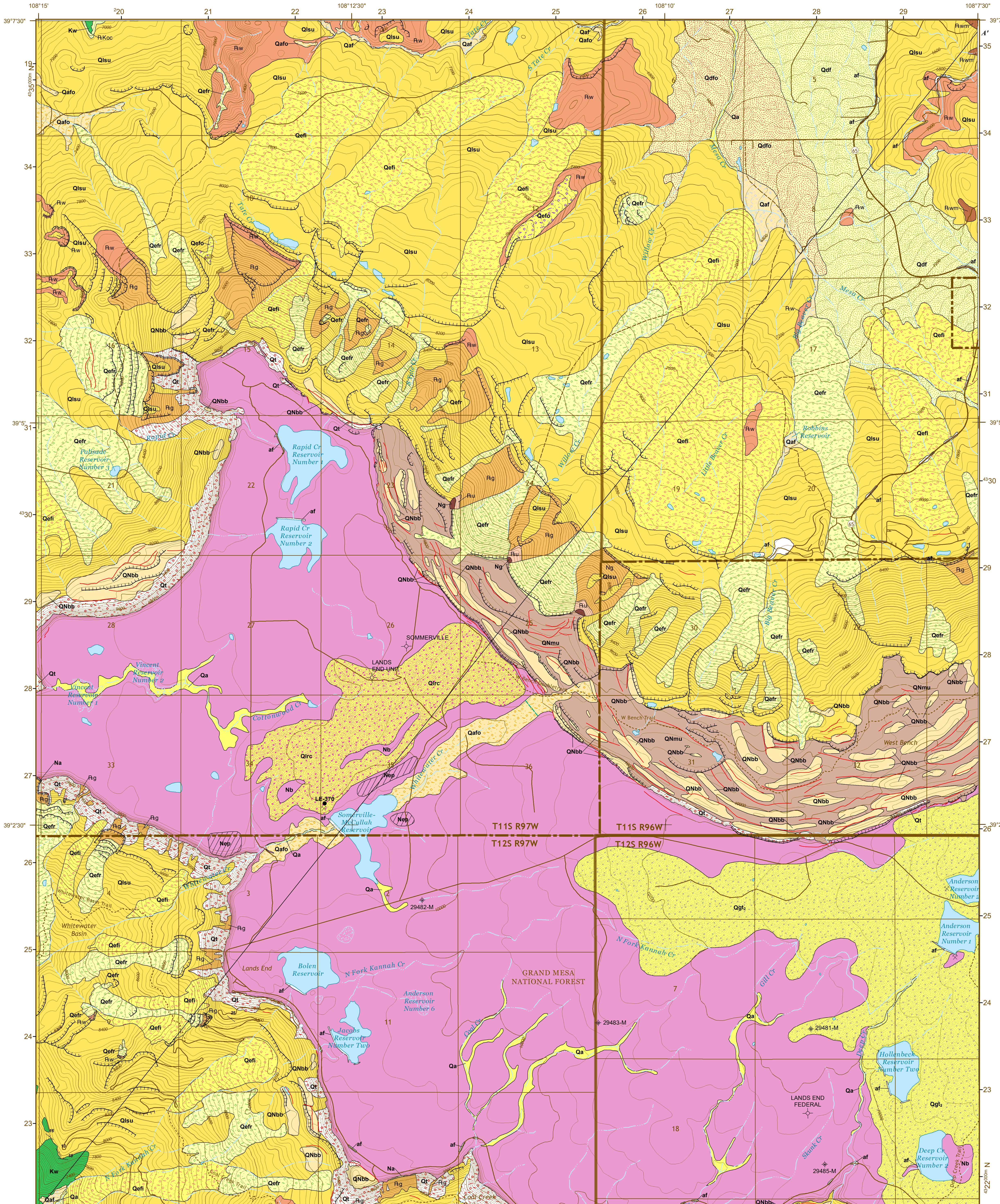

Geology mapped in 2017
GIS and cartography by Pangaea Geospatial, LLC.

Coordinate System: NAD 1983 UTM Zone 13 North
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.

Initial styling of this map document was provided by the US Geological Survey. The edited content in this document are neither done by nor endorsed by the USGS.

Roads..............................U.S. Census Bureau, 2015-2016
Roads within USFS Lands....................................FSTopo Data with limited Forest Service updates, 2012-2106
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
Wetlands................FWS National Wetlands Inventory, 1977-2014

SCALE 1:24,000

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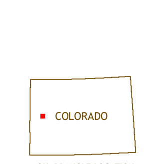
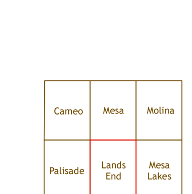
FEET 1000 500 0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000

CONTOUR INTERVAL 40 FEET



QUADRANGLE LOCATION



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 G17AC00259.

GEOLOGIC MAP OF THE LANDS END QUADRANGLE, MESA COUNTY, COLORADO

By Jonathan L. White and Martin J. Palkovic
2018

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 are from local sources and may be engineering material for roadway embankments, or uncontrolled and unsorted fill placed for reservoirs dams, canal embankments, and grading for development.

ALLUVIAL DEPOSITS

Qa — **Alluvial deposits (Holocene to Upper (?) Pleistocene)** — Alluvial deposits constrained along bottoms of ephemeral creeks on Grand Mesa, and valley floors of Mesa Creek and North Fork of Kannah Creek. Unit is tan-gray to brown-black, poorly sorted, and composed of a wide range of clast sizes from boulder-to-pebbly gravel, sand, silt, and clay that reflect either deposition from seasonal flash flooding or reworking of rocky till, loess, rocky debris-flow deposits, and Grand Mesa Volcanic Field (GMVF) basaltic regolith. Thickness is highly variable but likely does not exceed 5 to 7 ft (1.5 to 2 m). Areas of this unit are exposed to dangerous flash flooding along Mesa Creek and North Fork of Kannah Creek. On the mesa top this unit is dark-brown to black and exposed to seasonally perched water levels.

Qaf — **Alluvium and alluvial fan deposits (Holocene to Upper (?) Pleistocene)** — Valley-fill deposits of coalesced, tan-gray to brown-gray alluvium and alluvial-fan sediments composed predominantly of poorly sorted, poorly stratified sand, silt, and clay with dispersed subangular to subrounded cobble- and boulder-sized basaltic clasts. This deposit is derived from the erosion and transport of old landslide deposits, or easily erodible mudstone, down tributary channels and creeks onto gentle to moderate slopes. Recent shallow ravines have been incised up to 6 ft (1.8 m) into the floor of this unit. Flash flooding and debris flows may occur from the many tributary channels that discharge onto this unit.

Qafo — **Old alluvium and alluvial fan deposits (Pleistocene)** — Older valley fill of coalesced alluvium and alluvial-fan deposits. At lower elevations, the deposit partially infills small drainage ways with non to roughly stratified, boulder to pebble gravel that is dispersed in a tan, sandy to clayey matrix. The clasts are predominantly subangular to subrounded GMVF basaltic rocks that are reworked from old landslide deposits. The unit is 20-25 ft (6.1 to 7.6 m) above the current stream level. Exposed clasts may have discontinuous white-colored calcic crust. On Grand Mesa, the unit is more complex. A shallow valley, currently occupied by Whitewater Creek, is interpreted as being formed by an east-to-west flowing Neogene-age river that briefly incised into the Palisade Lobe after the cessation of GMVF eruptive activity (Yeend, 1969). Upon abandonment during the late Neogene, the valley was infilled during Pleistocene glacial epochs with pockmarked and edge-worn angular boulders in a gravelly to clayey residuum matrix; likely formed from mixed periglacial and alluvial transport of frost-shattered rock from nearby ledges of GMVF basalt. Topsoil is typically dark-brown to black. A well-developed orange-red Bt horizon is typically present that heavily stains the basaltic rocks. Thickness is likely less than 20 ft (6.0 m). The deposit in the valley contains a topographic divide (10,025 ft (3,056 m) in elev.) near the east inlet where the basalt-capped rim is now fissured and slumped into the landslide bench (QNmu) below. It is presently unknown whether remnants of Neogene gravel are buried below the Qafo deposit. However, nearby mapped locations of Neogene exotic pebbles (Nep) are likely related to this abandoned valley.

Qdf — **Debris-flow deposits (Holocene to Upper Pleistocene)** — Brown to gray, clast-supported, unsorted, poorly-stratified, bouldery deposits formed from episodic transport of fragmented rock in a hyperconcentrated debris-laden flow. Unit occurs in the Mesa Creek valley basin and North Fork of Kannah Creek. Sources of these debris-flow deposits are earth-flow landslide deposits and glacial till. Finer-grained matrix is unsorted pebble-gravel, sand, silt, and clay. Clasts are mostly basaltic rocks that may be up to 8 ft (2.4 m) in diameter. Less frequent are smaller cobble- to pebble-sized clasts of Neogene and Paleogene calcareous sandstone, chert, and limestone. Calcic crusts coat some surface clasts in lower elevations. In the Mesa Creek basin, the ground morphology of this deposit, as revealed in LiDAR hillshade imagery, suggest glacio-fluvial choked-stream and valley-confined debris-fan modes of deposition. Abundant weathered and pitted basaltic blocks are exposed on the surface. This unit had been previously mapped as glacial till (Grand Mesa Formation) of the Pinedale (?) glaciation by Yeend (1969). Baum and Odom (1996) mapped this unit as undifferentiated surficial deposits. Thicknesses compiled from water-well log data record a maximum of 212 ft (64.6 m) and an average of about 150 ft (46 m). Disturbed and deformed green, tan, and red mudstone was logged deep in the unit in some well borings, indicating that deposits of this unit aggraded over lower preexisting earth-flow landslide deposits. Along the North Fork of Kannah Creek, the surface of this unit has been incised about 25 ft (7.6 m) by subsequent creek erosion. Upper reaches of the Qdf unit in the Mesa Creek valley may be exposed to earth or debris flows.

Qdfo — **Old debris-flow deposits (lower Upper to upper Middle (?) Pleistocene)** — These old Pleistocene debris-flow deposits occur on the west side of the Mesa Creek valley. Water-well data record thicknesses of this unit from 70 to 100 ft (21.3 to 30.5 m). This bouldery unit forms a shallow rise, up to 40-ft (12 m) high, in the center of Mesa Creek valley. Late Pleistocene(?) Mesa Creek was diverted by earth-flow landslides to the west side of the valley and has cut a channel into this unit from 80 to 130 ft (24 to 40 m) deep.

GLACIAL DEPOSITS

Qgt_2 — **Glacial till two (upper Middle Pleistocene)** — Unsorted boulder to pebbly gravel dispersed in a sandy to clay matrix. Clasts are subrounded to subangular and composed entirely of GMVF basalt. Vesicular and/or smaller pebble- to cobble-sized clasts can be partially decomposed. This unit is equivalent to the Lands End Formation of Yeend (1969), which he assigned a Bull Lake (?) age. Thin, but well-developed soil horizons are present. The surface A-horizon is generally <1 ft (30 cm) thick and a distinctive very dark-brown to black color. Two lower Bt horizons are present. The upper Bt_1 is an 8- to 12-in (20-30 cm) thick, yellow-white to cream colored, non-calcareous horizon. The Bt_2 horizon is clay-rich, non-calcareous, and has a distinctive brick-red to reddish-brown color. The Bt_2 soil structure is platy with the high-plasticity ped surfaces having a waxy appearance. This soil profile thickness is unknown but, where observed, typically extends to the weathered Nb bedrock contact. The rinds of basalt rocks within this soil horizon have been stained brownish red. This soil likely represents the Sangamon interglacial stage. Maximum thickness of this till unit was reported by Yeend (1969) as up to 10 ft (3 m). On much of the mapped area above the mesa rim, contacts are approximate. This unit was not mapped where discontinuous and very thin (<5 ft (<1.5 m)). The unit commonly thins or is stripped away by erosion to highly weathered basalt (Nb), frost-shattered and partially decomposed basalt regolith with similar soil development, or grades to a <2-ft (0.6-m) thick surface veneer of reworked loess within the regolith. Glacial till one, of the Grand Mesa Formation of Yeend (1969), does not occur in the mapped area.

Qlrc — **Loess and periglacially derived regolith and colluvium, undivided (Middle Pleistocene)** — Orange-red sandy loess mantled with a veneer of stained and pockmarked, angular to subangular, boulder- to cobble-sized, edge-worn basaltic rocks. The unit soil profile includes a black to dark-brown rocky-loam A-horizon topsoil and brownish-red Bt horizon of uncertain depth. The deposit is surrounded by periglacial blockfields, and ledges and ridgelines of frost-shattered Nb-bedrock regolith. On the southwestern flank of the deposit, utility trench excavations and a prominent borrow-area scar expose the loess deposit. Trench excavations exposed 4 ft (1.2 m) of rocky colluvium overlying 9 ft (2.7 m) of orange-red loess. The Nb bedrock occurred at about 13 ft (4 m) in depth. The deposit was previously mapped as a recessional moraine of the Bull Lake-aged (?) Lands End Formation by Yeend (1969). Sample LE-370 has an infrared-stimulated luminescence age of 312,540 +/- 22,810 yrs (see age-dating table). The sample was taken at a depth of 5 ft (1.5 m) from loess exposed at the borrow excavation near the north dam abutment of the Sommerville-McCullah Reservoir. However, there were much older components of the sample that point to a 440 ka depositional age. The younger grains could possibly be attributed to later, but still pre-Illinoian, infiltration of dust (S. Mahan, written communication, 2018).

COLLUVIAL AND MASS-WASTING DEPOSITS

Qt — **Talus colluvium (Holocene)** — Dark-gray, fragmented rock that has fallen from mesa-rim exposures of jointed GMVF basalt flows (Nb) and accumulated on undisturbed steep slopes of intact underlying bedrock at the approximate angle of repose. Rock blocks are sharply angular and up to 8 ft (2.4 m) at the long-axis dimension. Many talus boulder fields have been disturbed and mobilized by subsequent landsliding of underlying Neogene and Paleogene sedimentary rocks. These deformed talus-covered areas are included in Qslu and QNmu landslide units. Thicknesses are variable, ranging from a rocky colluvial veneer less than 5 ft (1.6 m) thick to measured exposures at landslide scarps up to 12 ft (3.7 m).

Qefr — **Recent earth-flow landslides (upper to middle Holocene)** — Recent unsorted earth-flow deposits of very soft, clay-rich, disturbed sedimentary rock fragments and plastically deformed mudstone with abundant boulder-sized GMVF basalt blocks, which contain landforms that indicate recent movements that have superimposed older Qlsu and Qefi deposits. Observed landforms include flow banding, hummocks, lateral side-shear furrows and levees, and lobate toe deposits that over-thrust and spread over the pre-existing ground surface. Boundaries of this unit were interpreted from 1-m LiDAR bare-earth hillshade imagery. Where exposures occur, deposits derived from the Green River Formation are composed of breccia that are similar to those described by White and others (2015) and Coe and others (2016), which may be an indicator of very rapid movement and deposition. In those flows, ground hummocks appear more pronounced. Other deposits derived from the softer Wasatch Formation have a higher, more fluidized mud/clay content with common fragments of soft, plastically deformed claystone. Recent earth-flow pathways have undergone little erosion or ground-movement disturbance. In some of the most recent historic flows, the ruptured, torn, and contorted ground surfaces have not yet re-vegetated. This unit includes landslides that are presently active with ongoing ground movements that have been detected or measured. Thickness is unknown but likely highly variable.

Qefi — **Intermediate earth-flow landslides (lower Holocene to Upper Pleistocene)** — Earth-flow deposits where flow pathways can be discerned in LiDAR imagery. Intermediate earth-flow pathways are older than Qefr, based on either cross-cutting relationships, an overall smoothing of ground morphology by weathering and erosion, and development of drainage networks into the deposit. These older deposits may be susceptible to creep during periods of high precipitation. Thickness is unknown but likely highly variable.

Qefo — **Old earth-flow landslide deposits (upper Middle Pleistocene?)** — Old deposits of earth-flow landslides with abundant angular weathered blocks of basalt at the surface. These deposits are armored with basaltic blocks and are topographically inverted remnants compared to the younger surrounding landslide and earth-flow landslide topography. Thickness is unknown.

Qlsu — **Landslides, undivided (lower Holocene to upper Middle Pleistocene)** — Undivided, predominantly mud-rich earth-flow landslide deposits that mantle slopes below the rim of Grand Mesa where the underlying bedrock is weak, clay-rich Neogene and Paleogene formations. The deposit is typically unsorted, disturbed, plastically deformed mudstone and earth-flow breccia derived from bedrock that also contains abundant dispersed basaltic rocks from mobilized talus fields and unmapped QNbb blockfields. Unit thickness is highly variable. Where old landslide scarps occur, bedrock may be shallow but is likely disturbed. Near the toe of this unit, water well logs on file at the Colorado Division of Water Resources indicate mixed clay, mudstone and sandstone breccia, and basaltic boulders at depths ranging from 45 to 231 ft (14 to 70 m). Basaltic rock sizes range from cobble to boulder blocks up to 8-ft (2.4-m) wide. More recent earth-flow pathways (Qefr and Qefi) discerned by morphology in LiDAR imagery have been mapped separately.

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 basalt (Nb) rim by landslide slumping, generally by shear and bearing failures, rotation, and lateral displacement of the underlying, weak, Goodenough formation (Ng). Slump blocks have fissured from the rim retrogressively. This is most apparent on the north side of the rim at the West Bench above the Powerhorn Mountain Resort ski area where the Goodenough formation is thickest and successive ridges have been displaced and possibly “rafted” northward from the rim. Slump-block morphology includes a transitional range of forms. Where mostly intact, the displaced rock masses are fractured, but relatively coherent, back-tilted, linear blocks. Others are completely disaggregated and form linear blockfields composed of blocky basaltic clasts with sizes up to 10 ft (3 m). This disaggregation likely occurs from continued displacement of the rock mass by later differential, lateral, ground movement and periglacial frost wedging along discontinuities. Age is approximated by degree of disaggregation and the rough irregular rock surfaces that are typically heavily weathered and pitted. Thickness is unknown but limited to the maximum thickness of the Nb bedrock adjacent to the rim.

QNmu — **Mass movement ground displacement, undivided (Upper Pleistocene to Pliocene (?))** — This mixed unit forms the “West Bench” above the Powderhorn Mountain Resort ski area. The bench lies 400 to 500 ft (122 to 152 m) below the GMVF basaltic rim 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 movements away from the Nb rim. The bench elevation approximates the contact between the soft, easily disturbed Goodenough formation and the more indurated Green River Formation below. Near the slope break at the top of Powderhorn Mountain Resort ski area are poorly exposed, highly disturbed pockets of green and green-gray mudstone of the Goodenough formation. Age and thickness is difficult to determine, but the flattened low-relief aspect of the deposit suggests that the mass wasting began during the Pliocene and accelerated during 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 that forms the Grand Mesa Volcanic Field (GMVF) capping the Palisade Lobe of Grand Mesa. U.S. Bureau of Reclamation (USBR) well logs on the Palisade Lobe recorded up to 17 individual lava flows (Weston, 1987). Individual flows are typically highly jointed and texturally zoned from dense to highly vesicular. Long diameters of stretched vesicles approximate flow directions which generally trend westward. Joints and vesicles may be infilled with secondary minerals forming amygdules. Multiple flows commonly are separated by red paleosols that may be baked by contact metamorphism. Above the mesa rim, 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 "patterned boulders" that may be up to 6-ft (1.8-m) wide. In many locations, the basalt bedrock is covered by patchy veneers of rocky, frost-shattered regolith, which is characterized by advanced soil development that includes an orange-red to brick-red Bt horizon. A similar degree of soil development also occurs in basaltic regolith. In many areas, subsequent erosion of the soil profile constituent has left reddish-brown-stained, basaltic cobble- and small-boulder-sized rocks exposed at the surface. Cole and others (2017) reported age dates ranging from 10.49 +/- 0.06 to 9.63 +/- 0.16 Ma at the GMVF Palisade Lobe, and whole-rock and spectrometer analyses used to classify these lava flows as medium-K and high-K basalt and basaltic andesite. GMVF basalt thickness thins to the west. Unit thickness near the eastern map boundary was approximately 400 ft (122 m) reported in USBR logs (Weston, 1987). Along the western rim, near Lands End and Palisade Point, exposure thicknesses range from 200 to 220 ft (61 to 67 m). There is also a slight westward dipping gradient of 32.5 ft/mile (6.2 m/km) in the unconformable contact with the underlying Neogene/Paleogene sedimentary bedrock.

Na — **Neogene alluvium (Miocene)** — Tan to beige sandstone, siltstone, and polylithic sandy pebbly gravel. This fluvial deposit underlies and predates the GMVF basalt. The only in-situ exposure of this unit is known at Palisade Point in a recent, very steep landslide scarp that extends to the vertical face of the GMVF basalt rim (Czapla and Aslan, 2009; Aslan and others, 2012). However, well-rounded polylithic cobbles and pebbles composed of quartzite, sandstone, redbeds (red sandstone and mudstone), and granite and metamorphic rocks were also commonly seen in landslide deposits in west-facing slopes below the rim between Palisade Point and the northern tip of the Palisade Lobe. Within an earthflow deposit, a displaced pocket of this alluvium is exposed in a road cut to Palisade Reservoir No. 3. Thickness of this unit at Palisade Point rim was reported at 19 ft (5.8 m) and, based on clast lithologies and detrital sanidine tephra age constraints, it is theorized that this unit may be a Late Miocene ancestral Colorado River deposit prior to the GMVF eruptions (A. Aslan, written communication, 2018). Another location of gravel underlying GMVF basalt occurs in a 3-ft (1-m) thick exposure above Coal Creek Basin. This well-rounded pebble gravel is composed of intermediate volcanic clasts, likely from the West Elk Mountains (R. Cole, written communication, 2018).

Ng — **Goodenough formation, informal unit (Miocene?)** — 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 and very poorly exposed; ground movements have disturbed the unit along the rim. In earlier work, this unit was unnamed (Yeend, 1969; Baum and Odom, 1996), while work by USBR (Weston, 1987) and oil and gas well logs 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 variable. The USBR reported drilling into 20 ft (6 m) of this unit without encountering its basal contact (Weston, 1987). However, the unit could not be field identified along the west rim and likely edges out below the GMVF (A. Aslan, R. Cole, written communications, 2018). Unit appears thickest above the Powderhorn Mountain Resort where extensive retrogressive slumping and lateral spreading of basalt blocks occurred, forming the West Bench ground surface that approximates the contact elevation of the Goodenough formation with the underlying, more resistant Paleocene formations. Unit also thickens eastward, along the south rim of the Palisade Lobe. Approximately 7.5 miles (12.1 km) east of the SE map corner, the unit thickness is about 500 ft (152 m) (R. Cole, written communication, 2018) along State Highway 65 south of the Grand Mesa National Forest Visitor Center.

₽u — **Uinta Formation (Eocene)** — The Uinta Formation has been reported to wedge out in the map area below the GMVF. This unit interfingers within the upper part of the Green River Formation. Baum and Odom (1996) mapped the unit and describe light-brown to gray sandstone, gray marlstone, and gray siltstone. Formation contacts and rock descriptions could not be field checked, either obscured from an abundance of surficial-deposit cover, or lack of access to where it reportedly outcrops on private lands. No exposures were seen or reported by others along the western rim of the Palisade Lobe (A. Aslan and R. Cole, written communication, 2018).

₽g — **Green River Formation, undivided (Eocene)** — Gray-white to gray, yellow-tan to light-brown, and light green-gray mudstone, very fine- to fine-grained sandstone, limestone, marlstone, and minor oil shale. This unit records the sedimentation of Eocene intermountain lakes, both lacustrine and near-shore clastic facies. This more-consolidated formation creates steeper slopes above the underlying, conformable Wasatch Formation contact, and an upper landslide bench (West Bench) at the unconformable contact with the overlying Goodenough formation. This unit is prone to slope failure. Disaggregation and flow of the rockmass debris can cause extremely rapid landslides; rock-avalanche/earth-flow pathways have moved over a mile (1.6 km) down the Grand Mesa slopes. Unit thickness measured in oil and gas logs is about 960 ft (293 m).

₽w — **Wasatch Formation, undivided (Eocene and Paleocene)** — Mudstone, sandstone, and siltstone. Undivided terrestrial formation includes three members: the upper Shire Member is composed of prominently banded, variegated light-gray, gray, lavender and maroon, mudstone and channel sandstones that may have conglomeritic lenses. The middle Molina Member (sandstone) is included where it was not mapped separately in the northeast corner of the map area. The basal Atwell Gulch Member is banded light-gray, olive-gray, and maroon mudstone and thin, tan to brown sandstone. Unit contains fossil wood and plant imprints. The unit consists of soft, weakly consolidated mudstones and friable sandstones that are easily eroded and covered with rocky surficial deposits. Unit member contacts were typically obscured and could not be discerned in outcrop. Slopes in the Wasatch Formation are prone to instability and landsliding. Bedrock exposures are only infrequently seen in landslide scarps and scoured slopes where landsliding and accelerated erosion occurred. Unit thins to the southwest. Thickness measured from oil and gas logs is 970 ft (296 m).

₽wm — **Molina Member of the Wasatch Formation (Eocene)** — Massive, light-brown to olive-tan, medium- to coarse-grained, friable sandstone and infrequent beds of gray, green, and maroon to lavender mudstone. The Molina Member was only mapped in the northeast corner of the map area where 200-ft (61-m) thick sandstone outcrops are visible in surface exposures. Donnell and others (1985) stated that the Molina sandstone pinched out to the southwest on the west side of Chalk Mountain.

₽Koc — **Ohio Creek Formation (Paleocene (?) to Upper Cretaceous)** — Gray-white, light-gray, to light-brown sandstone, conglomerate, and minor thin beds of mudstone. Massive bedded, medium- to coarse-grained sandstone beds contain channel-form cross-stratified lenses ranging in grain sizes from very coarse-grained sandstone, granule conglomerate, to very coarse-pebble conglomerate with scattered small cobbles <3 in (8 cm). Polylithic, rounded to subrounded pebbles consists of chert, quartzite, sandstone, minor igneous and metamorphic rocks, and clay rip-up clasts. Dark-gray to lavender mudstone beds are thin, from lamination partings to 3-ft (1-m) thick. Sandstone at lower contact with mudstone beds contains vertical root casts. Unit is poorly exposed in the map area and typically buried by surficial landslide deposits, and only verified in exposures in the northwest corner of map area. Thickness varies between 50 and 60 ft (15 and 18 m).

Kw — **Williams Fork Formation of the Mesa Verde Group (Upper Cretaceous)** — Buff to tan, massive, cross-stratified, noncalcareous sandstone and interbedded gray siltstone, dark-gray shale, carbonaceous shale, and basal coal. This unit was deposited 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 maroon-red. The sandstone is very coarse- to medium-grained, well sorted, and contains occasional lenses of shale rip-up clasts. There are common small iron-oxide concretions. Contorted penecontemporaneous load-deformation structures occur. The upper part of the unit forms steep bench-forming cliffs. Down section, unit becomes increasingly shaley and a slope former, composed of stacked sequences of thick mudstone beds and interbedded, laterally discontinuous, channel sandstone benches. Orange-brown concretions and fossil wood are present. The basal Cameo Coal Zone outcrops about 900 ft (274 m) west of the southwest corner of the map boundary, where abandoned mine workings occur near the North Fork of Kannah Creek. The Williams Fork Formation is the oldest formation exposed in the map area. Thickness reported from oil and gas logs is about 2,200 ft (670 m).

Ki — **Iles Formation of the Mesa Verde Group (Upper Cretaceous)** — Shown in cross section only. Cross section thickness includes Cozzette and Corcoran Sandstones.

Km — **Mancos Shale, undivided (Upper Cretaceous)** — Shown in cross section only.

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

MAP SYMBOLS

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

Borrow pit

Oil and/or gas well

29482-M **US Bureau of Reclamation water well** — Showing Colorado Division of Water Resources permit number.

LE-370 **Infrared-stimulated luminescence sample** — Showing sample number

Contact

Fissures, furrows, and 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 that crosses the Palisade Lobe. The western outlet is currently occupied by Whitewater Creek.

A A' **Alignment of cross section**

Nep **Exotic pebbles (Miocene?)** — Map zones where scattered, well rounded, fine- to very-coarse pebbles, rare cobbles (< 6 in (15 cm)), and broken round fragments occur on weathered Nb bedrock surfaces. These pebbles are the only remnants of a gravel terrace that was deposited on the basalt bedrock surface in a post-eruptive river valley that flowed over the GMVF surface across the Palisade Lobe. This Neogene shallow valley is occupied by the current Whitewater Creek. Pebbles are predominantly quartzites, some vein-quartz and chert, and lesser amounts of metamorphic rocks.

TABLE 1: Feldspar IRSL Data and Date for Lands End Quad (Colorado)

Sample information	% Water content[a]	K (%)[b]	U (ppm)[b]	Th (ppm)[b]	Total Dose (Gy/ka)[c]	Equivalent Dose (Gy)	n[d]	Scatter[e]	Age (yrs)[f]
LE-370	25 (59)	1.48 ± 0.04	1.20 ± 0.21	9.17 ± 0.32	3.19 ± 0.09	997 ± 67[g]	12 (15)	15%	312,540 ± 22,810[g]

[a]Field moisture, with figures in parentheses indicating the complete sample saturation %. Ages calculated using 25% of the saturated moisture (i.e. 0 (25) = 25 * 0.25 = 6).
[b]Analyses obtained using high-resolution gamma spectrometry (high purity Ge detector).
[c]Includes cosmic doses and attenuation with depth calculated using the methods of Prescott and Hutton (1994). Cosmic doses were about 0.20-0.32 Gy/ka.
[d]Number of replicated equivalent dose (D_E) estimates used to calculate the total. Figures in parentheses indicate total number of measurements included in calculating the represented D_E and age using the central age model (CAM); analyzed via single aliquot regeneration on quartz grains.
[e]Defined as "over-dispersion" of the D_E values. Obtained by the "R" factor program. Values >30% are considered to be poorly bleached or mixed sediments.
[f]Dose rate and age for fine-grained 250-90 micron sized quartz. Exponential + linear fit used on D_E, errors to one sigma.
[g]Age for fine-grained 180-90 microns sized K-feldspar, post IR230C; no anomalous fade. Exponential + linear fit used on D_E, errors to one sigma.

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