of bouldery, alluvial fan gravel (**Qg**-series). North Fork Gunnison River alluvial deposits are similar to Gunnison River alluvial deposits except that the gravel clasts are composed primarily of basalt, monzonite or granodiorite porphyry, and minor hornfels and low-grade quartzite. Deposits **Qan_2** to **Qan_5** are age equivalent with, and merge into like-numbered Gunnison River deposits in the vicinity of the Pleasure Park confluence. Deposits **Qan_6** to **Qan_{10}** are completely separate, aerially, from the Gunnison River deposits. Their distributions show that the North Fork followed its own river valleys prior to being captured and routed to Pleasure Park. Deposits **Qan_6** and **Qan_7** are probably time equivalent to Gunnison River deposits **Qag_6** and **Qag_7**. The oldest deposits (**Qan_9** and **Qan_{10}**) were thought to be Pliocene in age by Cole and Sexton (1981), based on landscape position. Thickness of the alluvial deposits in the modern flood plain and older Pleistocene and Pliocene terraces ranges from 10 to possibly more than 50 feet.

Qa **Alluvial deposits along tributary streams (Holocene to late Pleistocene)** — Light- to dark-gray to grayish-purple, poorly to moderately sorted, poorly consolidated, sand, gravel, silt, and clay, comprising the modern flood plain of perennial tributary streams. The flood plain consists of active, low-sinuosity to meandering channels; poorly sorted, sandy to gravelly channel deposits; and finer-grained over bank deposits. The unit may include colluvial deposits along the valley margins. It is sometimes partially overlain by alluvial fan (**Qf**) or landslide (**Qls**) deposits. The gravel clasts in **Qa** deposits along Currant Creek and Leroux Creek consist of basalt cobbles and pebbles, with traces of monzonite porphyry and chert. Basalt boulders up to 8 feet in length may be present, but are probably locally sourced from erosion of adjacent, older, gravel-capped mesas (**Qg**-series). Discontinuous, fine-grained **Qa** deposits are found on the surfaces of Cedar, Redlands, and Rogers Mesas where steams developed at the junctures of older, underlying debris flow lobes. Two of those deposits, located on the western part of Redlands Mesa, are associated with some unusual, persistent springs (see GROUNDWATER RESOURCES). Thickness is poorly known but generally less than 15 ft.

Qaao **Older alluvial deposits of Alum Creek (late to early? Pleistocene)** — Moderately sorted sand, gravel, silt, and clay in isolated, remnant terrace deposits scattered at different levels along the dip slope of Scenic Mesa. Consists of round to subround pebbles in a reddish, muddy sand matrix. The gravel clasts are composed of light greenish-gray porphyry, sandstone chips, minor hornfels, and traces of basalt and vein quartz. We interpret these to be the ancient courses of Alum Creek, which may have extended eastward to the West Elk Mountains at one time. Thickness is 5 to 15 feet.

MUD FLOW, DEBRIS FLOW, AND ALLUVIAL FAN DEPOSITS

Qamf **Alluvial, mud flow and mud fan deposits (Holocene to late Pleistocene)** — Light-gray to pale-orange, well to occasionally poorly sorted, poorly consolidated, clayey to sandy silt deposited in valley-head and valley-side alluvial fans, tributary stream valleys, and coalescing fans in local basins. The unit comprises a complex system of mud-rich fan and channel-fill deposits that may extend for miles along tributary stream reaches. **Qamf** sediments were deposited primarily by muddy debris flows with occasional input from sheetwash, hyperconcentrated flows, and water-flood flows. The deposits consist of poorly defined silt layers, typically less than an inch to a few inches thick, which record individual mud flow depositional events. Some layers show incipient soil development. Occasional lenses of muddy gravel are present, especially near the base of the unit. The gravel clasts consist of subround to angular basalt with occasional sandstone chips or reworked alluvial pebbles and cobbles. Some of the deposits have been deeply dissected by stream erosion during the late Holocene, resulting in narrow, steep-walled arroyos that are 5 to 10 feet deep along the valley bottoms. Thickness may exceed 5 feet in valley-head and valley-side areas and may exceed 15 feet along the valley reaches and in the basins.

Qamfo **Older alluvial, mud flow, and mud fan deposits (late Pleistocene)** — Composition and mode of deposition is similar to **Qamf**. The unit forms a series of dissected fans and caps a number of North Fork alluvial terraces along the western side of Rogers Mesa. Occasional lenses of muddy gravel are present in exposures within the highest-elevation deposits, near the mouth of Stingley Gulch. It is possible that some of the terrace-capping silty deposits are eolian loess. Thickness is variable, but in general ranges from 5 to more than 20 feet.

Qf **Alluvial fan deposits (Holocene)** — Light-tan to light-brown, moderately to poorly sorted, poorly consolidated, sandy silt to sandy, bouldery gravel deposited in alluvial fans at the mouths of streams and arroyos, and as fan aprons along the base of gravel- or sandstone-capped hills. The deposits typically have a fan-shaped morphology. Sediments are locally derived and are deposited primarily as sheetwash, debris flows, and hyperconcentrated flows. The deposits consist of well- to poorly defined sand, silt, and gravel layers, typically several inches thick. Stringers and lenses of stream-reworked gravel and sand may be present. Depending on source material, sandstone fragments and blocks, alluvial pebbles and cobbles, and boulders can be abundant. Thickness may locally exceed 10 feet.

Qfo **Older alluvial fan deposits (late Pleistocene)** — Composition and mode of deposition is similar to **Qf**. The **Qfo** deposits occupy a slightly higher position on the landscape and are typically not in depositional contact with the modern stream valleys. A dissected apron of older alluvial fans is present along the base of the southern face of Redlands Mesa. They rest upon the **Qan**$_6$ alluvial terrace that forms Shamrock Mesa, and show evidence for several periods of deposition during late Pleistocene time. Thickness may locally exceed 30 feet.

Qg$_1$ **Gravel deposit one (Holocene)** —
Qg$_2$ **Gravel deposit two (late Pleistocene)** —
Qg$_3$ **Gravel deposit three (late Pleistocene)** —
Qg$_4$ **Gravel deposit four (late middle Pleistocene)** —
Qg$_5$ **Gravel deposit five (late middle Pleistocene)** —
Qg$_6$ **Gravel deposit six (middle Pleistocene)** —
Qg$_7$ **Gravel deposit seven (early middle Pleistocene)** —
Qg$_8$ **Gravel deposit eight (early? Pleistocene)** —
Tg$_9$ **Gravel deposit nine (late Pliocene?)** —
Tg$_{10}$ **Gravel deposit ten (late Pliocene?)** —
Qg **Gravel deposits, undifferentiated (Pleistocene)** —

Light- to medium-brown to light-reddish-brown to grayish-purple, poorly to moderately well sorted, moderately to well-consolidated gravel, boulders, clay, silt and sand. The deposits are commonly matrix-supported, poorly sorted, poorly stratified, bouldery gravels with a muddy matrix, with occasional lenses and layers of moderately sorted sand or sandy gravel. In certain places on Redlands and Rogers Mesas, there are intervals of interstratified sand, gravelly sand, and muddy gravel. The gravel clasts are subround to subangular, well graded, and range in size from granules to cobbles. Boulders up to 12 feet long are common in the muddy, poorly stratified deposits. The gravel clasts and boulders are composed almost entirely of basalt, although sandstone blocks and pebbles of chert, iron, and calcareous oil shale are occasionally present. The sand-size materials are mostly basalt grains, with minor quartz grains. In general, the degree of weathering and presence of clayey and calcic soil development (Bt and Bk) increases with increasing age of the deposits. We interpret the deposits to be debris flows with minor alluvial deposits, associated with modern or former valley-fill or fan systems. **Qg**$_1$ deposits occur at modern stream levels. Deposits **Qg**$_2$ to **Qg**$_{10}$ typically occur as mesa- or ridge-capping deposits, approximately 40 to 2250 feet higher than the modern rivers. Each level is progressively older and higher in elevation. The thickness of **Qg**-series gravels varies even within individually mapped gravel bodies, depending on position within the fans or valley fills. The smaller gravel bodies are mostly less than 40 feet thick. Gravels in the larger fan deposits, however, may be quite thick. The Rogers Mesa mega-fan appears to be an amalgamation of deposits **Qg**$_3$, **Qg**$_4$, and **Qg**$_5$; its total thickness is 32 to 255 feet, based on subsurface well data (Watts, 2008). We measured 140 feet of basalt gravel **Qg**$_7$ at the southern (distal) edge of the Red Mesa mega-fan, on top of paleo North Fork River alluvial deposit **Qan**$_7$. Similarly, we measured 230 feet of basalt gravel **Qg**$_7$ above paleo North Fork River alluvial deposit **Qan**$_{10}$ at the southern (distal) edge of the Oak Mesa mega-fan.

Surficial gravel lag deposits (late to middle? Pleistocene) — Remnant deposits of basalt, porphyry, or sandstone gravels that are too small in extent to map as polygons. The deposits may mark the courses of former streams, or they may be eroded from other, older gravel deposits and redeposited. Thickness is typically 10 feet or less.

MASS WASTING DEPOSITS

Qls **Landslide deposits (Holocene to middle Pleistocene)** — Unsorted to moderately sorted clay, silt, sand, gravel, boulders, or angular rock fragments or blocks. The deposits record the failure of a hill slope and the down-slope movement of debris, either within an individual landslide or a larger landslide complex. The heterogeneous mixtures of 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 northern two-thirds of the quadrangle, landslides form in mesa side slopes composed of clay-rich Mancos Shale, with head scarps in Pleistocene mesa-capping gravels (**Qg**-or **Qan**-series). Smaller landslides are present within the Gunnison River gorge, on side slopes composed of clay-rich Morrison Formation, with head scarps in the Dakota Sandstone rim rock. Mesa-capping gravels or sandstone rim rock 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 10 to possibly greater than 100 feet.

Qc **Colluvial deposits (Holocene to middle Pleistocene)** — Unsorted, locally derived clay, silt, sand, gravel, and boulders, transported by water and gravity. The deposits are found generally at the base and lower part of slopes or as remnant patches of former slopes. 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 Redlands and Oak Mesas. In most cases, colluvial material has raveled onto the modern or former scarp faces, sourced by gravel deposits (**Qg**-series) that cap the mesas. Thickness is approximately 5 to 30 ft.

- - - - - - **Colluvial flatiron (Pleistocene)** — The authors mapped a small number of colluvial flatirons on the western side of Sulphur Gulch. They are shown on the map as thin, dashed, black lines. These are the remnants of colluvial deposits on the sides and ridges of gravel capped, or formerly gravel capped, shale-cored hills. The line represents a boundary between gravelly slope material (which is typically too thin to map as a colluvial deposit) and in-place shale bedrock. Thickness is less than 5 feet.

EOLIAN AND LACUSTRINE? DEPOSITS

Qel **Loess and lacustrine? deposits (Holocene to middle Pleistocene)** — Loess deposits overlie the gravel deposits on the mega-fans of Redlands and Rogers Mesas; however, we could not discern the boundaries between the units in the field for mapping purposes, and so those areas are mapped as **Qg**-series deposits. The mapped **Qel** unit refers to an unusual deposit found at the southeastern tip of Rogers Mesa. The deposits consist of medium-reddish silty clay to clayey silt to gravel-rich, sandy, clayey silt. The unit is underlain by the **Qan**$_3$ North Fork Gunnison River alluvial terrace. The uppermost alluvial gravels are unusual, in that they contain imbricated cobbles dipping at moderate angles of 35° to 45° (as opposed to typical low-angle imbrications seen elsewhere). They are overlain by either gravel-poor or and gravel-rich facies. The gravel-poor facies predominate, and consists of very weakly stratified clay and silt. The gravel-rich facies occurs near to the valley walls, and contain lenses of poorly sorted gravel and small boulders of basalt and North Fork Gunnison River alluvial rocks. Those deposits transition laterally into landslide deposits at the valley sides. A very low angle, earth-spread-type landslide is developed on the clay-rich cap of the **Qel** deposit. We interpret that a blockage of the canyon downstream (by **Qg**$_3$ debris flows across Rogers Mesa) dammed the North Fork Gunnison River canyon for a period of time, forming a short-lived lake, which we tentatively call "*Lake Hotchkiss*." The steeply imbricated alluvial deposits would be Gilbert deltas, formed in shallow standing water. As the water deepened, fine-grained sediments were deposited. (Similar, reddish deposits are found today in Paonia Reservoir, on Muddy Creek, a major tributary to the North Fork Gunnison River.) In time, the canyon blockage was breached and the lake was drained. It is possible that the deposit is capped by wind-blown loess. More study would be needed to understand this interesting deposit. Thickness is 20 to 30 feet.

MINERAL SPRING DEPOSITS

* **Limestone tufa and gypsum deposits (Holocene to late Pleistocene)** — Light-brown, roughly textured limestone or white to dark-gray gypsum. The overall form is that of a localized, shield- or mound-like sinter deposit that formed at a mineral spring seep. Beds are a few inches to a few feet thick, with indistinct to distinct bedding planes, and generally dip gently in the downhill direction. The gypsum deposits, in particular, are highly eroded and are associated with relict mineral springs.

Several active mineral springs occur along the canyon of the North Fork Gunnison River, and within Sulphur Gulch. The springs issue from Dakota Sandstone or Morrison Formation bedrock (see GROUNDWATER RESOURCES). Thickness is 5 to 15 feet.

BEDROCK UNITS

Mancos Shale (Upper Cretaceous)
We recognize seven members or sub-formations of the Mancos Shale in the quadrangle, 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. The thickness of each mapping unit is derived from geophysical logs of oil-and-gas wells to the north of the quadrangle, in the Piceance Basin.

Kmu **Mancos Shale, upper part** — Olive-gray to pale-yellowish-brown, non-calcareous, silty to sandy shale. The unit is mostly covered by surficial deposits. It is exposed in patches on the forested slopes of Oak Mesa, in the northeastern part of the quadrangle. There, we mapped a sandy interval that contains fossiliferous limestone concretions with *Baculites perplexus* ammonites and *Cataceramus subcompressus* bivalves. A new species of *Baculite* (according to W. Cobban, USGS), having oval-shaped bumps on its side instead of ribbing, was collected from this zone by the lead author. All but the uppermost 100 feet of the unit are present in the quadrangle. Overall thickness is about 1300 feet.

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 best exposed just to the east of Leroux Creek, where it has been eroded by a breach in an irrigation ditch. It contains a number of white to orange bentonite beds (0.5 to 6 inches thick), discontinuous, sometimes lenticular-shaped concretions, and abundant healed fractures. The Sharon Springs Member may influence the occurrence of several persistent ground-water springs on Redlands Mesa (see GROUNDWATER RESOURCES). The unit is about 80 to 100 feet thick.

Kmp **Prairie Canyon Member** — Light- to medium-gray to pale-yellowish-brown, silty to sandy shale. In outcrop, it weathers grayish orange to grayish yellow. This unit is mostly covered by Redlands Mesa and other surficial deposits. The Prairie Canyon Member occasionally contains small, rounded discs of very fine, bioturbated sandstone. The discs appear to be individual sand ripples that weather out of the shale. Fossils are sparse and consist of thin *Inoceramus* fragments. The upper contact is mostly covered by vegetation. The lower contact is marked by a transition from calcareous shale to noncalcareous, sandy shale. Thickness is about 1200 feet.

Kms **Smoky Hill and Fort Hays (Niobrara) Members, undivided** — These two members are age-equivalent to the Niobrara Formation of central and eastern Colorado. The Smoky Hill Member makes up most of the map unit. It 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 foot thick, and bentonite beds up to 1 inch thick. Fracture-filling seams of fibrous gypsum are present throughout the unit. The Fort Hays Member forms the basal strata of the Niobrara interval, and overlies a regional unconformity. It consists of thinly interbedded limestone, marl, and shale beds, and is about 50 feet thick. Its outcrop is distinctive in that it is whitish in color and flanked by darker shale rocks. Thickness of the undivided Smoky Hill and Fort Hays Members is about 750 to 800 feet.

Kmj **Montezuma Valley and Juana Lopez Members, undivided** — The Montezuma Valley Member is a medium- to dark-gray, shaly mudstone. The sub-unit forms hill-capping outcrops on top of the Juana Lopez hogback. The outcrops are weathered and consist of brownish-gray residuum. Light-gray limestone concretions are found in the upper 15 feet. The underlying Juana Lopez Member is medium gray to black. In outcrop, it may weather to light red to moderate reddish orange. It consists of 1- to 6-inch thick interbeds of rippled calcarenite and organic-rich shale. The calcarenite beds contain shell hash and broken 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 well exposed across the west-central map area, where it forms extensive, low-angle hogbacks. Thickness of the undivided unit is 120 to 140 feet 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. 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.

Kmbc **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. The zone is typically deeply weathered to residuum. 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. The authors collected *Pycnodonte aff. P. newberryi* oysters from the contact zone between the two subunits. This unit is included with unit **Kmg** in the cross section on **Plate 2**. 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. The members are nonfossiliferous in the Lazear quadrangle, and we could not distinguish a contact between them in the field. Thickness is 90 to 120 ft.

Kmow **Mowry Shale (Upper Cretaceous)** — Dark- to medium-gray, clayey to silty shale with thin interbeds of tan siltstone and very fine-grained sandstone. Bedding thickness is on the scale of millimeters to a few inches. It is a transitional unit between the Dakota Sandstone and Mancos Shale. It occurs around the rims of the Gunnison and North Fork Gunnison gorges, and in patches on the Dakota Sandstone dip slope. It is sometimes preserved beneath remnant alluvial gravel deposits. This member is included with unit **Kdb** in the cross section on Plate 2. Thickness is 40 to 50 feet.

Kdb **Dakota Sandstone and Burro Canyon Formation, undivided (Upper and Lower Cretaceous)** — The Dakota Sandstone consists of interbedded shale and sandstone. The upper part contains mostly pale-yellowish-brown marine shale with thin zones or lenses of light brown, very fine to fine grained, well-cemented, rippled to hummocky cross-stratified sandstone. In some places, there are thick, discontinuous channel deposits consisting of rippled, bidirectional, trough cross-bedded sandstone, which we interpret to be tidal inlet channels. The lower part contains lenticular to tabular bodies of moderately to well cemented, fine to medium grained sandstone, carbonaceous shale, and coal, and is variable in thickness. Its lower contact with the Burro Canyon Formation is unconformable. The Burro Canyon Formation contains lenticular bodies of light-gray to pale-orange to light-greenish-gray, chert-pebble conglomerate, conglomeratic sandstone, sandstone, and minor shale. It is highly variable in thickness. The thickness of the undivided unit varies from 150 to 220 feet.

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 light greenish-gray to grayish-purple, noncalcareous shale with occasional lenses of light- to moderate-brown sandstone. The sandstone is moderately to well cemented. The more friable sandstone appears to be clay cemented. The Salt Wash Member is similar to the Brushy Basin Member, but it contains more abundant lenticular sandstone bodies. There are occasional lenses of conglomerate in the Brushy Basin and Salt Wash Members (including the distinctive "Christmas conglomerate," made known to the authors by Dr. Rex Cole, Colorado Mesa University, which contains red and green chert pebbles). The Tidwell Member contains beds of tan, gypsiferous shale, gypsum, and tabular to lenticular sandstone. The Morrison Formation is exposed in the steep lower slopes of the Gunnison River Gorge and its tributary gulches, and in the canyon of the North Fork Gunnison River. The undivided formation is 660 to 690 feet thick.

Jwe **Wanakah Formation and Entrada Sandstone, undivided (Middle Jurassic) —** The Wanakah Formation contains relatively laterally continuous beds of shale, gypsum, thinly bedded sandstone, and minor limestone. The Entrada Sandstone consists of very fine to fine grained, well to moderately cemented sandstone with eolian cross bedding, horizontal planar bedding, and massive fabrics. It is the oldest sedimentary formation in the area. We mapped these formations at the bottom of the Gunnison River gorge, at the south end of the quadrangle. There, they are mostly covered by landslides. The thickness of the undivided unit is 120 to 150 feet.

pC **Precambrian Rocks (Proterozoic)** — Shown on cross section only. The Precambrian crystalline basement rocks of the Gunnison Uplift include mica schist, quartzitic and migmatitic gneiss, amphibolite, granodiorite, and pegmatite. The top of the Precambrian surface, which is overlain by unit **Jwe**, is a major nonconformity.

STRUCTURAL GEOLOGY

Based on our field measurements, the regional dip of sedimentary strata in the Lazear quadrangle is at gentle angles, typically less than 10°, toward the northwest, north, and northeast. This marks the regional tilting of the Gunnison uplift in the southern part of the quadrangle, which is reflected in the dip slope of the Dakota Sandstone (**Kdb**). In the northern two-thirds of the map, Mancos Shale strata with similar dips occupy the transition from the Gunnison uplift to the Piceance Basin to the north. These features were formed during the Laramide orogeny, during Late Cretaceous to Early Tertiary time (Hansen, 1965; Dickinson and others, 1988). The regional dip is interrupted in places by small, monoclinal folds or paired anticlines and synclines that downwarp the Dakota Sandstone dip slope to the north or northeast. The folds are curvilinear and are oriented obliquely to the dip slope, and to each other. The folds are beautifully exposed in the walls of the Gunnison River gorge and the North Fork Gunnison River canyon. One of these folds, an anticline-syncline pair, is shown in **Cross Section A-A'** (**Plate 2**) as a down-to-the-south fold. The authors did not recognize any mappable faults during our field work. Although the brittle rock of the Dakota Sandstone shows conjugate shears associated with folding, those rocks are not faulted. 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. Few strike and dip readings were recorded in the northern two-thirds of the quadrangle, particularly north of the Gunnison and North Fork Gunnison Rivers. This is due in part to deep weathering of the shale, resulting in thick, residual soil cover and deformation of the primary bedding planes by downhill creep. Also, the shale there is mostly hidden beneath Quaternary gravels, landslides, and colluvium.

MINERAL RESOURCES

Despite an abundance of gravel deposits in the Lazear quadrangle, there are no active sand and gravel pits. There are two pits with terminated permits that produced from alluvial gravel terraces, one in a **Qag$_6$** deposit to the northwest of Pleasure Park and one in **Qan$_6$** in the northwestern corner of Rogers

Mesa, and seven older gravel or borrow pits scattered around Redlands and Rogers Mesas (Guilinger and Keller, 2002; Keller and others, 2002; Colorado Division of Reclamation, Mining and Safety, 2011). Two types of gravel were mined: river-rounded cobbles and pebbles with sand matrix from the **Qag**- and **Qan**-series alluvial deposits, and bouldery basalt gravels with muddy matrix from **Qg**-series debris flow deposits. Historically, sulphur was mined near the mouths of Sulphur Gulch and Alum Creek (Keller and others, 2002), from areas associated with mineral springs. Seven oil-and-gas wells have been drilled in the quadrangle (Colorado Oil and Gas Conservation Commission, 2012; Fitzgerald and others, 2014), near Sulphur Gulch and on Redlands Mesa. All are listed as drilled and abandoned or plugged and abandoned. Historic, potential target formations in the region included the Dakota Sandstone (part of **Kdb**) and the Entrada Sandstone (part of **Jwe**). Current oil and gas exploration activity in western Colorado focuses on the Niobrara-equivalent interval of the Mancos Shale (**Kms**). Horizontal drilling is being used to test calcareous, brittle, fractured strata. Unit **Kms** forms surface outcrops across the central part of the map area. It is erosionally removed from the southern part of the map. It extends into the subsurface and is overlain by 0 to 1800 feet of shale strata on Redlands Mesa in the northwestern part of the quadrangle (see **Cross Section A-A', Plate 2**), and by up to 2500 feet of shale at the southwestern corner of Oak Mesa.

GROUNDWATER RESOURCES

There are 230 groundwater wells in the Lazear quadrangle, which are permitted for domestic, household, irrigation, and commercial use (Colorado Division of Water Resources, 2011). A majority of the wells are drilled on Rogers Mesa (116 wells), Redlands Mesa (59), or in the Leroux Creek valley (37), in gravels of late to middle Pleistocene age (**Qg$_3$**, **Qg$_4$**, and **Qg$_7$**). The wells vary considerably in depth, from 5 to over 250 feet. This probably reflects the great thickness and internal variability of those gravel deposits. The groundwater system in the mesas is significantly charged by infiltration of surface water from irrigation ditches, including the Fire Mountain Canal and Highline Ditch (Rogers Mesa and Leroux Creek valley) and Overland Canal and Stull and Durkee Ditches (Redlands Mesa).

From field observations, we surmise that the permeability of the gravel deposits may vary considerably, both with depth and laterally. The mesas contain abundant, clay-matrix debris flow deposits having relatively low permeability. In places, they also contain basal alluvial-terrace deposits and fairways of tributary outwash deposits, both having high permeability. On Rogers Mesa, three different ages of debris flow and alluvial fan deposits (**Qg$_3$**, **Qg$_4$**, and **Qg$_5$**) have amalgamated to form a mega-fan feature, with the younger deposits partially eroding the older deposits. As a result of this considerable heterogeneity of facies and ages of deposits, there appears to be differential water movement beneath the mesas. The underground flows are funneled into certain pathways, which discharge at the mesa edges to high-volume springs such as Tommy Dowell Spring on Rogers Mesa, or as seep-driven landslides on both mesas.

Rogers Mesa features two subsurface-water-flow gradients. Groundwater in the surficial, mega-fan deposits (**Qg**-series) flows radially to the southeast, south, and southwest, toward the distal edges of the fan. Groundwater in the basal alluvial deposits (**Qan**-series), however, flows toward the west into Allen Gulch, following the gradient of former courses of the North Fork Gunnison River. In the west-central part of Redlands Mesa, numerous perpetual springs are locate around two shallow valleys. We interpret that the valleys occupy the sites of former shale hills that have eroded away to a lower elevation than the flanking **Qg$_7$** gravels. The springs formed because groundwater flows from upgradient are constricted around the former hills and squeezed into a smaller gravel volume, forcing spring discharge at the edges of the gravel deposit. Another possible influence is the presence of the Sharon Springs Member of the Mancos Shale, which we have projected through the area, dipping at a shallow angle to the north. The Sharon Springs serves as a low-permeability confining unit. Its presence would further constrict and perch the groundwater flows in the vicinity of the springs. A groundwater sustainability study for Rogers Mesa is available (Watts, 2008), but it does not consider the heterogeneity of the mesa deposits and the associated effects on funneling the subsurface flows.

The geochemistry of groundwater associated with mineral spring deposits in Sulphur Gulch and at Doughty Springs, in the North Fork Gunnison River canyon at its eastern, upstream end, were studied by Headden (1905) and Cadigan and others (1976). They found that groundwater from mineral springs contains elevated amounts of calcium carbonate, salt and sulphur precipitates, occasional iron precipitates, and minor sodium, lithium, boron, mercury, molybdenum, arsenic, beryllium, and boron. Additionally, 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. They 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. They 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, possibly located in the subsurface roughly in the vicinity of Hotchkiss to Paonia.

GEOLOGIC HAZARDS

Geologic hazards are natural processes that can cause damage to buildings, roads, and other infrastructure, often with accompanying ground movements or failures. Human activities can greatly amplify the hazard in many cases. This geologic map may be used to anticipate particular hazards, but in all cases, site-specific geotechnical studies are recommended so that potential hazards may be recognized and mitigated. Stream flooding may occur along the modern Gunnison River and North Fork Gunnison River flood plains (**Qag_{1a}**, **Qag_{1b}**, **Qan_{1a}**, and **Qan_{1b}**). Stream flooding, mud and debris flows, and ground settlement from soil hydrocompaction or dispersion may occur along the tributary stream washes and in alluvial fans (**Qa**, **Qamf**, **Qf**, **Qfo**, and **Qg_1**). All of the Mancos Shale units contain expansive bedrock, with units **Kmg**, **Kmb**, **Kms** and **Kmss** having the highest potential for swelling and ground heaving. Surficial deposits derived from Mancos Shale, particularly **Qamf** and **Qamfo**, may contain expansive soils. For more information about expansive soil and bedrock and collapsible soil, see Noe (2007) and White and Greenman (2008). All landslide and colluvial deposits (**Qls** and **Qc**) should be considered as potentially unstable. Steep slopes on the sides of mesas may be prone to landslide failures or rockfalls, especially in slopes where the Mancos Shale is overlain by permeable, groundwater-bearing, Quaternary gravel deposits.

ACKNOWLEDGEMENTS

The authors wish to thank the following individuals and entities for land access, information, and assistance in support of our geologic mapping of the Lazear quadrangle: Lance and Anna Hanson, John Hawkins and Lawrence McKendrick, Stan Adams, Thomas Gray, Carma Newton, Wind Clearwater, Lance Swigart, Thomas Alvey, Nellie Smith, the Salinas family, Robert Jordan, Evelyn Waitman, Ross Allen, William Day, Marvin White, Joseph Wells, Harold Matteson, Peter Blake, Marina Beadleston, Alvin Williams, John Stroh, Eugenia and Kevin Bone, Mat Turnbull, Mick Cotton, Colorado Department of Natural Resources, Colorado West Gun Club, Durkee Ditch Company (Louis Bridges) and Fire Mountain Canal Ditch Company. Bill Cobban (USGS) provided identification of marine invertebrate fossils that we collected, and K.C. McKinney (USGS) curated the fossils into the USGS Cretaceous Western Interior Seaway (CWIS) collection. Karen Tucker (USBLM Uncompahgre Field Office) served as our liaison for work on Bureau of Land Management public lands. John Keller (Colorado Geological Survey) provided peer a review of the map materials. Caitlin Bernier and David Barnett (Pangaea Geospatial) provided GIS and cartographic support for creating the map plates. Larry Scott (CGS) assisted with creating the 3-D map image.

REFERENCES

Cadigan, R.A., Felmlee, J.K., and Rosholt, J.N., 1976, Radioactive mineral springs in Delta County, Colorado: U.S. Geological Survey Open-File Report 76-223, 39 p.

Cole, R.D., and Sexton, J.L., 1981, Pleistocene surficial deposits of the Grand Mesa area, Colorado, *in* Epis, R.C., and Callender, J.F., eds., Western Slope Colorado: New Mexico Geological Society Guidebook, 32nd Field Conference, p. 121-126.

Colorado Division of Mining, Reclamation and Safety, 2011, Shapefile for mining permits: GIS data provided by CDRMS.

Colorado Division of Water Resources, 2011, Shapefile for water well applications and permits: GIS data provided by CDWR.

Colorado Oil and Gas Conservation Commission, 2012, Shapefile for oil and gas well permits: GIS data provided by COGCC.

Dickinson, W. R., Klute, M.A., Hayes, M.J., Janecke, S.U., Lundin, E.R., McKittrick, M.A., and Olivares, M.D., 1988, Paleogeographic and paleotectonic setting of Laramide sedimentary basins in the central Rocky Mountain region: Geological Society of America Bulletin, v. 100, p. 1023-1039.

Fitzgerald, S., Eisinger, C., and Milne, J.J., 2014, Oil and gas wells map of Colorado, through March 31, 2014: Colorado Geological Survey Map Series 44, 1 sheet, scale 1:500,000.

Guilinger, J.R., and Keller, J.W., 2004, Directory of active and permitted mines in Colorado – 2002: Colorado Geological Survey Information Series 68, CD-ROM.

Hansen, W.R., 1965, The Black Canyon of the Gunnison – today and yesterday: US Geological Survey Bulletin 1191, 76 p.

Headden, W.P., 1909, Notes on some mineral springs: Proceedings of the Colorado Scientific Society, Vol. IX, p. 259-272.

Keller, J.W., Phillips, R.C., Morgan, K., 2002, Digital inventory of industrial mineral mines and mine permit locations in Colorado: Colorado Geological Survey Information Series 62, CD-ROM.

Leckie, R.M., Kirkland, J.I., and Elder, W.P., 1997, Stratigraphic framework and correlation of a principal reference section of the Mancos Shale (Upper Cretaceous), Mesa Verde, Colorado: New Mexico Geological Society Guidebook 48, p. 163-216.

Merewether, E.A., and Cobban, W.A., 1986, Biostratigraphic units and tectonism in the mid-Cretaceous foreland of Wyoming, Colorado, and adjacent areas, *in* Peterson, J.A., ed., Paleotectonics and sedimentation in the Rocky Mountain region, U.S.: American Association of Petroleum Geologists Memoir 41, p. 443-468.

Morgan, M.L., Noe, D.C., White, J.L, and Townley, S.M., 2008, Geologic map of the Delta quadrangle, Delta and Montrose Counties, Colorado: Colorado Geological Survey Open-File Report 08-02, 59 p., scale 1:24,000.

Noe, D.C., 2007, A guide to swelling soil for Colorado homebuyers and homeowners, second edition: Colorado Geological Survey Special Publication 43, 52 p.

Noe, D.C., and Rodgers, E.L., 2014, Geologic map of the Hotchkiss quadrangle, Delta County, Colorado: Colorado Geological Survey Open-File Report 14-15, 41 p., scale 1:24,000.

Noe, D.C., and Zawaski, M.J., 2013, Orchard City quadrangle geologic map, Delta County, Colorado: Colorado Geological Survey Open-File Report 13-05, 40 p., scale 1:24,000.

Sinnock, S., 1978, Geomorphology of the Uncompahgre Plateau and Grand Valley, western Colorado, U.S.A.: Ph.D. dissertation, West Lafayette, Indiana, Purdue University, 196 p.

Sandoval, M.M., 2009, Quaternary incision history of the Black Canyon on the Gunnison, Colorado: Albuquerque, University of New Mexico, master's thesis, 96 p.

Watts, K.R., 2008, Availability, sustainability, and suitability of ground water, Rogers Mesa, Delta County, Colorado – types of analyses and data for use in subdivision water-supply reports: US Geological Survey Scientific Investigations Report 2008-5020, 53 p.

White, J.L., and Greenman, C.A., 2008, Collapsible soils in Colorado: Colorado Geological Survey, Engineering Geology 14, 108 p.