Mapped, edited, and published by the Geological Survey

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Topography by photogrammetric methods from aerial photographs taken 1964. Southwest portion copied from U. S. Bureau of Reclamation mapping 1965
Field checked 1965

Polyconic projection. 1927 North American datum
10,000-foot grids based on Colorado coordinate system, central and south zones
1000-meter Universal Transverse Mercator grid ticks, zone 13, shown in blue

Fine red dashed lines indicate selected fence lines

There may be private inholdings within the boundaries of the National or State reservations shown on this map

UTM GRID AND 1979 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

Revisions shown in purple compiled from aerial photographs taken 1976 and other source data. This information not field checked. Map edited 1979

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

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 number G14AC00220

QUADRANGLE LOCATION

1	2	3
4		5
6	7	8

1 Hotchkiss
2 Paonia
3 Minnesota Pass
4 Grand View Mesa
5 Mount Guero
6 Grizzly Ridge
7 Cathedral Peak
8 X Lazy F Ranch

ADJOINING 7.5' QUADRANGLES

Geology mapped in 2014
Cartography by Karen Morgan,
Colorado Geological Survey

GEOLOGIC MAP OF THE CRAWFORD QUADRANGLE, DELTA AND MONTROSE COUNTIES, COLORADO

By David C. Noe and Alexander T. Klink
2015

DESCRIPTION OF MAP UNITS
SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af — **Artificial fill (late Holocene) —** Gravel, sand, silt, clay, and rock or concrete debris placed 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

Qa — **Alluvial deposits (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 floodplain of perennial tributary streams. The floodplain consists of active, low-sinuosity, poorly sorted sandy to gravelly channel deposits, and finer-grained overbank deposits. The unit may include colluvial deposits along the valley margins. It is sometimes partially overlain by alluvial fan (**Qf**) or mud fan (**Qamf**) deposits. The gravel clasts in **Qa** deposits along Little Coal and Second Creeks consist primarily of monzonite porphyry. Within the canyons of the Clear Fork, Doug and Muddy Creeks, the gravel consists primarily of andesite and andesitic breccia. Smith Fork contains a mix of monzonite and andesite gravel clasts. Iron Creek, in Iron Canyon, contains a mix of andesite and sandstone gravel clasts. Thickness is poorly known but generally less than 15 ft.

Qao — **Older alluvial deposits (late to middle? Pleistocene) —** Light- to dark-gray to grayish-purple, poorly to moderately sorted, well-consolidated gravel, sand, silt, clay, and minor boulders in stream terrace deposits approximately 20 to more than 800 feet higher than the modern streams. There are at least 10 levels of relict river terraces, with older deposits occurring at progressively higher terrace elevations. In general, the degree of weathering and presence of clayey and calcic soil development (Bt and Bk paleosol horizons) increases with increasing age of the deposits. May be overlain by older alluvial fan deposits (**Qfo**), older debris-flow gravel deposits (**Qg**-series), or may be capped by unmapped, eolian loess. In cases where it is mostly obscured by overlying deposits, we show **Qao** as a dashed red line along the exposed face of the alluvial gravel. The deposits form relatively stable building surfaces, and are potential sources of sand and gravel. Average thickness of the deposits within each terrace level varies from 10 to 20 feet. An unusually thick (100+ feet) gravel deposit caps the flat hill to the west of Crawford Dam. This deposit contains mostly monzonite porphyry gravel clasts on its north side, and mostly andesite clasts on its south side. It appears to be the confluence between two different stream systems during a period of glacial outwash runoff. Relict deposits associated with the former courses of Iron Creek are strewn across the gentle, upper slopes of Fruitland Mesa in the southwestern part of the quadrangle.

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 deposits comprise a complex system of 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 monzonite porphyry, andesite, or sandstone. Areas mapped as **Qamf** may be subject to future flash floods and mud flow events, especially in non-incised areas, and within the deeply dissected modern arroyo channels. The deposits may be prone to significant collapse from dispersion, hydrocompaction, or slope failure when wetted or loaded. Thickness may exceed 5 feet in thickness in valley-head and valley-side areas and may exceed 15 feet along the valley reaches and in the basins. 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.

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 poorly formed terrace deposits on the tops or flanks of low hills, primarily within the south-central part of the quadrangle. The deposits increase in age at progressively higher terrace elevations. We interpret that they are remnants of former mud fans and valley fills that have been mostly eroded away. The deposits occupied paleo-stream valleys and basins that are no longer in depositional contact with modern drainages. They are now inverted, positive features in the landscape. Some of the deposits contain concentrations of basal gravel, consisting in most cases of subround to angular andesite pebbles and cobbles. The deposits may be prone to collapse from dispersion, hydrocompaction, or slope failure when wetted or loaded. Thickness is variable, but in general ranges from 5 to more than 15 feet.

Qf — **Alluvial fan deposits (Holocene) —** Reddish-brown to light-brown, well-sorted to locally poorly sorted, poorly consolidated, sandy silt to sandy bouldery gravel deposited in alluvial fans at the mouths of streams, and as fan aprons along the base of 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, which record individual depositional events. Stringers and lenses of locally reworked gravel and sand may be present. Depending on source material, cobbles and boulders can be abundant. Areas mapped as alluvial fans are subject to future flash floods and debris flow events. The deposits may be prone to significant collapse from dispersion, hydrocompaction, or slope failure when wetted or loaded. 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. Thickness may locally exceed 10 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 (middle Pleistocene) —**
Qg_5 — **Gravel deposit five (middle Pleistocene) —**
Qgo — **Older gravel deposits (late to middle? Pleistocene) —**
Light- to medium-brown to light-reddish-brown to grayish-purple, poorly to moderately sorted, moderately to well-consolidated gravel, boulders, clay, silt and sand. The deposits are commonly matrix-supported gravels with a muddy matrix, with occasional lenses and layers of moderately sorted sand or sandy gravel. We interpret them to be debris flow deposits with minor alluvial deposits, associated with modern or former valley-fill or fan systems, or as rock-avalanche deposits on high benches surrounding steep-sided laccoliths. **Qg_1** deposits occur at modern stream levels. The older **Qg**-series deposits typically occur as mesa- or ridge-capping deposits, approximately 20 to 600 feet higher than the modern streams. Deposits **Qg_2** to **Qg_5** are progressively older and higher in elevation and occupy similar landscape elevations as those mapped by CGS in the nearby Hotchkiss quadrangle, relative to stream terraces of the North Fork Gunnison River (Noe and Rodgers, 2014). The **Qgo** deposits are quite variable with regard to the mode of origin for each deposit. They occupy a number of different elevations and levels, but no systematic differentiation of elevation levels was attempted. **Qgo** deposits capping the chaotic, breccia-block landslide deposits (**Qlbr**) in the central and eastern parts of the quadrangle may mark locations where former streams reworked portions of the landslides. In general, the degree of weathering and presence of clayey and calcic soil development (Bt and Bk) increases with increasing age of the deposits. Thickness is approximately 10 to 20 feet.

Surficial gravel lag deposits (late to middle? Pleistocene) — Remnant deposits of sandstone, monzonite porphyry, or andesite 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 5 feet or less.

MASS-WASTING DEPOSITS

Qt — **Talus deposits (Holocene to late Pleistocene) —** Light- to dark-gray, angular blocks and fragments of monzonite porphyry, with a variably distributed matrix of sand-, gravel-, and silt-sized material of the same composition. The rock blocks are commonly up to 6 feet in length, but occasionally blocks of up to 20 feet in length are present. Talus cones and aprons form along the steep sides of laccolith peaks, sheets, and plugs, as composite aprons or at the mouths of rock chutes. They are primarily deposited by rockfall or snow-avalanche processes. Thickness is poorly known, but may range from 5 to 100 feet.

Qrg — **Rock glacier deposits (Holocene to late Pleistocene —** Medium-orange, angular blocks of monzonite porphyry, forming undulating surfaces with visible flow lobes. The rock blocks are commonly up to 6 feet in length. They have been roughly size-sorted by freeze-thaw processes and movements of interstitial ice. Finer matrix materials are typically not present at the surface, but may occur deeper within the deposits. The rock glaciers form at the base of talus cones, and are basically talus material that has been remobilized. The contact between the talus and rock glacier deposits is marked by a change in color and sorting. The toes of the rock glacier deposits are typically well formed, with steep, rounded, terminal slopes. It is unknown whether there is still interstitial ice remaining within the rock glaciers, or whether they are actively moving. Thickness is poorly known, but may range from 5 to 30 feet.

Qls — **Landslide deposits (Holocene to middle? Pleistocene) —** Heterogeneous deposits of unsorted to poorly sorted clay, silt, sand, gravel, and boulders. 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 reflect the properties of the local source areas. The landslide debris may contain bodies of relatively undisturbed rock or soil. In most places, the landslides show obvious geomorphic expression that disrupts the profile of the slopes. Head scarps and internal scarps (the near-vertical detachment scars exposed at the top of and internally within the landslides) are often readily recognizable, and are shown on the map. Many of the mapped scarps are inactive and have been erosionally degraded, while other scarps are distinct, sharp, and indicative of recent landslide movements. Other common diagnostic features include hummocky topography, closed depressions, sag ponds, fissures, terracettes, tension cracks, and pressure ridges. There are three main types: 1) Landslides rooted in Mancos Shale, which are abundant and widespread throughout the quadrangle and may contain very large blocks of displaced, weathered shale bedrock. 2) Landslides on Fruitland Mesa in the western part of the quadrangle, which most commonly form in Mowry Shale atop the Dakota Sandstone dip slope. 3) Younger (Holocene to late Pleistocene) landslides on stream-dissected flanks of older, breccia-block landslide deposits (**Qlbr**), which are comprised of remobilized andesitic breccia material. Landslide areas are subject to future movement during episodes of heavy rainfall or snowmelt. They may be reactivated by human-made disturbances such as cutting of slopes for roads, quarries, grading for housing developments, agricultural and household irrigation, and septic systems. Landslide deposits may be prone to settlement when loaded or wetted. The deposits may contain expansive soils where derived from shale formations. Thickness is highly variable, and typically ranges from 10 to more than 50 feet.

Qlbr — **Breccia-block landslide deposits comprised of West Elk Breccia (late to early? Pleistocene) —** Heterogeneous deposits of grayish-purple, unsorted, chaotic breccia. The breccia material consists of andesite and minor latite, as subround to angular clasts in an andesitic matrix. The deposits are derived from the West Elk Breccia (**Tbr**), which is present in extensive outcrops just to the east of the quadrangle, along Mendicant Ridge (see unit **Tbr** for more detailed rock descriptions). **Qlbr** deposits are nearly identical to **Tbr** in terms of composition and texture; however, they are located far too low in the landscape and are thus too young to be in-place West Elk Breccia deposits. We interpret that the **Qlbr** deposits were emplaced as massive landslide failures from Mendicant Ridge, which swept down and filled the existing valleys, and also as large-scale earthflow deposits within the landslide complex. It appears that huge blocks of intact breccia, up to over 1,000 feet in length, were pulled apart from each other as they were carried along with the slide movements, resulting in a block-and-gap topography. Based on landscape position of the base of the deposits, we identify possibly three episodes of large-scale failures. Subsequent erosion of the landslide complex has produced a deeply dissected landscape, including the deep canyons of Clear Fork and Doug Creek. In certain eroded exposures, we found former Mancos Shale hills and valley side-walls, all buried beneath breccia material. Some of the deposits may approach 500 feet in thickness, coincident with the deepest parts of the paleovalleys into which they flowed as landslides. Exposures of eroded and weathered **Qlbr** deposits are commonly peppered with extremely large, resistant breccia blocks, some of which can be as large as a house. Areas mapped as **Qlbr** are susceptible to landsliding and localized rockfall (blockfall) and debris avalanche events.

MINERAL SPRING DEPOSITS

Qtuf — **Limestone tufa deposits (Holocene to late Pleistocene) —** Light-brown, roughly textured limestone with indistinct to distinct bedding planes. Beds are a few inches to a few feet thick, and generally dip gently in the downhill direction. The overall form is that of a mineral spring seep and its resultant, shield- or mound-like sinter deposit. The seeps appear to be inactive. The deposits occur within landslide terrain, and are located just down-dip from a monoclinal fold. Thickness is 5 to 12 feet.

Limestone tufa deposits (Holocene to late Pleistocene) — Same as above, but the individual tufa mounds are too small in extent to map as polygons at this map scale.

Gypsum deposits (Holocene to late Pleistocene) — Localized deposits of white to light-gray gypsum forming domes and mounds upon the ground surface. The mounds are located either within landslide terrain, or in close association with a monzonite porphyry sill. There appears to be active seepage occurring at a few mounds. The individual gypsum mounds are too small in extent to map as polygons at this map scale. Thickness is 5 to 10 feet.

BEDROCK UNITS

TERTIARY IGNEOUS ROCKS

Ti — **Monzonite porphyry (Oligocene) —** Light to medium gray when fresh, medium orange to light reddish-brown to whitish when weathered, medium-grained monzonite porphyry to hornblende-rich monzonite porphyry. The rock is densely dotted with light gray to whitish and brown to black phenocrysts. The light-colored phenocrysts are plagioclase feldspar as equant to sub-equant, euhedral to irregular, broken or partially digested crystals, up to 1/8 inch in length. The dark-colored phenocrysts are primarily hornblende as elongate crystals up to 1/8 inch in length that are commonly cracked or broken, which in some samples have been partially altered to ferrous oxide compounds. There are some opaque minerals, possibly magnetite, and possibly occasional pyroxene and biotite. Quartz is exceedingly rare, and occurs as solitary, very fine grains that have a rounded form and partially digested margins. The matrix typically makes up about 60% of the rock and consists of a mixture of microcrystalline alkali feldspar and small fragments of plagioclase (based on feldspar staining of thin sections). We did not recognize quartz as a matrix component. The overall feldspar-quartz composition of the rock from several laccoliths and intrusive sheets is estimated to be 60-65% plagioclase and 35-40% alkali feldspar, with only a trace of quartz, which identifies the rock as a monzonite. One of the rock samples, from Youngs Peak, contained an abundance of alkali feldspar and could be classified as a hornblende-rich, syenite/monzonite porphyry.

The rock forms intrusive laccoliths, sheets, sills, dikes, and plugs. North and South Saddle Peak and Second Creek Ridge are laccoliths with exposed magma-body relief of 600 to 1,800 feet. They have steep sides that are draped in places by moderately dipping sedimentary rocks, which were upturned during the emplacement of the magma bodies. The Second Creek laccolith appears to have satellite sheets of intrusive rock to the south and east. Youngs Peak appears to be a small laccolith, connected to or flanked by intrusive sheets to the northwest and southeast; these sheets underlie most of the Youngs Peak massif and crop out along its edges. Needle Rock, a near-vertical, compact plug, has previously been interpreted as a conduit that was beneath a now-eroded and removed laccolith (Gaskill, 1977). However, based on our field work, we propose an alternate interpretation of Needle Rock as the crown of a buried laccolith (see **STRUCTURAL GEOLOGY** section, on Plate 2, for a more detailed description of the morphology of these laccoliths and their relationships with bounding sedimentary rocks). The intrusive sheets, sills, and dikes closely resemble the laccolith intrusions in terms of rock composition and fabric.

A notable exception occurs in **Ti** intrusions in an area of discontinuous to interconnected sills and dikes along the valley of Doug Creek. There, the intrusive rock is typically pale gray to pale yellow, and contains micro- to large-scale flow laminae that are distinguished by darker flow bands. This rock contains bimodal-sized plagioclase, as phenocrysts and very fine broken particles, an alkali feldspar matrix, and fine-grained quartz crystals. Hornblende was not observed. The darker laminae contain disaggregated particles and xenoliths of shale that have been metamorphosed to hornfels. Some of the quartz may be derived from silt grains that are abundant in the shale hornfels. Based on petrographic analysis, we classify this rock as quartz monzonite. The lowermost 3-4 feet of some of the sills contains a breccia of intrusive rock fragments within a matrix of remobilized shale hornfels. Other locations where poorly exposed sills of this type and composition are present include “Shale Hill,” a solitary point of Mancos Shale (Smoky Hill Member) along Cottonwood Creek Road, and along a fin-like hill to the west of Needle Rock. In both locations, the sills consist of a light-colored intrusive rock that has a distinctive, “shotgun-blast” fabric that incorporates disseminated shards of shale hornfels. The chaotic breccias at those locations could be classified as peperite, a rock resulting from explosive mingling of magma and country rock sediments in the subsurface.

Areas mapped as **Ti**, and areas downhill from **Ti** outcrops, may be prone to rockfall, debris avalanche, and snow avalanche hazards. Some of the rockfall chutes and talus fans may be susceptible to debris flows. The draping or bounding sedimentary rocks around these intrusions may be prone to landslide hazards.

Tbr — **West Elk Breccia (Oligocene) —** Light-purplish-red to light-brownish-purple andesite and minor amounts of light-gray latite as coarse, fragmental breccia clasts within an andesitic matrix of similar color and composition. The andesite fragments are somewhat porphyritic, with small (0.046 in - 0.078 in), euhedral to broken crystals of plagioclase and hornblende in a groundmass that is mostly plagioclase. The hornblende is often weathered and partially replaced by iron oxides. Trace amounts of pyroxene and quartz are present. The latite fragments consist of fine-grained crystals of plagioclase and hornblende in a groundmass of plagioclase and potassium feldspar. The breccia contains fragments of all sizes, from sand-sized grains to small, boulder-sized clasts to gigantic, re-transported breccia blocks that may be up to several hundred feet across in size. The individual rock pieces range from subround to angular and irregular in shape.

The West Elk Breccia forms an extensive, 4,000-foot-thick accumulation of volcaniclastic deposits to the east of the Crawford quadrangle (Gaskill, 1977). In-place **Tbr** deposits are found in only one location within the quadrangle, on a high ridge above the northeastern headwaters of Muddy Creek, where it is about 400 feet thick. This concurs with the westward extent of the West Elk Breccia as it was mapped by Gaskill (1977). Unit **Tbr** is the source for breccia-block landslide deposits (unit **Qlbr**) that occur extensively in the southeastern part of the quadrangle. Areas mapped as **Tbr**, and areas downhill from **Tbr** outcrops, may be prone to rockfall, debris avalanche, and landslide hazards.

MESOZOIC SEDIMENTARY ROCKS

Mancos Shale (Upper Cretaceous)
We recognize eleven 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. All of the members contain expansive clay minerals, to different degrees. Houses and other engineered infrastructure built on the shale may experience damaging ground-heave movements. Mancos Shale is susceptible to landsliding and other types of slope failures, especially where the shale is overlain by permeable, ground-water-bearing Quaternary deposits.

Kmu — **Mancos Shale, upper part —** Olive-gray to pale-yellowish-brown, non-calcareous, silty to sandy shale. The unit is present in a few small outcrops in the upper reaches of the Muddy Creek basin, in the southwestern part of the quadrangle. There, the unit is mostly covered by landslides. Only the lowermost 200 feet of the unit is exposed beneath a body of West Elk Breccia. Overall unit thickness (from oil-and-gas well logs to the north, in the Piceance Basin) is around 2,000 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 locally exposed in one location, in the upper part of the Muddy Creek basin. It occurs at the side of an earthflow landslide, in a slide evacuation zone. The exposure is relatively fresh and 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 bentonite beds are occasionally locally sheared and folded. The top or bottom of the unit could not be positively identified, and so the entire exposure was mapped as the Sharon Springs Member. The unit is about 100 to 120 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 crops out in the highlands around Second Creek Ridge and in the southeastern part of the quadrangle. Mostly, it is covered by landslide deposits (**Qls** and **Qlbr**). 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 *Inoceramu*s fragments. The upper contact is covered. The lower contact is marked by a transition from calcareous shale to non-calcareous, sandy shale. It is about 60 feet above the highest limestone bed in the underlying Smoky Hill Member. Thickness is about 1,000 to 1,200 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. 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. **Kms** outcrops are often covered by thin residuum. The undivided map unit is partially exposed in the middle-altitude areas of the map, where it is often covered by different landslide deposits (**Qls** and **Qlbr**). Thickness of the undivided Smoky Hill and Fort Hays Members is about 700 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. It is poorly exposed and is most often used as grassy pasture land. The outcrops are weathered and consist of brownish-gray residuum. Light-gray limestone concretions are found in the upper 15 feet. Thickness of the Montezuma Valley Member is 110 to 120 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 observed in place; they are usually strewn as a thin, colluvial cover of angular calcarenite fragments across the outcrop. The Juana Lopez Member is well- to poorly exposed across the central map area, where it forms extensive, low-angle hogbacks and dip surfaces. The Juana Lopez Member is 45 to 50 ft thick. Thickness of the undivided unit is 160 to 170 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 50 feet. The middle part is fissile shale with distinct bedding planes. The contact between the upper and middle parts contains two zones of abundant, moderate-red concretions up to 5 feet 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. The Blue Hill Member forms low benches, slopes, and ridges in the central part of the quadrangle. Along with several sheets and sills of monzonite porphyry, it forms the bulk of the Youngs Peak massif, north of the town of Crawford. Thickness of the entire unit is 160 to 200 feet.

Kml — **Mancos Shale, lower part, undivided —** This unit includes several members of the Mancos Shale that have been mapped in detail by CGS in nearby quadrangles. From youngest to oldest, they are the Fairport, Bridge Creek, and Hartland-Graneros Members. The unit contains intervals of calcareous to non-calcareous shale. Certain intervals contain calcarenite beds (Fairport) or abundant concretion horizons (Bridge Creek). The unit forms low ridges and gentle slopes. It is poorly exposed and is most often used as grassy pasture land. The thickness of the undivided unit is 200 to 250 feet.

Kdb — **Mowry Shale, Dakota Sandstone, and Burro Canyon Formation, undivided (Upper and Lower Cretaceous) —** The Mowry Shale consists of clayey to silty shale with thin interbeds of silica-cemented 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. Most of the pasture land atop Fruitland Mesa, in the western part of the study area, is in Mowry Shale that overlies the resistant Dakota dip slope. The Dakota Sandstone consists of interbedded shale and silica-cemented sandstone. The upper part contains mostly marine shale with thin zones or lenses of very fine to fine grained, rippled to hummocky cross-stratified sandstone. The lower part contains lenticular to tabular bodies of 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 chert-pebble conglomerate, conglomeratic sandstone, sandstone, and minor shale. It is highly variable in thickness. The thickness of the undivided Mowry-Dakota-Burro Canyon interval varies from 150 to 200 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 non-calcareous shale with occasional lenses of sandstone. 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 gypsiferous shale, gypsum, and tabular to lenticular sandstone. Only the uppermost 100 feet of the Brush Basin Member is exposed in the quadrangle. It occurs in Iron Canyon, in the canyon to the north of Crawford Dam, and on the eastern and northern flanks of Saddle Peak. The undivided Morrison Formation is 660 to 690 feet thick, and is shown in the cross section on Plate 2.

Jwe — **Wanakah Formation and Entrada Sandstone of the San Rafael Group, undivided (Middle Jurassic) —** Shown on cross section only. 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 sandstone with eolian cross bedding, horizontal planar bedding, and massive fabrics. It is the oldest sedimentary formation in the area. The Wanakah Formation is 45 to 55 feet thick. The Entrada Sandstone is 50 to 100 feet thick.

p€ — **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-Precambrian surface is a major nonconformity.

MAP SYMBOLS

Contact — Approximately located

U / D — **Fault —** Dashed where inferred, dotted where concealed; U on upthrown side, D on downthrown side

Anticline — Dashed where approximately located

Syncline — Dashed where approximately located

Monocline, upper fold axis

Monocline, lower fold axis

Landslide scarp — Top of scarp; tic marks point downhill

Lobe crest in landslide deposit

15 — **Strike and dip of inclined bedding —** Showing direction and angle of dip

66 — **Strike and dip of fracture sets —** Showing direction and angle of dip

50 — **Strike and dip of joint sets —** Showing direction and angle of dip

Oil/Gas well, abandoned

A —— A' — **Alignment of cross section**

A note about map shading: The map has a shaded relief underlayer that generally enhances the appearance of the topography, but can make the geologic unit colors darker or lighter in areas of steep topography.