COLORADO GEOLOGICAL SURVEY
COLORADO SCHOOL OF MINES
GOLDEN, COLORADO

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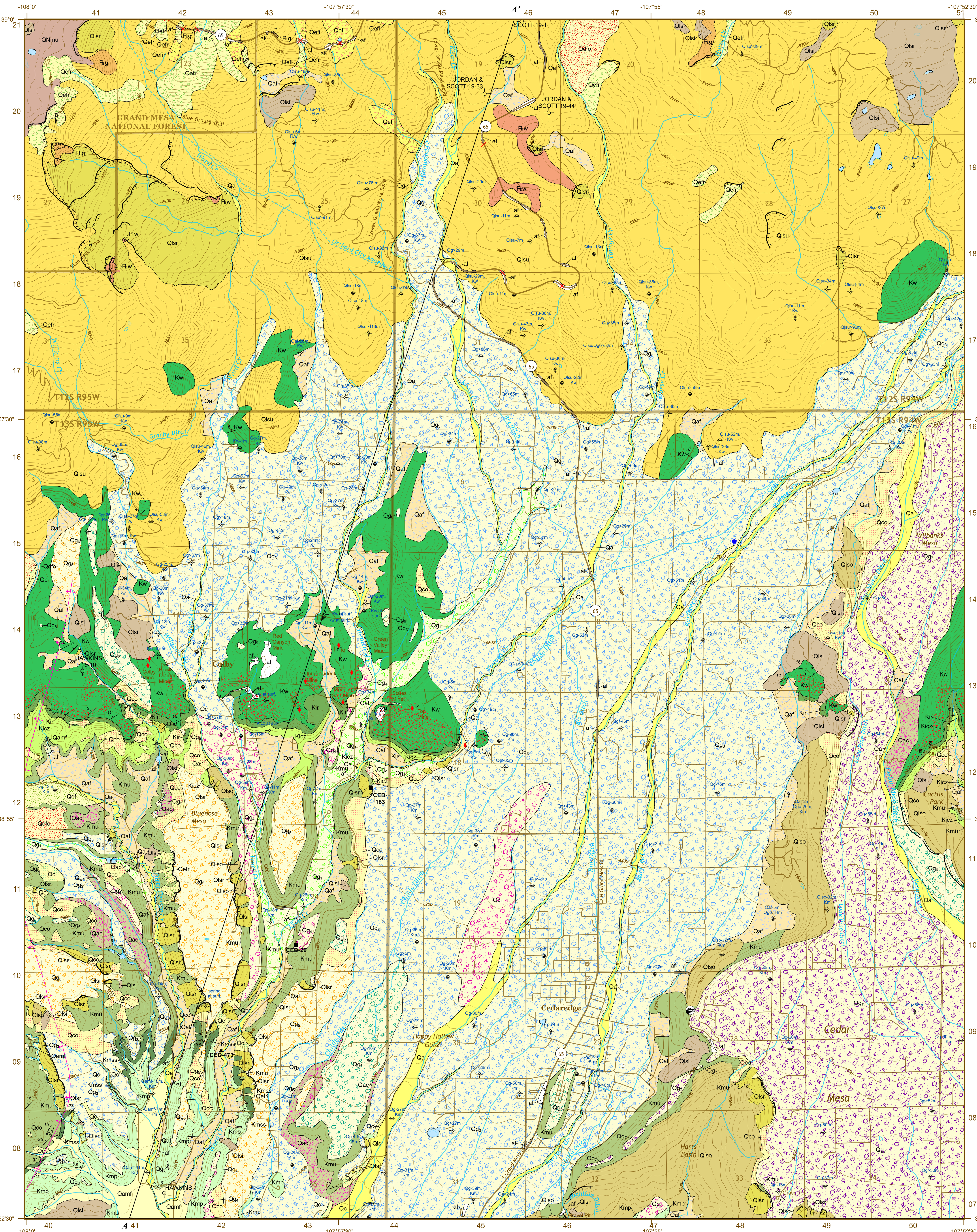

Geology mapped in 2019
GIS and cartography by Pangaea Geospatial, LLC.

SCALE 1:24,000

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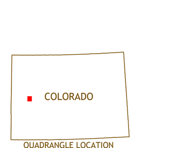
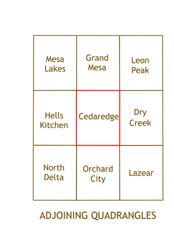
CONTOUR INTERVAL 40 FEET



QUADRANGLE LOCATION



ADJOINING QUADRANGLES

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

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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
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

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GEOLOGIC MAP OF THE CEDAREDGE QUADRANGLE, DELTA COUNTY, COLORADO

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2023

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DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af **Artificial fill (uppermost Holocene)** — Gravel, sand, silt, and clay emplaced by human activities. Artificial fill may include both controlled engineered and (or) uncontrolled and unsorted fills locally placed for road embankments, reservoirs dams, and coal-mine reclamation sites. Thickness is highly variable, from shallow disturbed grading areas to embankment fills up to 10-m thick measured on State Highway 65.

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 events. Clasts are typically subangular to rounded Neogene basaltic rocks of the Grand Mesa Volcanic Field (GMVF), reworked from rocky alluvial and debris-flow deposits (Qg) and various mass-wasting deposits. However, sandstone clasts are present in the unit where streams flow through exposures of Williams Fork Formation (Kw) and Rollins Sandstone (Kir). Deposits typically occur along the floors of other incised creek channels. The unit may not locally be mapped if the channel is too narrow (<12 m wide). Thicknesses are highly variable; in some locations it is limited to bed-load sediments in a ravine, but in broader channels likely does not exceed 1.5 to 2 m. Areas of unit Qa along narrow creek bottoms, ravines, and channels are periodically subject to dangerous flash flooding. Unit Qa is also mapped on the floor of the underfit Happy Hollow Gulch valley, which incised into Mancos Shale (Km) bedrock as it neared its confluence with Ward Creek. Holocene stream capture by Surface Creek resulted in a lower-energy depositional change, and deposition of finer-grained gravelly to sandy mud sediments.

Qaf **Alluvial-fan and slopewash deposits (Holocene to Upper Pleistocene)** — Gray to dark-brown to dark reddish-brown, unsorted to poorly sorted, poorly stratified, sandy to silty clay that locally may contain dispersed pebble- to boulder-sized clasts. Unit contains valley-fill deposits of coalesced alluvial fans and may include unmapped alluvial-colluvial (Qac) sediments including slopewash and small, highly fluidized earthflow sediments transported from soil slips on adjacent hillsides. The typical deposit generally consists of fine-grained sediments transported as mud derived from clay-rich bedrock onto gentle to moderately sloping valley-side slopes and valley floors. The unit locally may contain shale fragments and can be gravelly where reworked pebble-to-cobble clasts were eroded from older and higher basaltic gravel (Qg) units that cap adjacent mesas. In valleys such as Ward and Dirty George creeks, the unit locally may have buried lower stream alluvium (Qa). Unit Qaf is also mapped in broad swales and shallow valleys on the lower flanks of mesa risers, near exposed bedrock, and landslide terrain where the unit is more typical of slopewash in low-gradient areas such as slump-block depressions. Unit thickness is variable. Thickness in water-well logs range from 5 to 11 m. In typical slopewash swales it is likely to be thinner, as indicated by one water-well log that suggests a thickness of 3 m. Sample CED-473 collected from valley fill at 2.5 m below ground surface (BGS) at a cut bank along Ward Creek yielded a radiocarbon age estimate of 6,640±30 years BP (table 1). Younger channels and unmapped side gullies have been incised 2 to 6 m into this unit. Flash flooding and mud and (or) debris flows locally may occur in and downstream of the many tributary channels that discharge onto, and through this unit. Swelling-soil hazards may occur where unit Qaf sediments are derived from expansive clay units such as in the Mancos Shale, swelling-soil hazards may locally occur.

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 on broad alluvial fans and valley floors in local drainage basins underlain by the Mancos Shale (Km) in the southwest corner of the map area. Sediments were deposited primarily by hyperconcentrated water-flood sources with occasional local input by muddy debris flows and hillside slopewash. The deposit consists of interlaminated to thinly interbedded beds that record individual mudflow depositional events. Some layers have incipient Bt-soil horizons, which suggest perhaps a few thousand years of nondeposition and soil development prior to burial. Lenses of muddy gravel are locally present, especially near the base of the unit. The gravel clasts consist predominantly of reworked sub-rounded to sub-angular basaltic pebbles and cobbles. This unit has been dissected up to 2.5 m by recent stream erosion. Thicknesses from water-well logs range from 6.7 to 15.5 m. This clay-rich unit may be susceptible to swelling-soil and piping soil-dissolution (pseudokarst) hazards.

Mixed Alluvial and Debris-Flow Gravel Deposits (Pleistocene) — Basaltic gravel deposits at various heights above stream level and of different ages cover extensive areas throughout the central and southern parts of the map area where they aggraded and formed broad treads of coalesced fluvial outwash, debris-flow fans, and paleovalley-fill sediments. Through the process of topographic inversion, these deposits now form a series of elevated and dissected, gravel-capped, relatively flat-lying mesas that have terrace or fan-like geometries with a slope profile that slopes upward toward older landslide-complex source areas (Qlsu), towards the northern part of the map area and to the northwest (White and Palkovic, 2019) along the high flanks of Grand Mesa. The gravel deposits remnants are typically older at progressively higher elevations. However, sediment age dating and surface morphology suggest that major drainage basins, such as Surface Creek, remained actively aggrading during the Late Pleistocene to Holocene, and younger gravel deposits buried older gravel deposits, making the relative age hierarchy of some different Late to upper Middle Pleistocene-aged gravel units difficult to determine. Other complexities in assigning relative age of these deposits include the segregation and isolation of concurrent alluvial-fan aggradation and down-cutting alluvial systems in paleovalleys separated by bedrock ridges, which have both differing elevations and longitudinal slope profiles. The gravel surfaces elevations are similar where they outlet from the landslide terrain. However, the longitudinal gradient for some gravel unit surfaces, such as that of the Ward Creek basin, is steeper where they cross Cretaceous sandstone (Kw and Kir) knickpoint to highly erodible Mancos Shale.

Within Qg units, three major types of deposits are present: 1) tan to tan-gray, debris-flow deposits, stratified by individual flow events, containing very poorly sorted, sub-angular pebbles to boulders in an unsorted sandy-mud matrix that contain very large boulder (≤ 2.5 m) trains and levees; 2) gray, riverine, alluvial deposits containing beds of sub-rounded to well-rounded pebbles to small boulders, densely packed and imbricated in a moderately to well-sorted sand matrix; and 3) olive-gray to tan-gray, fine-grained, thinly bedded to interlaminated sandy mudflow deposits with scattered, matrix-supported pebbles to small boulders. Cut-and-fill channel deposits are present, typically composed of debris-flow deposits. Gravel clasts in the deposit are composed predominantly of basaltic rocks of the GMVF. Minor amounts (<5%) of non-basaltic rock types may be locally present, including sandstone, siltstone, clinker, chert, carbonate concretions, and well-rounded polylithic pebbles and cobbles. These minor clasts constituents are eroded from Upper Cretaceous rocks or reworked from Paleogene- to Miocene-aged sedimentary rock units within the landslide complexes. The thickness of the deposits varies within individually mapped gravel units listed below. The degree of weathering and presence of white- to cream-colored calcic soil development (Bk horizon) increases with increasing relative age of the deposits. Topsoil on the older units is typically reddish-brown to reddish-tan. Erosion and weathering of the ground surface has modified the normal reddish-brown topsoil, creating a pinkish-white chalky appearance from the erosion of surface soil horizons and the exposure of the well-developed Bk calcic horizon. This horizon is best exposed along mesa rims. Basaltic boulders exposed on the surface have weathering rinds, may be heavily stained with desert varnish, fractured, and have deep weathering pits that form a pockmarked appearance. With increasing relative age, sediments are typically more consolidated, and streaks of blue-gray mineral staining are locally common. In certain basal zones of some of the older deposits, there is sufficient calcite cement to form conglomerate that outcrop as thin ledges (≤ 1 m). Side slopes and swales eroded into risers of the older units are typically mantled with deposits of unit Qaf, old colluvial deposits (Qco), and landslide deposits. Terminology for gravel deposits generally follow that of Noe and Zawaski (2013) and Noe and others (2015a and 2015b). However, based on recent lidar data of the southern map boundary at the Surface Creek gravel surface, this map has different interpretations with the enumerated Late Pleistocene units. Gravel deposits are present at seven level in the map area. Symbols with number on gravel deposits indicate thicknesses of basaltic gravel that were based on water-well log data accessed from the Colorado Division of Water Resources (DWR) map viewer.

Qg_1 **Gravel deposit one (Lower Holocene)** — Unit underlies lowest terrace level on valley floors. Division of Water Resources water-well drill logs indicate that thicknesses of the unit ranges from 18 to over 34 m near the confluence of Cottonwood and Kiser creeks. The unit surface is typically incised 6 to 9 m to the stream level channel that contains unit Qa, and locally may be buried by hillside Qaf deposits.

Qg_2 **Gravel deposit two (Lower Hoocene and Upper Pleistocene)** — Qg_2 deposits are not commonly recognized in the map area, and may have either been deposited onto older fan surfaces and not recognized, or been locally reworked and (or) buried by later aggradation of gravel deposits that were deposited by the many streams that flow into the central part of the map area (e.g., Surface Creek surface). One Qg_2 remnant, 20 m above stream base level, is mapped approximately at the confluence of Young and Kiser creeks northwest of the Town of Cedaredge.

Qg_3 **Gravel deposit three (Upper Pleistocene)** — Unit Qg_3 includes the major alluvial fans that outlet and coalesced to form the broad mesa that underlies the towns of Cedaredge and Orchard City (Surface Creek surface), which extends southward, off map, to the confluence with the Gunnison River (Noe and Zawaski, 2013). In a landslide scarp exposure, a sandy mud sample (CED-183) collected 11 m BGS near the base of this unit, yielded an OSL age estimate of 19,245±1,640 yrs BP. The gravel that underlies this extensive surface likely was deposited as outwash during the later Pinedale glaciation (Marine Isotope Stage 2 (MIS-2)). The aggradation of unit Qg_3 likely buried remnants of older Qg units. The upper surface of unit Qg_3 may also be overlain by unmapped deposits of units Qg_1 and Qg_2 that issued from the mouth of drainage channels at the apex of the gravel fans. DNR water-well log point locations shown on the map reveal unit thicknesses commonly 50 to 60 m, with some wells exceeding 80 m. Other conspicuous Qg_3 mesa remnants lie west of Dirty George Creek on a alluvial-fan slope that rises northwestward towards the flank of the Flowing Park Lobe of Grand Mesa (White and Palkovic, 2019). These mapped gravel surfaces are grouped into unit Qg_3 based on elevation above base level; however, the reddish-brown topsoil and Stage III (Machette, 1985) Bk horizons that outcrop as a chalky white-colored band suggests they may be more correlative with Qg_4.

Qg_4 **Gravel deposit four (Upper Pleistocene)** — Deposits of unit Qg_4 units underlie terrace remnants and treads within the valleys of Ward and Kiser creeks. From a fluvial terrace tread exposed in a road cut along R Road, 40 m above the current confluence of Ward and Kiser creeks, a sample (CED-20) of pebbly sand was taken approximately 5 m BGS that yielded an OSL age estimate of 34,145±2,560 yrs BP (MIS-3). The dated deposit is 60 m lower in elevation than the top of the mesa (Qg_3 – Surface Creek surface) near Cedaredge. This can be attributed by a paleomorphological isolation and accelerated incision of the Ward Creek basin from the continued aggradation of the Surface Creek depositional surface. There are remnants of older mesa ridgelines of Qg_5 and Qg_6 gravel and older colluvium (Qco) that capped a shale bedrock rise between Ward Creek and the Surface Creek Qg_3 surface, now mostly eroded away. On the Surface Creek surface, morphology based on the lidar hillshade model appears to indicate that the Qg_3 unit aggraded and buried most Qg_4 surfaces except for an isolated subtle thin ridgeline near Happy Hollow. The Qg_4 unit correlates to the early part of the Pinedale glaciation.

Qg_5 **Gravel deposit five (upper Middle Pleistocene)** — The Qg_5 unit forms high mesa remnants in the Ward/Kiser drainage basin such as Bluenose Mesa that are underlain by Pierre Shale (Km). The gravel deposits have a reddish-brown to red-tan topsoil and a 1- to 2-m thick, strong Stage III$^+$ (Machette, 1985) K horizon has developed where the gravel clasts are fully encrusted and interclast pores are filled with secondary calcium carbonate. The K horizon forms a chalky-white band in the deposit where it is exposed at landslide scarps. Along mesa rims, the petrocalcic K horizon may weather to form abundant angular pebble-sized calcrete clasts in a chalky white-colored matrix. Unit is downslope of former outcrops and near-surface beds of Kw and Kir sandstones, which resulted in noticeably more sandstone and red clinker clasts in the gravel. Thicknesses observed along landslide scarps were 6 to 10 m. No water-well data is available for thicknesses in the middle of the mesas composed of unit Qg_5. Deposits of unit Qg_5 may correlate with outwash of the Bull Lake glaciation.

Qg_6 **Gravel deposit six (upper Middle Pleistocene)** — Gravel remnants of unit Qg_6 form isolated small flattened hilltops and narrow ridgelines on hills of exposed Kw bedrock, low mesas isolated on the Qg_3 Surface Creek surface east of Happy Hollow Gulch and the Cedaredge cemetery, and an alluvial-fan tread on the east side of the apex of the Cedar Mesa (Qg_7) mesa. The topsoil is a reddish-brown color. A water well log on a Qg_6 mesa remnant penetrated 16 m of basaltic gravel. Based on elevation and soil development, Qg_6 unit may correlate with pre-Illinoian to early Bull Lake glaciation.

Qg_7 **Gravel deposit seven (lower Middle Pleistocene)** — Unit Qg_7 is very similar to Qg_6 and forms an ancient, extensive, and prominently higher-elevation alluvial fan east of Cedaredge called Cedar Mesa. The topsoil is silty clay, reddish-brown in color, and contains reworked loess at the surface. Below the reddish-brown topsoil is a 1- to 2-m thick, well-developed, Stage III$^+$ to IV (Machette, 1985) K horizon that forms a chalky-white band in the deposit where it is exposed at landslide scarps. Near, and above the mesa rims, the petrocalcic K horizon forms a pinkish-white, well-consolidated calcrete that weathers into abundant angular pebble-sized clasts in a chalky looking matrix. Comparatively, the downslope longitudinal profile of the top of Cedar Mesa is steeper than it is for the top of Cedaredge Mesa (unit Qg_3, Surface Creek surface); the surface elevation is 160 m higher than the Qg_3 surface near its apex, but decreases to 115 m at the south border of the map area where the fan morphology of the unit is best expressed. Cretaceous bedrock from the upper Mancos Shale (Kmu) to the Williams Fork (Kw) Formation is exposed along the steeper-sloped riser. Various-age landslides (Qlsr, Qlsi, and Qlso) have also formed along the riser on the flanks of Cedar Mesa. Unit thickness is variable and likely reflects aggradation of the gravel fan into a topographic low such as a preexisting valley in the paleolandscape. Thickness of 30 m was measured along the west riser at the Cedar Mesa Road and in exposed landslide scarps near the south map boundary. However, DWR log data from water wells in the interior of the mesa fan recorded up to 80 m of basaltic bouldery gravel. The unit is approximately the same elevation as Petrie Mesa, which Noe and others (2015a) reported contains the Lava Creek B ash (640 ka). Ash was not encountered in the map area.

Qdf **Debris-flow deposits (Holocene)** — Brown-gray to tan-gray, clast-supported, poorly sorted, poorly stratified, bouldery deposits formed from episodic transport of rock fragments in a viscous to hyperconcentrated debris-laden flow. The deposit matrix is unsorted pebble-gravel, sand, silt, and clay. Clasts are mostly subangular-to-rounded basaltic rocks of the GMVF up to 3 m long. Much less common are smaller boulder- to cobble-sized sandstone and clinker clasts derived 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 (Tg). This unit's surface, as observed in lidar hillshaded imagery, suggests channelized and braided stream morphology. The top of this unit is 6 to 12 m above the Dirty George Creek where the creek enters the map area. Thickness is variable but log data from a water well that penetrates the unit records a thickness of 12 m. As this unit transitions to low gradient (<5°) and smooth slopes, it likely correlates with unit Qg_1.

Qdfo **Old debris-flow deposits (Upper Pleistocene)** — Late Pleistocene debris-flow deposits commonly occur where creek channels exit areas of steeper slope and sediments fan out and aggrades in broader valleys. Deposits and surface morphology are similar to those of Qdf deposits. Unit is mapped in two areas within the map area. In high landslide terrain at the north border of the map unit, east of State Highway (SH) 65, the Qdfo unit in the basin of Youngs Creek includes an older debris-flow fan that rises 25 m above the stream channel. Further south, the unit surface is reddish-tan in color and mapped within the paleovalley of Dirty George Creek and its tributary, Sand Creek. Transported basaltic blocks in the southern part of the map units, exposed on the surface, are highly fractured, and heavily stained with deep weathering pits and covered in lichen. Well-rounded quartzite pebbles and cobbles are present in the deposit; likely, they are reworked from conglomerate of Paleogene and Neogene age. Unit thickness is 4 m 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 8 m into the deposit. Near Dirty George Creek, as this unit transitions to low gradient (<5°) and smooth slopes, it correlates to unit Qg_3.

ALLUVIAL-COLLUVIAL DEPOSITS

Qac **Alluvial-colluvial deposits (Holocene)** — Olive-gray to dark-gray, sandy-to-silty clay with sporadic dispersed pebbly gravel that was deposited in a low-energy mixed alluvial and colluvial environment on low-gradient (typically <15°) slopes. Gravel is composed chiefly of basaltic clasts reworked from older gravel deposits. The sediments are typically deposited by slope rilling and slopewash processes. Unit is poorly sorted and poorly stratified and is typically deposited along the lower flanks of hillsides and mesa ridges in areas where an active stream or drainage channel is not present. Unit is around 2-m thick and localized areas may include bedrock residuum. Swelling-soil hazards may occur in clay-rich deposits of this unit where it is derived from the weathering of Mancos Shale.

MASS-WASTING DEPOSITS

Qc **Colluvial deposits (Holocene)** — Olive-gray to tan-gray rocky sediments on hillsides 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 units. The reworked basaltic boulder- to pebble-sized clasts are dispersed in a sandy clay matrix derived from the underlying bedrock. Deposit thickness likely does not exceed 3 m with some deposits ranging from less than 1.5 m to a stony residuum on weathered bedrock slopes at the angle of repose. Swelling-soil hazard may occur where the deposit is clay rich and derived from Cretaceous shale rocks.

Qco **Old colluvial deposits (Upper and Middle Pleistocene)** — Old colluvial deposits that mantle hillsides, mesa risers, and swales on steeper slopes with gradients up to the angle of repose. The sediments are reworked from Upper and Middle Pleistocene gravel units (Qg_3 through Qg_7) and exposed bedrock. These deposits are reddish-brown to light tan-gray and moderately consolidated. They may contain slopewash sediments that mobilized downslope from exposed bedrock and (or) rocky surficial deposits that cap higher slopes. Unit is unsorted and poorly stratified, containing abundant subangular to subrounded, boulder-sized clasts in a gravelly clay matrix. A well-developed, Stage III (Machette, 1985), Bk soil horizon forms a chalky-white band where exposed in landslide scarps. Where derived from older mesa gravel, weathered basaltic boulders exposed on the surface are heavily stained, fractured, and pockmarked by weathering pits. Basal zones in older Qco deposits in contact with underlying Pierre Shale (Km) locally may be cemented by calcium carbonate. At the base of near-vertical sandstone outcrops of the Kw and Kir units, the deposit forms talus. Deposit thickness likely does not exceed 3 m. Some deposits are less than 1.5 m thick and locally may only be a veneer of rocks consolidated within a weathered K-horizon soil matrix that extends into the underlying bedrock. Unit may locally contain localized unmapped soil-slip landslide deposits. The bouldery deposit armors the slope and subsequent erosion into softer underlying bedrock has formed triangular-shaped facets on some Qco deposits.

Qlsr **Recent landslide deposits (uppermost to Middle Holocene)** —Variegated brown, brown-gray, gray and reddish-gray, unsorted, unstratified, chaotically mixed deposit of abundant cobble- to boulder-sized basaltic rocks of the GMVF in a matrix of gravelly to silty clay with soft, plastically deformed, clay-rich sedimentary rock fragments. Recent landslide morphology was interpreted from lidar 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 landforms. In the landslide terrain in the northern portions of the map area, Qlsr deposits behave more plastically and failed to mobilize as a fluidized flow with long sinuous runout zones (Qefr). Most of the mapped Qlsr deposits overlie heavily weathered clay-rich Cretaceous rocks. However, the most extensive Qlsr landslide deposit near the northwest corner of the map area is underlain by Paleogene Green River (Tg) and Wasatch (Tw) formations. Many Qlsr landslides are historical and were initiated along mesa risers (where shale bedrock is shallow) when lands were developed for agricultural use and irrigation commenced. Thicknesses are unknown, but likely variable depending on the size of the landslide deposit. For land-use purposes, this map unit should be considered to contain potentially active landslides and prone to continued movement.

Qlsi **Intermediate landslide deposits (Middle Holocene to Upper Pleistocene)** — Intermediate-aged landslide deposits similar in size and composition to Qlsr landslides that can be discerned in lidar hillshade imagery, but they have been smoothed and revegetated during extended exposure to weathering and erosion. These deposits are prehistoric, but they may be susceptible to reactivation during periods of above normal precipitation or if disturbed by ground modifications such as excavations and (or) fill placements. The stability of intermediate-aged landslide deposits in unknown, but they should not be considered to be dormant. They will likely be sensitive to ground disturbance and (or) addition of water. Stability analyses should be completed prior to land usage that may include engineered works and (or) occupied structures.

Qlso **Old landslide deposits (Upper and Middle Holocene)** — Old landslide deposits typically occur in riser slopes that flank the older mesas (Qg_5 through Qg_7) that overlie weak clay-rich bedrock units. Thick chalky-white Bk horizons are present. These landslide deposits contain abundant weathered and pitted basaltic boulders at the surface that armor slopes. The ground morphology is more smoothed and eroded compared to that of the Qlsi unit. However, landslide morphology is still discernable in lidar hillshade imagery. Unit thickness is highly variable. Water well driller's logs recorded thicknesses of 12 m and 32 m. Old landslide deposits are generally stable, but they can be sensitive to ground disturbances and (or) addition of water.

Qefr **Recent earthflow deposits (Upper to Middle Holocene)** — Recent, variably colored, unsorted landslide deposits composed of very soft, clay-rich, disturbed sedimentary rock, plastically deformed mudstone fragments, and silt and clay. The unit contains abundant pebble to boulder-sized basaltic rock clasts derived from glacial till and basaltic blockfields below the GMVF rim that lies north of the map boundary. Unit contains landforms that indicate recent earthflow movements that have remobilized older mass movement (QNmu) and landslide (Qlsu) deposits within the northern part of the map area. 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 lidar imagery. Recent earthflow pathways have undergone little erosion or subsequent ground-movement disturbance. On some of the more recent flows, ruptured, torn, and contorted ground surfaces have not yet revegetated. SH 65 crosses many earthflow paths along the northern margin of the map area; and where it does, there is typical road damage related to continued ground movements. Thickness is unknown, but likely is highly variable. A 1.7 km-long Qefr deposit within the Grand Mesa National Forest flows from above SH 65 to partially block the Ward Creek valley below. Lobate forms at the top of the earthflow toe are up to 40 m above the adjacent valley floor. These deposits are susceptible to creep and reactivation during periods of high precipitation. Deposits of the Qefr unit are unstable, susceptible to continued movement, and are considered potentially active when being considered for land development.

Qefi **Intermediate earth-flow deposits (Lower Holocene and Upper Pleistocene)** — Variably colored, landslide deposits that are mapped where earthflow pathways can be discerned on lidar imagery within undivided landslide (Qlsu) deposits. Intermediate earthflow pathways are older than those of unit Qefr, based on a combination of cross-cutting relationships, muting of ground morphology by weathering and erosion, and development of drainage networks on the deposit. Thickness is unknown, but likely highly variable. 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 rim of Grand Mesa and the QNmu unit bench in the northwest corner of the map area where the underlying bedrock is weak, clay-rich Paleogene (Peg and Pew) formations, and shale intervals of the upper Williams Fork (Kw) Formation. The deposit is typically unsorted, disturbed, plastically deformed mudstone and earthflow breccia derived from clay-rich bedrock, which also contains abundant, angular to subrounded, basaltic clasts that were mobilized from talus deposits, glacial till, and blockfield deposits to the north below the GMVF basaltic rim (White and Palkovic, 2019). Basaltic clasts fragments range in size from cobbles to boulders as much as 2.5 m wide. Unit thickness is highly variable. At landslide scarps bedrock may be shallow, but it is likely to be disturbed. Water-well logs on file at the Colorado DWR shown on the map indicate thicknesses of landslide deposits with entrained basaltic boulders locally exceed 113 m. Early Pleistocene landslide deposits of this unit were the source materials for younger Pleistocene (Qg_3 through Qg_7) gravel deposits mapped on this quadrangle and adjacent quadrangles (Noe and Zawaski, 2013; Noe and others, 2015a; White and Palkovic, 2019). More recent earthflow mobilizations and landslide reactivations within this unit, discerned by scarps and ground morphology in lidar imagery, have been mapped separately as units Qefr, Qefi, Qlsr, and Qlsi.

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 that lies 122 to 152 m below the GMVF basaltic rim where the Granby Reservoirs/Land O' Lakes topographic bench is located (White and Palkovic, 2019; Chesnutt and others, 2019). This unit only occurs in the upper northwest bench of the map area and contains linear blockfields composed of basalt clasts, flat-lying linear depressions, fine-grained slopewash deposits, and brown-black fine-grained pond deposits. This unit is characterized by parallel to arcuate scarps that indicate continued or episodic lateral ground movement down slope and away from the GMVF basalt rim that is off map to the north and northwest. The bench elevation approximates the contact between the soft, easily deformed Goodenough formation (informal unit of Cole and others, 2013) and the underlying more indurated Green River Formation (Tg). Age and thickness is difficult to determine, but the 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).

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Tg **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 thinly bedded to interlaminated unit records the sedimentation within an intermountain lake during the Eocene. Unit contains both lacustrine and nearshore clastic facies. This more consolidated formation creates steeper slopes between the conformable interfingering contact with the underlying Wasatch (Tw) Formation and, outside of the map area to the north, the upper landslide bench (Granby Reservoirs/Land O' Lakes bench) near the unconformable contact with the overlying informal Goodenough formation of Cole and others (2013). However, unit Tg is also prone to slope failure; it is almost entirely buried by surficial landslide deposits of Quaternary and Early Neogene age (QNmu and Qlsu units) and is only exposed at the northern margin of the map area at landslide scarps, soil slips, and some road cuts along SH 65. Disaggregation and flow of rock debris from this unit can form long pathways of earthflow deposits (Qefr) that have moved as much as 1.5 km downslope. Unit thickness shown in cross section is estimated at 230 m.

Tw **Wasatch Formation, undivided (Eocene and Paleocene)** — Undivided, variegated reddish-brown, light-gray, gray, lavender, and maroon mudstone, weakly cemented sandstone, and shale. This color-banded formation was deposited in a terrestrial environment and is clay rich and poorly indurated. Predominantly a weak rock unit, the Wasatch Formation is disturbed at the ground surface by mass-movement processes and very poorly exposed within the undivided landslide complex (Qlsu); only locally exposed in landslides scarps, landslide slopes scoured by erosion, and SH 65 road excavations. Slopes in the Wasatch Formation at high (>2,300 m) elevations and correspondingly greater annual precipitation are prone to instability and landsliding. Unit thins to the southwest. Thickness shown in cross section is estimated at 240 m.

Kw **Williams Fork Formation (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 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. Rare, thin (<60 cm) shale beds are locally maroon-red in color. The sandstone is very coarse- to medium-grained, well sorted, friable, and locally contains ripple marks and lenses of shale rip-up clasts. There are common small (~5 cm) iron-oxide concretions. Contorted penecontemporaneous load-deformation structures locally occur. Many areas underlain by Kw bedrock are covered by landslide deposits and the sandstone is very friable and poorly exposed. However, where sandstone is exposed, the upper part of the unit locally forms outcrop benches. Down section, the unit contains more shale beds and forms ledgy slopes, composed of stacked sequences of mudstone beds and interbedded, laterally discontinuous, channel sandstone beds. Orange-brown concretions, dinosaur tracks, and fossil wood are locally present. The basal Cameo-Wheeler coal zone outcrops along a west-to-east trending belt in the left center part of the map area. This zone contains abandoned and reclaimed mine workings. Within the coal zone, ancient coal fires have formed prominent red clinker deposits that are encrusted with white mineral precipitate. Ash beds, formed by the subsurface burning of thicker coal seams, locally underlie deformed strata. Clinker types range from red stained but principally unaltered sandstone to brick-red collapse breccia, fused to form a porcellanite. Much of the upper strata of the Kw unit is buried by surficial deposits, including the Paleocene and Upper Cretaceous Ohio Creek Formation. This 30 m-thick unit is composed of sandstone and conglomerate that contains polylithic quartzite, chert, and minor igneous and metamorphic pebbles and small cobbles. These clasts were observed in landslide deposits. Total thickness estimated from oil and gas logs is 550 m shown in cross section.

Kir **Rollins Sandstone Member of the Iles Formation (Upper Cretaceous)** — Grayish-white to tan to pale-orange, fine- to medium-grained, thick- to massive-bedded, cross-stratified sandstone deposited as sandy sediment in a shoreface marine environment. Where it is not covered by expansive gravel-capped mesas, the exposed Kir unit weathers to landforms that range from benchy cliffs to, more commonly, a 30-m tall continuous vertical cliff that forms a prominent, northward-sloping cuesta. The upper massive section consists of low-angle cross-bedded sandstone capped by subhorizontal bedded sandstone. The upper part of the sandstone is commonly bleached gray-white, is increasingly friable, and has a "slick-rock" appearance that helps to make it a prominent marker bed in outcrop. Marine mollusk fossils (*Inoceram sp.*) and burrow trace fossils are locally present; most common in orange-tan, coarse-grained, calcite-cemented, medium-thick beds. The sandstone unit's upper contact locally may be stained red from ancient coal fires within the Cameo-Wheeler Coal Zone of the overlying Williams Fork Formation. Lower in the section, below the upper massive sandstone, sandstone becomes increasingly fine-grained with hummocky and swaley cross-bedding. Down section the bedding is thinner, bioturbated, and increasingly interbedded with silty marine shale. The basal contact of this unit was mapped at the first marine sandstone bed that is conformably interbedded with the underlying tongue of Mancos Shale of the Kicz member. Total thickness ranges from 40 to 45 m.

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, locally bioturbated sandstone with swaley cross-bedding and basal, interlaminated to very thin interbeds of sandy shale. The Cozzette Sandstone forms a conspicuous tan-colored, 10-m high cuesta at the Hawkins Ranch where Dirty George Creek enters the map area. The Kicz unit includes the Mancos Shale tongue interval between the Cozzette and the Rollins (Kir) sandstone members. Thickness is about 55 m.

Mancos Shale (Upper Cretaceous) — The Mancos Shale is present in the southern part of the quadrangle exposed in valleys and mesa risers ("Adobe hills"), and typically capped by gravel deposits (Qg). Hillslopes of Mancos Shale are susceptible to instability and commonly disturbed by landslides. Twelve members of this marine shale, distinguished on the basis of composition, color, and fossil assemblages were mapped in the bordering Orchard Mesa, North Delta, and Lazear quadrangles (Noe and Zawaski, 2013; Noe and others, 2015a; Noe and others, 2015b). Three upper members occur within the Cedaredge quadrangle, as well as a tongue of Mancos Shale that is included in the Iles Formation within the Kicz member. The three member contacts are conformable. On mesa risers and ridgelines, the gray to dark-gray shale typically contains an oxidized, yellow-tan stained horizon that is strongly fractured. Crystalline gypsum is the typical fracture filling. This approximately 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, the Mancos Shale is undivided. The Mancos Shale has thin bentonite beds and locally contains expansive clay minerals; swelling-soil hazards may occur.

Kmu **Mancos Shale, upper part** — Dark-gray to olive-gray, non-calcareous, fissile to subblocky, silty to sandy shale. It contains scattered, very large, orange-brown concretions up to 3.5 m long along bedding. Unit locally contains thin (<10 cm), light yellow-tan colored bentonite seams. Unit thickness is about 330 m. The shale contains invertebrate mollusk and gastropod fossils. Near Cedaredge, a shale exposure of this unit in the riser of Cedar Mesa was the site of a major marine vertebrate fossil discovery of an 11-m long mosasaur, which the author discusses in the section on Fossil Resources on Plate 2.

Kmss **Sharon Springs Member** — Dark-gray to black, organic-rich, non-calcareous, platy to fissile shale. This thin unit is typically poorly exposed and mostly covered by landslides and residuum. The exposures contain: prominent white to light yellow-tan bentonite beds (1.3 to 15 cm thick) that create a banded appearance to outcrops and 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 the bentonite beds. Partings in the shale contain powdery coatings of soft, tan to light yellow-greenish tan colored minerals. 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 upward change from black clayey shale to brownish-gray silty shale. The unit is very poorly exposed and contacts difficult to infer, except where steeply dipping at the monoclinal fold in the southwest corner of the map area where the unit was measured from 21 to 24 m thick.

Kmp **Prairie Canyon Member** — Gray to dark-gray, silty to sandy shale that is finely fissile to subspheroidal in outcrop. This unit forms residuum-covered outcrops in the southwest corner of the map area. The Prairie Canyon Member locally contains thin bentonite seams and small, rounded chips of very fine-grained, slight to moderately calcareous, cross-laminated, sandstone that may locally contain burrow trace fossils. The chips appear to be sand ripples that weather out of the shale. However, in thin interlaminated sandstone zones they can weather out into platter-sized slabs up to 4 cm thick and 40 cm wide. The top of the unit generally contains many large dolomitic concretions that, in outcrop, weather orange-tan to tan; calcite typically fills internal fractures in the concretions. In surface exposures of the shale, gypsum locally fills fractures, bedding partings, and joints. Total thickness of member shown in cross section is estimated at 381 m (Noe and Zawaski, 2013).

Km **Mancos Shale, undivided (Upper Cretaceous)** — Shown in cross section only. Thickness is about 930 m.

Kdb **Dakota Sandstone and Burro Canyon Formation, undivided (Upper to Lower Cretaceous)** — Shown in cross section only. Thickness is about 56 m.

Mz **Mesozoic Formations, undivided (Jurassic and Triassic)** — Major units include the Morrison Formation, Entrada Sandstone, and Chinle Formation. Shown in cross section only. Aggregate thickness is about 260 m.

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

MAP SYMBOLS

- **Strike and dip of inclined bedding** — Showing direction and angle of dip
- **Quarry/Borrow pit**
- **Water well** — Labeled with Quaternary map units and depth to bedrock. Bedrock map unit is labeled only if there is confidence in well-log descriptions. (>) symbol indicates bedrock was not encountered and the total depth of the well remained within the surficial deposit. Drill-log data from Colorado DWR well-permit map viewer.
- **Radiocarbon (C14) sample site (See age tables)**
- **Optically stimulated luminescence sample site (See age tables)**
- **Stream capture location of Milk Creek/Happy Hollow Gulch by Surface Creek**
- **Coal-mine spoils and piles**
- **Road damage** — Locations of cracked, heaved, buckled, and scarp-offset pavement related to ground movement.
- **Mosasaur fossil quarry site**
- **Oil and (or) gas well**
- **Contact** — Dashed where approximately located
- **Monocline** — Arrow points toward dip direction, axis line approximates steepest dip of fold, dashed where concealed.
- **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.
- 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.

Table 1. Radiocarbon ages

Field Number	Lab. No.	Material Dated	Sediment Type (map unit)	Latitude	Longitude	Elev. AMSL (m)	Approx, depth (m)	^{4}C age (^{14}C yr BP)[a]
CED 473	Beta-545254	Organic Sediment	Silty to sandy clay (Qaf)	38.89258	-107.97402	1723	2.5	6,640±30

[a] Conventional radiocarbon age, normalized to -25‰, based on 5,568 year half-life; uncertainty ± 1σ

Table 2. Single Aliquot Regeneration, optically-stimulated luminescence (SAR-OSL) ages on quartz grains from fluvial deposits (Baylor University, Waco, TX, May 11, 2020)

Field Number	Lab No.	Sediment type (map unit)	Latitude	Longitude	Elev. AMSL (m)	Depth below ground surface (m)	Aliquots[a]	Grain size (µm)	Central/ Minimum Age Model De (Gy)[b]	Over-dispersion (%)[c]	U (ppm)[d]	Th (ppm)[d]	K (%)[d]	Cosmic Dose rate (mGray/yr)	Dose Rate (mGray/yr)[d]	Central Minimum Model SAR age (yr)[b]
CED-183	BG4871	Silty sand (Qg3)	38.90357	-107.96405	1912	10	57/67	150-250	63.62 ±5.00	37 ±4	2.57 ±0.01	9.56 ±0.01	2.31 ±0.01	0.138 ±0.014	3.30 ±0.11	19,245±1,640
CED-20	BG4872	Sand and gravel (Qg4)	38.91992	-107.95393	1801	5	50/59	150-250	68.93 ±4.74	33 ±3	1.00 ±0.01	4.79 ±0.01	1.54 ±0.01	0.160 ±0.016	2.02 ±0.07	34.145±2,560

[a] Aliquots measured, used and that define lowest most De
[b] Equivalent dose calculated on a pure quartz fraction with ultra-small aliquots with 20-80 grains/aliquot and analyzed under blue-light excitation (470 ± 20 nm) by Single Aliquot Regeneration protocols (SAR; Murray and Wintle, 2003; Wintle and Murray, 2006). Equivalent dose (De) was calculated by the Finite Mixture Model (Galbraith and Green, 1990) and the four parameter Minimum Age Model (Gralbraith and Roberts, 2012) (see Fig x 2015)
[c] Overdispersion values reflects precision beyond instrumental errors; values of ≤ 25% (at 1 sigma limit) indicate low dispersion in equivalent dose values and defines a unimodal distribution. Values > 25% are associated with mixed equivalent dose signature reflecting multiple grain populations or partial solar resetting.
[d] U, Th, Rb and K content analyzed by inductively-coupled plasma-mass spectrometry by ALS Laboratories, Reno, NV; and includes dose contribution from Rb and an assumed moisture content of 10 ± 3% for the burial period.
[e] includes also a cosmic dose rate calculated from parameters in Prescott and Hutton (1994) and includes soft components.
[f] Systematic and random errors calculated in a quadrature at one standard deviation by the Luminescence Dating and Age Calculator (LDAC) at https://www.baylor.edu/geosciences/index.php?id=962356 (Peng and Forman, 2019). Datum year is AD 2010.

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