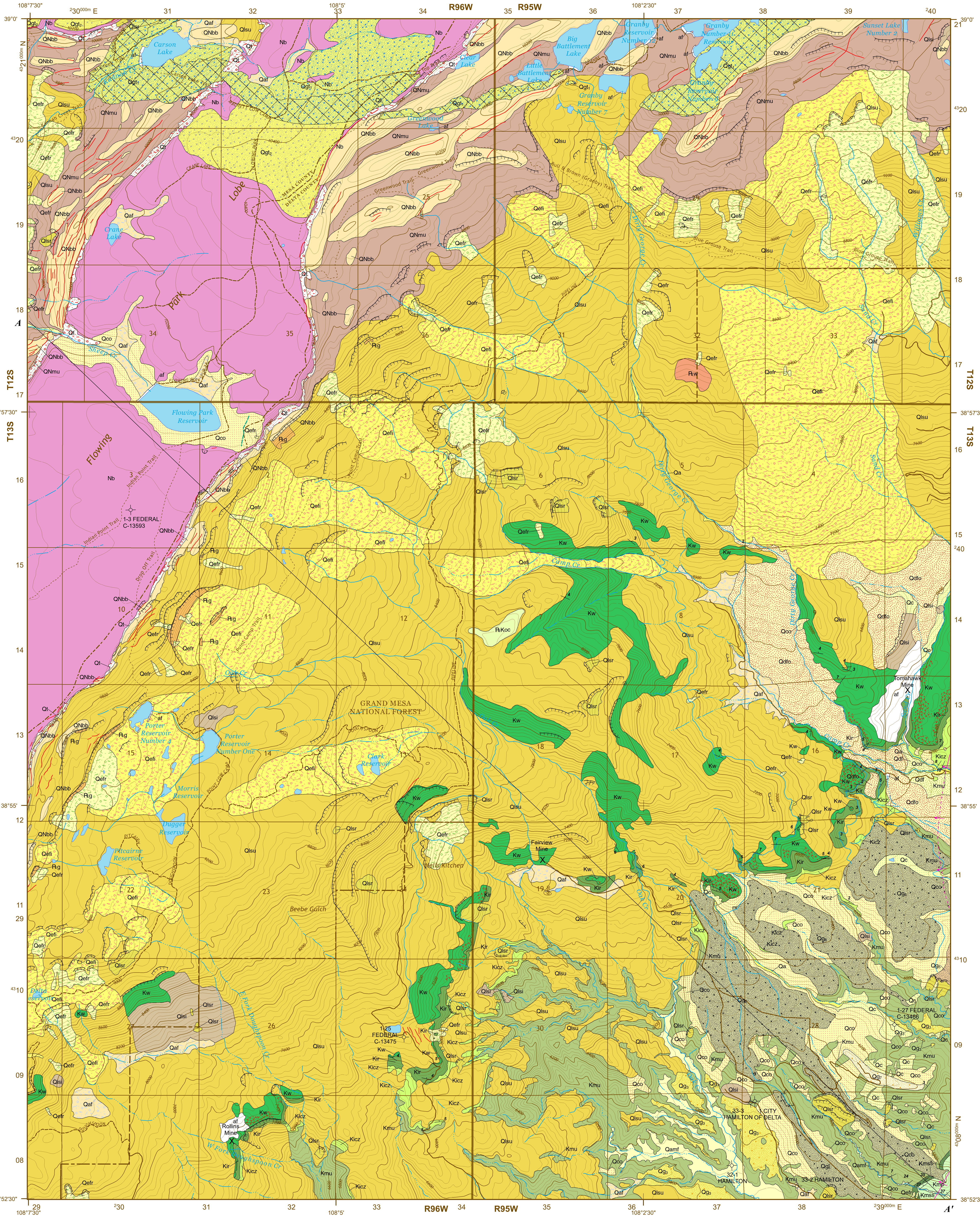

Geology mapped in 2018
GIS and cartography by Pangaea Geospatial

Coordinate System: NAD 1983 UTM Zone 13N
Projection: Transverse Mercator
Datum: North American 1983

This map is not a legal document. Boundaries may be generalized for this map scale. Private lands within government reservations may not be shown. Obtain permission before entering private lands.

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Roads............U.S.Census Bureau, 2015-2016
Roads within US Forest Service Lands........FSTopo Data with limited Forest Service updates, 2012-2016
Names............GNIS, 2016
Hydrography............National Hydrography Dataset, 2013
Contours............National Elevation Dataset, 2006
Boundaries............Multiple Sources, see metadata file, 1972-2016
Public Land Survey System............BLM, 2011

SCALE 1:24,000

1 0.5 0 KILOMETERS 1 2
1000 500 0 METERS 1000 2000
1 0.5 0 MILES 1
1000 500 0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000 FEET

CONTOUR INTERVAL 40 FEET

COLORADO
QUADRANGLE LOCATION

Lands End	Mesa Lakes	Grand Mesa
Indian Point	Hells Kitchen	Cedar-edge
Point Creek	North Delta	Orchard City

ADJOINING QUADRANGLES

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 G18AC00199.

GEOLOGIC MAP OF THE HELLS KITCHEN QUADRANGLE, MESA AND DELTA COUNTIES, COLORADO

By Jonathan L. White and Martin J. Palkovic
2019

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af — **Artificial fill (uppermost Holocene)** — Gravel, sand, silt, and clay emplaced by human activities. Artificial fills locally may include engineering material and (or) uncontrolled and unsorted fill placed for road embankments, reservoirs dams, and coal-mine reclamation sites.

ALLUVIAL DEPOSITS

Qa — **Alluvial deposits (Upper Holocene)** — Tan-gray, poorly sorted, boulder-to-pebbly gravel, sand, silt, and clay that are typically deposited by seasonal flash flooding. Subangular to rounded clasts are typically Neogene basaltic rocks (Nb unit) of the Grand Mesa Volcanic Field (GMVF), reworked from rocky debris-flow and landslide deposits. Many sandstone clasts are present in the unit where Dirty George Creek flows across exposures of Williams Fork Formation (Kw) and Rollins Sandstone (Kir). Thickness is highly variable but likely does not exceed 5 to 7 ft (1.5 to 2 m). Deposits typically occurs along the floors of many incised creek channels but the unit is too narrow (<40 ft (12 m) wide) to be mapped. Areas of this unit along creek bottoms, ravines, and channels are exposed to dangerous flash flooding.

Qaf — **Alluvium and alluvial-fan deposits (Holocene to Upper (?) Pleistocene)** — Valley-fill deposits of coalesced, tan-gray to brown-gray alluvium, alluvial-fan, and slopewash sediments. At higher altitudes, the deposit is derived from basalt regolith and glacial till, and forms a cobbly to bouldery gravel composed of angular to subangular, pockmarked, edge-worn basaltic rocks in a clayey to pebbly sand matrix. At lower elevations of the map area, the deposit is derived from older landslide deposits and clay-rich bedrock where finer-grained alluvial sediments were transported down tributary channels and creeks onto gentle to moderate slopes. This lower-elevation deposit contains only scattered smaller boulder- to cobble-sized basaltic rocks dispersed in a very dark-brown poorly sorted, poorly stratified, silty to sandy clay matrix; a deposit more typical of slopewash in low-gradient areas. Very recent, shallow gullies and channels have incised 6 to 20 ft (2 to 6 m) into this unit. Flash flooding and debris flows may occur from the many tributary channels that discharge onto this unit.

Qamf — **Alluvial mudflow and mud-fan deposits (Holocene)** — Light-gray to pale-tan-gray, poorly sorted, poorly to moderately consolidated, gravelly to sandy clay and silt deposited in valley-head and valley-side alluvial fans, tributary stream valleys, and coalescing fans in local drainage basins underlain by the Kmu unit in the southeast corner of the map area. Sediments were deposited primarily by muddy debris flows with occasional input from slopewash, and hyperconcentrated water-flood sources. The deposits consist of interlaminated mud to thicker gravelly beds that record individual mudflow depositional events. Some layers have incipient Bt-soil horizons, which suggest perhaps a few thousand years of non deposition and soil development prior to burial. Lenses of muddy gravel are locally present, especially near the base of the unit. The gravel clasts consist of reworked sub-rounded to sub-angular basaltic and reworked alluvial pebbles and cobbles. This unit has been dissected up to 17 ft (5 m) by recent stream erosion. Thickness from water-well logs is about 30 ft (9 m).

Mixed Alluvial and Debris-Flow Gravel Deposits (Pleistocene) — Upland gravel deposits of various ages are scattered throughout the southeastern parts of the quadrangle where they form erosional remnants of coalesced debris-flow fans, outwash, and valley-fill sediments. These gravel deposits have also been referred to as "pediment deposits" (Sinnock, 1978; Cole and Sexton, 1981). Through topographic inversion, they now form a series of elevated and dissected, gravel-capped, relatively flat-lying mesa and hillside remnants that have terrace to fan-like geometries that extends upslope to the landslide-complex source areas along the higher-elevation flanks of Grand Mesa. From younger to older, the remnants are at progressively higher elevations. Three major types of deposits are present: 1) tan to tan-gray, non-stratified, debris-flow deposits containing very poorly sorted, sub-angular pebbles to very large boulders in an unsorted sandy-mud matrix; 2) olive-gray to tan-gray, fine-grained, thinly bedded to interlaminated mudflow deposits with scattered dispersed matrix-supported pebbles to small boulders; and 3) gray riverine alluvial deposits containing imbricated sub-rounded to well-rounded pebbles to small boulders, densely packed in a well-sorted sand matrix. Cut-and-fill channels are present, typically filled with the debris-flow deposits. Gravel clasts in the deposit are composed nearly entirely of Nb basaltic rocks of the GMVF. Minor (<5%) amounts of sandstone, siltstone, clinker, chert, carbonate concretions, and well-rounded polylithic pebbles and cobbles may be present. These minor clasts constituents are reworked from Upper Cretaceous to Miocene-aged bedrock fragments within the landslide complexes. The thickness of the deposits varies within individually mapped gravel units. The degree of weathering and presence of calcic soil development (Bk horizon) increases with increasing age of the deposits. Topsoil for the older units is also typically reddish-brown to reddish-tan. Significant erosion and weathering of the ground surfaces has also typically occurred. In many areas the normal reddish-brown topsoil has a pinkish-white chalky appearance from erosion into the well-developed Bk calcic horizon. This horizon is best exposed along the mesa rims of the deposit. Transported basaltic boulders, exposed on the surface to long-term weathering, are heavily stained, fractured, and highly pockmarked with deep weathering pits. Sediments are typically more consolidated and orange-tan to red-brown, and blue-gray mineral staining is common. In certain basal zones, the older deposits have sufficient calcite cement to form conglomerate that outcrop as subtle, thin ledges. Side slopes and swales eroded into the older units are typically mantled with old colluvial deposits (Qco). Gravel-deposit enumeration follows that of Noe and Zawaski (2013) and Noe and others (2015). Four elevation levels of gravel occur in the map area.

Qg_3 — **Gravel deposit three (Upper Pleistocene)** — The top of the deposit surface is about 100 ft (30.5 m) above the adjacent valley floor underlain by the Qamf unit. Deposit caps local mesas and ridgelines of dissected paleovalleys within the Mancos Shale. The light-gray to gray-tan poorly stratified unit was deposited predominately as mud with pebble-to boulder-sized clasts, ranging from dispersed and matrix-supported to thin (3-10 cm) gravelly beds and lenses. Unit is 5 to 10 ft (1.5 to 3 m) thick.

Qg_5 — **Gravel deposit five (upper Middle Pleistocene)** — Only a remnant of this gravel surface lies in the map area. The top of the deposit surface forms a mesa remnant that, off map to the east, is about 305 ft (93 m) above the Dirty George Creek valley floor.

Qg_6 — **Gravel deposit six (Middle Pleistocene)** — The top of the deposit surface is about 400 ft (122 m) above the valley floor (at the confluence of Tongue and Dirty George creeks) underlain by the Qamf unit. Thickness was measured at 46 and 60 ft (14 and 18 m) where well exposed at recent landslide scarps. Very large basalt blocks, almost 50 ft (15 m) wide, occur along mesa edges formed in this unit. Their size suggests lone remnants moved during the early Pleistocene by earth-flow landslides that have subsequently eroded away. Northernmost deposits of the map unit have an irregular topographic surface, unlike typical fan morphology, and appear more as debris-flow deposits that may locally contain earthflows.

Qg_7 — **Gravel deposit seven (lower Middle Pleistocene)** — This unit is very similar to Qg_6 but the surface elevation is 250 ft (76 m) higher, or 660 ft (201 m) above the confluence of Tongue and Dirty George creeks. Compared to the Qg_6 unit, this unit has slightly higher content of sandstone and red clinker clasts of the Iles (Kir, Kicz) and Williams Fork (Kw) formations, and noticeably more well-rounded polylithic pebbles and cobbles (reworked from the Ohio Creek Formation (PeKoc) and possibly Wasatch Formation (Pew). Unit was measured at 40 ft (12 m) thick at a road cut and thins to 9 to 10 ft (3 m) thick at the east end of the mesa remnant.

Qdf — **Debris-flow deposits (Holocene)** — Brown-gray to slightly reddish tan-gray, clast-supported, poorly sorted, poorly stratified, bouldery deposits formed from episodic transport of rock in a viscous to hyperconcentrated debris-laden flow. Sources of these debris-flow deposits are predominantly earth-flow landslide deposits. The deposit matrix is unsorted pebble-gravel, sand, silt, and clay. Clasts are mostly subangular-to-rounded basaltic rocks of the GMVF that may be up to 10 ft (3 m) in long dimension. Much less common are smaller boulder- to cobble-sized sandstone and clinker clasts from the Kw unit and, rarer still, smaller cobble- to pebble-sized clasts of calcareous sandstone, chert, and limestone eroded from the Green River Formation (Peg). The surface morphology of this deposit, as revealed in lidar hillshade imagery, suggest braided and channelized, valley-confined, debris-fan modes of deposition. The top of this unit is 40 to 20 ft (12 to 6 m) above the creek floor where the Dirty George Creek exits the map area. Thickness is unknown but at a 1000 ft (333 m) off map, water-well data indicates a thickness of about 40 ft (12 m).

Qdfo — **Old debris-flow deposits (Upper Pleistocene)** — Late Pleistocene debris-flow deposits commonly occur where creek channels exit steeper-slope landslide regions and sediments fan out and aggrade to form broader valleys. Deposits and surface morphology are similar to Qdf deposits, but the surface color is more reddish-tan. Unit includes two elevations. The major deposit is within the valleys of Dirty George Creek and its tributary, Sand Creek. Other nearby older debris-flow fan remnants are 85 to 110 ft (26 to 34 m) higher. Transported basaltic blocks, exposed on the surface, are abundantly fractured, pockmarked, and lichen covered. Well-rounded quartzite pebbles and cobbles are also present in the deposit; likely, they are reworked from PeKoc unit conglomerates. Unit thickness was measured at 13 ft (4 m) thick where it overlies sandstone of the Kir unit. However, it is thicker in other areas where the present Dirty George Creek channel has incised up to 26 ft (8 m) into the deposit. Deposits of this unit, near the base of older undivided landslide (Qlsu) and intermediate earth flow (Qefi) units, may lie within potential run-out zones for future debris flows and earth-flow landslides.

GLACIAL DEPOSITS

Qgt_1 — **Glacial till one (Upper Pleistocene)** — Tan to tan-brown, unsorted, unconsolidated, angular boulder- to pebble-sized basaltic clasts in a pebble-gravelly loam that was deposited during the last major glacial period of the Central Rocky Mountains (Pindale Glaciation). Unit is discontinuous, and may locally include periglacially shattered zones of GMVF Nb unit regolith above the Grand Mesa rim. Deposits are thickest (up to 50 ft (15 m)) at the outside edge of the terminal moraine. The Qgt_1 unit correlates with off-map till of the Grand Mesa Formation of Yeend (1969). Below the Grand Mesa rim, glacial till deposits have been disturbed and mobilized by landsliding and have been incorporated into landslide deposits.

Qgt_2 — **Glacial till two (upper Middle Pleistocene)** — Orange-tan to tan-brown, unsorted, unconsolidated, boulder to pebbly gravel dispersed in a granule-to-clayey gravel matrix. Clasts are subrounded to subangular and composed entirely of GMVF basaltic rocks (Nb unit). The unit is poorly exposed on the Flowing Park Lobe of Grand Mesa as a flattened topographic band in front of the Qgt_1 terminal moraine. This deposit is likely a terminal-moraine remnant of the Bull Lake Glaciation of the Central Rocky Mountains. Thickness is estimated by the elevation rise of about 30 ft (9 m) from the adjacent Nb unit bedrock surface exposures. The rinds of basalt rocks on the surface of the deposit have been stained orange-brown. This glacial unit could not be discerned below the GMVF rim and is likely incorporated into landslide deposits.

MASS-WASTING DEPOSITS

Qt — **Talus deposits (Holocene)** — Dark-gray, blocky to angular rock fragments that have fallen from mesa-rim exposures composed of jointed GMVF basalt flows (Nb unit) and accumulated at the angle of repose (35 to 45 degrees) on relatively undisturbed bedrock. The broken rock blocks typically have sharp edges, are lichen covered, and up to 8 ft (2.4 m) in long dimension. Where talus boulder fields have been disturbed and mobilized by subsequent landsliding of underlying Neogene and Paleogene sedimentary rocks, those slopes are included in Qslu and undivided mass-movement (QNmu) landslide units. Thicknesses are variable but likely do not exceed 15 to 20 ft (4.5 to 6 m). Talus deposit slopes are very steep and prone to rockfall.

Qc — **Colluvial deposits (Holocene)** — Olive-gray to tan-gray rocky sediments on slopes and swales of mesas and ridgelines, deposited primarily by gravity with limited additions of slopewash sediments. The unconsolidated deposit is typically rocky, poorly sorted, and poorly stratified. It is derived from the erosion of older gravel, debris flow, and landslide units. The reworked, basaltic, boulder-to-pebble sized clasts are dispersed in a sandy clay matrix derived from the underlying shale bedrock. Deposit thickness likely does not exceed 10 ft (3 m) with some map areas ranging from less than 5 ft (1.5 m) to a stony residuum on weathered bedrock slopes.

Qco — **Old colluvial deposits (Upper to Middle Pleistocene)** — Old colluvial deposits that mantle hillslopes and swales. This unit is mapped in two different environments. The alpine environment above the Grand Mesa rim contains rocky slopes within the Sheep Creek valley near the Flowing Park Reservoir where angular, basaltic, boulder-sized rocks have been locally transported downslope from shattered Nb unit ledges and unmapped block-field deposits. This deposit is similar to talus (Qt) but the slopes are flatter, vegetated, and the deposit has a finer-grained matrix and very dark-brown to reddish-brown, stony, loam topsoil. In lower, more arid, elevations in the southeast quadrant of the the map area, old colluvial deposits, reworked from Middle Pleistocene gravel (Qg_6 and Qg_7) and landslide (Qlsu) deposits, mantle downslope hillsides and swales. These reddish-tan to light-tan-gray, poorly to unsorted, moderately consolidated deposits may also contain slopewash sediments that washed down from both the exposed Mancos Shale and the rocky deposits that cap the slopes above. The typical deposit is unstratified, containing abundant subangular to subrounded, basaltic clasts in a gravelly clay matrix. Well-developed, thick, calcic (Bk horizon) soils impart a chalky-white appearance to the deposit where it is exposed. Very weathered basaltic boulders exposed on the surface are heavily stained, pockmarked, and fractured. Deposit thickness likely does not exceed 10 ft (3 m) with some mapped areas less than 5 ft (1.5 m), predominantly only a veneer of rocks cemented in a weathered Bk-horizon matrix that extends into the underlying shale bedrock.

Qlsr — **Recent landslide deposits (Upper to Middle Holocene)** — Gray to tan-gray, unsorted, unstratified, chaotically mixed deposit of sandy-to-silty clay; soft, contorted and plastically deformed clay-rich sedimentary rock fragments; and abundant cobble- to boulder-sized basaltic rocks of the GMVF. Recent landslide morphology was interpreted from 1-m resolution lidar bare-earth hillshade imagery. Observed landslide forms include relatively fresh and oversteepened scarp and side-shear slopes, ruptured and fissured ground, rotated slump blocks, pressure ridges, and hummocky to lobate terrains. Qlsr deposits behave more plastically and failed to mobilize as a fluidized flow with long sinuous runouts. Most of the mapped Qlsr deposits overlie heavily weathered clay-rich Cretaceous rocks. Thicknesses are unknown but likely highly variable depending on the size of the landslide. This map unit should be considered containing potentially active landslides and prone to continued movement.

Qlsi — **Intermediate landslide deposits (Lower Holocene to Upper Pleistocene)** — Older landslides similar in size and composition to Qlsr landslides that can be discerned in lidar hillshaded imagery but have been smoothed during extended exposure to weathering and erosion. These deposits may be susceptible to reactivation during periods of high precipitation.

Qefr — **Recent earthflow deposits (Upper to Middle Holocene)** — Variably colored, unsorted landslides composed of very soft, clay-rich, disturbed sedimentary rock, plastically deformed mudstone fragments, and silt and clay with abundant pebble to massive boulder-sized GMVF basaltic rocks. Contains landforms that indicate recent earth-flow movements that have re-mobilized older Qlsu and Qefi landslide deposits. Observed landforms include flow paths, flow banding, hummocks, sinuous lateral side-shear furrows and levees, soil ripples, and lobate toes of the deposit that overthrust and spread over the preexisting ground surface. Boundaries of this unit were predominantly interpreted from 1-m resolution lidar imagery. Recent earth-flow pathways have undergone little erosion or subsequent ground-movement disturbance. On some of the most recent flows, ruptured, torn, and contorted ground surfaces have not yet revegetated. Thickness is unknown but likely highly variable. Lateral levee and lobate toes were measured up to 105 ft (32 m) higher than the interior earth-flow path and undisturbed ground below the toe. These deposits may be susceptible to creep and reactivation during periods of high precipitation. Deposits of unit Qefr are very unstable, susceptible to continued movement, and should be considered to be potentially active.

Qefi — **Intermediate earth-flow deposits (Lower Holocene to Upper Pleistocene)** — Variably colored, landslide deposits that are mapped where earth-flow pathways can be discerned on lidar hillshaded imagery within Qlsu and QNmu landslide deposits. Intermediate earth-flow pathways are older than those of unit Qefr, and much larger, based on either cross-cutting relationships, an overall muting of ground morphology by weathering and erosion, and development of drainage networks into the deposit. Thickness is unknown but likely highly variable. Very large intermediate earthflows are up to 3.2 mi (5.1 km) long with lobate toe slopes up to 200 ft (60 m) in height. These deposits may be susceptible to creep and reactivation during periods of high precipitation.

Qlsu — **Landslides, undivided (Holocene to Lower Pleistocene)** — Undivided landslide deposits that mantle slopes below the GMVF basalt rim (Nb unit) and QNmu bench where the underlying bedrock is weak, clay-rich Neogene and Paleogene formations (Ng, Pew, and Peg units). The deposit is typically unsorted, disturbed, plastically deformed mudstone and earth-flow breccia derived from bedrock. The unit also contains abundant dispersed basaltic rocks mobilized from talus deposits and blockfields formed from basaltic slump blocks (QNbb). Unit Qlsu has also mobilized and incorporated till of units Qgt_1 and Qgt_2. Unit thickness is highly variable. Where landslide scarps occur, bedrock may be shallow but is likely disturbed. Water-well logs on file at the Colorado Division of Water Resources indicate landslide deposits 266 ft (81 m) thick near the northeast margin of the map area. Basaltic rocks range in size from cobbles to boulders that typically range in size up to 8 ft (2.5 m) wide. However, massive blocks up to 20 ft (6 m) wide are also locally present. At lower elevations in the southern part of the map area, the landslide deposits are heavily armored with basaltic boulders and more resistant to erosion than the underlying Mancos Shale. Topographic inversion has occurred and many irregular erosional remnants of this landslide unit cap the hills and ridgelines. At the southern, more arid margin of the map area, the landslide deposits are likely much older with thick Bk-horizon soil development (up to 5 ft (1.5 m) thick) that is commonly expressed as chalky-white rims at slope breaks. These Early Pleistocene landslide deposits were the source materials for Middle Pleistocene Qg_6 and Qg_7 fan deposits mapped on this quadrangle and in the adjacent North Delta quadrangle (Noe and others, 2015). More recent earth-flow mobilizations and landslide reactivations in this unit, discerned by recent scarps and morphology in lidar hillshaded imagery, have been mapped separately in units Qefr, Qefi, Qlsr, and Qlsi.

QNbb — **Slump blocks of GMVF basalt (Holocene to Pliocene (?))** — Fissured, down-dropped, and back-tilted linear blocks of basalt that have been displaced from the GMVF rim (Nb unit) by landslide slumping, generally by shear and bearing failures, rotation, and lateral displacement of the underlying, weak, Goodenough formation (Ng). Along fissures that develop at the basaltic rim, QNbb blocks slide retrogressively. This is most apparent on the south side of the rim at the topographic bench of the Granby Reservoirs where Ng is thickest and successive basaltic ridges have been displaced and possibly "rafted" southward from the rim. Slump-block morphology includes a transitional range of forms. Where mostly intact, the displaced linear rock masses are fractured and back tilted, but relatively coherent. Others are completely disaggregated and form linear blockfields composed of basaltic boulders with sizes up to 10 ft (3 m) in long dimension. This disaggregation likely occurs from continued displacement of the rock mass by later differential, lateral-ground movement, ice loading, and periglacial frost wedging along discontinuities. Age is inferred by degree of disaggregation and the rough irregular angular rock surfaces that are typically heavily weathered and pitted. Several slump blocks on the bench of the Granby Reservoirs were buried by ice during the Pinedale and Bull Lake Glaciations and are currently overlain by glacial moraine till (Qgt_1). Thickness is unknown but limited to the maximum thickness of the Nb bedrock adjacent to the Flowing Park Lobe rim of the GMVF.

QNmu — **Mass-movement ground displacement, undivided (Upper Pleistocene to Pliocene (?))** — This unit is composed of various types of mass-movement deposits. It forms the topographic bench where the Granby Reservoirs are located. The bench lies 400 to 500 ft (122 to 152 m) below the GMVF basaltic rim (Nb unit) and contains many linear slump blocks of basalt (QNbb) separated by flat-lying linear depressions that are infilled with glacial till, fine-grained slopewash, and brown-black pond deposits. This unit is characterized by many parallel to arcuate ground furrows that indicate continued lateral ground movement down slope and away from the Nb rim. The bench elevation approximates the contact between the soft, easily deformed Goodenough formation (Ng) and the more indurated Green River Formation (Peg) below. In isolated patches and near the slope break with the Qlsu unit, there are poorly exposed, highly disturbed masses of green-gray and brownish-red mudstone of the Goodenough formation. Age and thickness is difficult to determine, but the muted low-relief aspect of the deposit suggests that the mass wasting began during the Pliocene and accelerated during episodic Pleistocene ice loading (Yeend, 1969; Baum and Odum, 1996).

BEDROCK GEOLOGY

Nb — **Basalt of Grand Mesa Volcanic Field (Miocene)** — Dark-gray, gray-black to reddish-gray basalt of the Grand Mesa Volcanic Field (GMVF) that caps Grand Mesa. Individual flows are typically highly jointed and texturally zoned, varying from dense to highly vesicular. Long dimensions of stretched vesicles approximate flow directions, which generally trend southwestward. Joints and vesicles are locally infilled with secondary minerals forming amygdules. Multiple interbedded flows commonly are separated by brick-red paleosols that may be baked by contact metamorphism. Above the mesa rim and beyond the lower limit of glacial till, the heavily pockmarked, stained, and edge-worn surfaces of the GMVF basalt bedrock have been exposed to long-term weathering and periglacial processes since its Miocene eruption. Outcrops typically occur along low-relief ledges and flats of at-surface joint-patterned rock that may be up to 6 ft (1.8 m) wide. In many locations above the rim, south of the older till deposit (Qgt_2), the basalt bedrock is covered by patchy veneers of rocky, frost-shattered regolith that is characterized by advanced soil development, including an orange-red to brown-red Bt horizon. In many areas, erosion of the soil has left reddish-brown stained rocks exposed at the surface. Cole and others (2017) reported ages ranging from 10.05 +/- 0.06 to 9.82 +/- 0.05 Ma on the Flowing Park Lobe of Grand Mesa, and classified these lava flows as medium-K and high-K basalt and basaltic andesite. Near the fork of the Flowing Park Lobe and Palisade Lobe, 3,300 ft (1,006 m) due north from the quad boundary, a U.S. Bureau of Reclamation (USBR) water-resource investigation recorded 21 individual flows with a total thickness of 540 ft (164.5 m) (Weston, 1987). The basal contact of the basalt is obscured by talus and QNbb blocks. A minimum thickness of the unit was measured at 306 ft (93 m) at the west-rim outlet of Sheep Creek from Flowing Park Reservoir. Oil and gas exploration near Flowing Park Reservoir (Fed. C-13593) indicates the GMVF near the Flowing Park Reservoir contains a 35 ft (11 m) thick lens of alluvial gravel beginning at a depth of about 102 ft (31 m). Reported materials logged in the alluvial interbed include well-rounded pebbles, cuttings of brown sandstone, as well as basalt, feldspar, and quartz. This gravel was attributed to fluvial deposition during a lull in volcanic activity (Buckhorn Geotech, 1981). Lateral extent of this alluvium bed within the GMVF Nb unit is unknown.

Ng — **Goodenough formation, informal unit (Miocene?)** — This informal unit (Cole and others, 2013) consists chiefly of variegated maroon and greenish-gray, weakly consolidated claystone and siltstone that is interbedded with tan, brown, and light greenish-gray fine-grained to pebble-conglomerate sandstone and minor grayish-white cherty limestone. Pebble clasts are predominantly andesite. Unit may contain streaks of orange-tan staining. Unit is in unconformable contact with the overlying GMVF basalt (Nb). The unit is highly disturbed by mass-movement processes, and only poorly exposed in landslide deposits. It is covered by QNbb, QNmu, and Qlsu landslide deposits where ground movements have disturbed the unit along the bench rim. In earlier work, this unit was unnamed (Yeend, 1969; Baum and Odom, 1996), while work by USBR (Weston, 1987) and nearby oil and gas well logs incorrectly refer to the unit as the Tertiary North Park Formation. More recent work has further described and informally named this formation (Cole and others, 2013). Unit thickness is unknown and likely variable, which thins and likely pinches out to the southwest in the map area where the QNmu unit topographic bench ends below the basalt (Nb) rim of the GMVF. Unit may be thickest in the northeast corner of the map area where extensive retrogressive slumping and lateral spreading of basalt blocks occurred, forming the bench of the Granby Reservoirs. This ground surface approximates the contact elevation of the Goodenough formation of Cole and others (2013) with the underlying, more resistant Paleocene formations. The unit is about 500 ft (152 m) thick where exposed approximately 1.3 miles (2.1 km) north of the northeast map corner near State Highway 65, (R. Cole, written communication, 2018). The unit thins in the map area and shown in the cross section with a thickness up to 125 ft (38 m). Lands on moderate to steep slopes underlain by this unit may be prone to slope instability or landsliding.

Peg — **Green River Formation, undivided (Eocene)** — Gray-white to gray, yellow-tan to light-brown, and light green-gray marlstone, mudstone, very fine- to fine-grained sandstone, limestone, and minor oil shale. This unit records the sedimentation in Eocene intermountain lakes, both lacustrine and nearshore clastic facies. This more consolidated formation creates steeper slopes between the conformable contact with the underlying Wasatch Formation and the upper landslide bench (Granby Reservoirs bench) near the unconformable contact with the overlying Goodenough formation. However, this unit is prone to slope failure, it is almost entirely buried by surficial landslide deposits, and only exposed at landslide scarps. Disaggregation and flow of rockmass debris from unit Peg can cause extremely rapid landslides; rock-avalanche/earth-flow pathways (Qefr) have moved 2 miles (3.2 km) down the Grand Mesa slopes in this quadrangle. Unit thickness is estimated at about 550 ft (168 m).

Pew — **Wasatch Formation, undivided (Eocene and Paleocene)** — Undivided, variegated reddish-brown, light-gray, gray, lavender, and maroon mudstone, sandstone, and shale. The formation was deposited in a terrestrial environment and is clay rich and poorly indurated. The weak rock unit is highly disturbed by mass-movement processes and very poorly exposed within the greater landslide complex (Qlsu); only locally exposed in landslide scarps and scoured slopes where landsliding and erosion occurred. Slopes in the Wasatch Formation at higher elevations and correspondingly higher average annual precipitation are prone to instability and landsliding. Unit thins to the southwest. Thickness estimated from oil and gas exploration logs is about 725 ft (221 m).

PeKoc — **Ohio Creek Formation (Paleocene and Upper Cretaceous)** — Gray-white, light-gray, to light-brown poorly cemented sandstone, conglomerate, and minor thin beds of mudstone. Typically buried by deposits of unit Qlsu, bedrock outcrops were difficult to discern. However, the presence of the pebble to cobble conglomerate was verified in landslide deposits above the Williams Fork Formation, where a high percentage of polylithic quartzite, chert, and minor igneous and metamorphic pebbles littered the slope. The unit was mapped where small conglomerate clasts were observed, containing pebbles in a cemented, very coarse-sand matrix. Well logs from gas and oil wells suggest that unit thickness is about 100 feet (31 m).

Kw — **Williams Fork Formation (Upper Cretaceous)** — Buff to tan, massive, cross-stratified, noncalcareous sandstone and interbedded gray siltstone, dark-gray shale, carbonaceous shale, clinker, and basal coal. This unit was formed from sediments in a terrestrial floodplain environment. The top half of the unit is predominantly massive bedded, laterally extensive, cross-stratified sandstone interbedded with thin- to medium-bedded siltstone and shale. In rare occurrences, thin shale beds are locally maroon-red. The sandstone is very coarse- to medium-grained, well sorted, and locally contains lenses of shale rip-up clasts. There are common small iron-oxide concretions. Contorted penecontemporaneous load-deformation structures occur. Many areas underlain by Kw bedrock are covered by landslide deposits. However, where sandstone is exposed, the upper part of the unit forms steeper bench-forming cliffs. Down section, the unit becomes increasingly shaly and a ledgy slope former, composed of stacked sequences of thick mudstone beds and interbedded, laterally discontinuous, channel sandstone beds. Orange-brown concretions and fossil wood are present. The basal Cameo-Wheeler Coal Zone outcrops along a northeast-trending belt in the southeast corner of the map area. Within the historically mined coal zone are prominent red clinker deposits that are encrusted with white mineral precipitate. Clinker types range from heavy reddish-stained but principally unaltered sandstone to brick-red displaced collapse breccia with incorporated landslide-deposit basaltic rock clasts, fused to form a porcellanite. Thickness is estimated at about 1,700 ft (518 m).

Kir — **Rollins Sandstone Member of the Iles Formation (Upper Cretaceous)** — Gray-white to tan to pale-orange, very fine- to medium-grained, massive-bedded, cross-stratified sandstone deposited in a shoreface marine environment. Where it is not covered by landslides, its landforms range from benchy cliffs to a 100 ft (30.5 m) tall, continuous vertical cliff. The upper section consists of low angle crossbedded sandstone capped by subhorizonal bedded sandstone. At the top third, the sandstone is commonly bleached gray-white, is increasingly friable, and has a slick-rock appearance that becomes a prominent marker bed in outcrop. Marine mollusk fossils (*Inoceramid sp.*) and burrow trace fossils are present; most common in orange-tan, coarse-grained, calcite-cemented, medium-thick beds. The sandstone upper contact can be stained red from clinker deposits within the Cameo-Wheeler Coal Zone of the overlying Williams Fork Formation. Lower in the section, it has hummocky and swaley crossbedding, contains silty marine shale beds, and is somewhat bioturbated. The basal contact of this unit was mapped at the first thin sandstone bed that is conformably interbedded with the underlying tongue of Mancos Shale in the Kicz member. Total thickness of 167 ft (51 m) was measured above Dirty George Creek. Cliffy exposures of this unit may be source areas for potential rockfall hazards.

Kicz — **Cozzette Sandstone and tongue of Mancos Shale members of the Iles Formation (Upper Cretaceous)** — Light orange-brown to tan-brown, coarsening-upward, very fine- to medium-grained, somewhat bioturbated sandstone with swaley cross bedding and basal, interlaminated to very thin interbeds of sandy shale. The Cozzette Sandstone forms a conspicuous tan-colored 33-ft (10-m) high cuesta where Dirty George Creek exits the map area. This unit includes the Mancos Shale tongue interval between the Cozzette and the Rollins (Kir) sandstone members. Thickness is about 180 ft (55 m). Cliffy exposures of this unit may be source areas for potential rockfall hazards.

Mancos Shale (Upper Cretaceous) — The Mancos Shale is present in the southern part of the quadrangle in adobe hills that may be capped by old landslide, colluvium, and alluvial deposits. Twelve members of this marine shale, distinguished on the basis of composition, color, and fossil assemblages, were mapped in the bordering Orchard Mesa and North Delta quadrangles (Noe and Zawaski, 2013; Noe and others, 2015). Three upper members occur within this quadrangle, as well as a tongue of Mancos shale that is included in the Iles Formation within the Kicz unit. The three member contacts are conformable. On mesas and ridgelines, the gray to dark-gray shale typically contains an oxidized, yellow-tan stained horizon that is highly fractured with crystalline gypsum filling. This approximately 30 to 50 ft (9 to 15 m) thick weathered interval, once subaerially exposed and subsequently buried by Pleistocene surficial deposits, has been referred to colloquially as the Mancos "blonde" by local Natural Resources Conservation Service soil scientists. In cross section, unit Km incorporates the Kmp and older members.

Kmu — **Mancos Shale, upper part** — Gray to olive-gray, non-calcareous, fissile to subblocky, silty to sandy shale. It contains sporadic, unusually large, orange-brown concretions up to 11 ft (3.5 m) in diameter. Overall unit thickness is about 1,300 ft (396 m).

Kmss — **Sharon Springs Member** — Dark-gray to black, organic-rich, shale. This relatively thin unit is mostly covered by landslides and residuum, but is well exposed near the southeastern corner of the quadrangle at the monoclinal fold. The exposures contain prominent white to orange bentonite beds (0.5 to 6 inches (1.3 to 15 cm) thick), horizons of discontinuous, occasionally lenticular-shaped orange-brown concretions, and abundant healed fractures. Secondary crystalline gypsum (selenite) is common as fracture filling, as seams along bedding, and encrusting bentonite beds. The lower contact of the unit with the underlying Prairie Canyon Member is comprised of abundant, orange-brown concretions. The upper contact with the overlying, upper part of the Mancos Shale is marked by a subtle change from black clayey shale to brownish-gray silty shale. The unit is about 70 to 80 ft (21 to 24 m) thick where exposed and steeply dipping near the southeast corner of the map area.

Kmp — **Prairie Canyon Member** — Light- to medium-gray, finely fissile to subfissile, silty to sandy shale. This unit forms residuum-covered outcrops near the extreme southeast corner of the map area on the synclinal side of the monoclinal fold. The Prairie Canyon Member locally contains small, rounded chips of very fine-grained, bioturbated sandstone. The chips appear to be individual sand ripples that weather out of the shale. About 750 ft (229 m) of this unit is exposed where steeply folded near the monoclinal fold. Total thickness of this member is 1,250 ft (381 m) (Noe and others, 2015).

Km — **Mancos Shale, undivided (Upper Cretaceous)** — Shown in cross section only, includes Kmp and older members.

Kdb — **Dakota Sandstone and Burro Canyon Formation, undivided (Upper to Lower Cretaceous)** — Shown in cross section only.

Mz — **Mesozoic Formations, undivided (Jurassic and Triassic)** — Major units include the Morrison Formation, Entrada Sandstone, and Chinle Formation, Shown in cross section only.

p€ — **Precambrian Rocks, undivided (Proterozoic)** — Crystalline igneous and metamorphic rocks, shown in cross section only.

MAP SYMBOLS

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

Borrow pit

Coal mine

Oil and (or) gas well

Contact — Approximately located

Monocline — Arrow points toward dip direction, axis line approximates steepest dip of fold, dashed where concealed.

Fissures, furrows, and aligned depressions — Extensional ground rupture and other landslide linear landforms. Includes widened fissures in rock, tension cracks, ground furrows, transverse ridges, and linear orientations of ground depressions related to retrogressive slumping, lateral spreading, or pressure-ridge formation.

Landslide scarp — Crest of a landslide where the ground surface has ruptured and underlying earth materials have moved down-slope forming the landslide deposit below. Landslide scarp slopes are oversteepened and may be vegetated, or bare rock and soil exposures if the landslide is recent. Sub-parallel scarp lines mark secondary ruptures where retrogressive detachment and slump-block failures occur. Hachures lines indicate direction of landslide movement.

Drainage divide — East-west divide of the shallow Neogene (?) valley where Flowing Park Reservoir is located. The western outlet is currently occupied by Sheep Creek.

A A′ — **Alignment of cross section**

Clinker zones — Outcrops of naturally occurring coal clinker produced by coal-bed fires in the William Fork Formation Cameo-Wheeler coal zone.

Glacial Moraine — Rolling, sinuous, ridge-and-closed-depression landforms composed of unsorted, unconsolidated till (Qgt_1). The terminal moraine of this deposit crosses Grand Mesa at the Flowing Park Lobe on this map and across the Palisade Lobe (Chesnutt and others, 2019). In the vicinity of the Granby Reservoirs below the Grand Mesa rim, morainal land-form morphology becomes obscured by subsequent and/or concurrent landslide activity.

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