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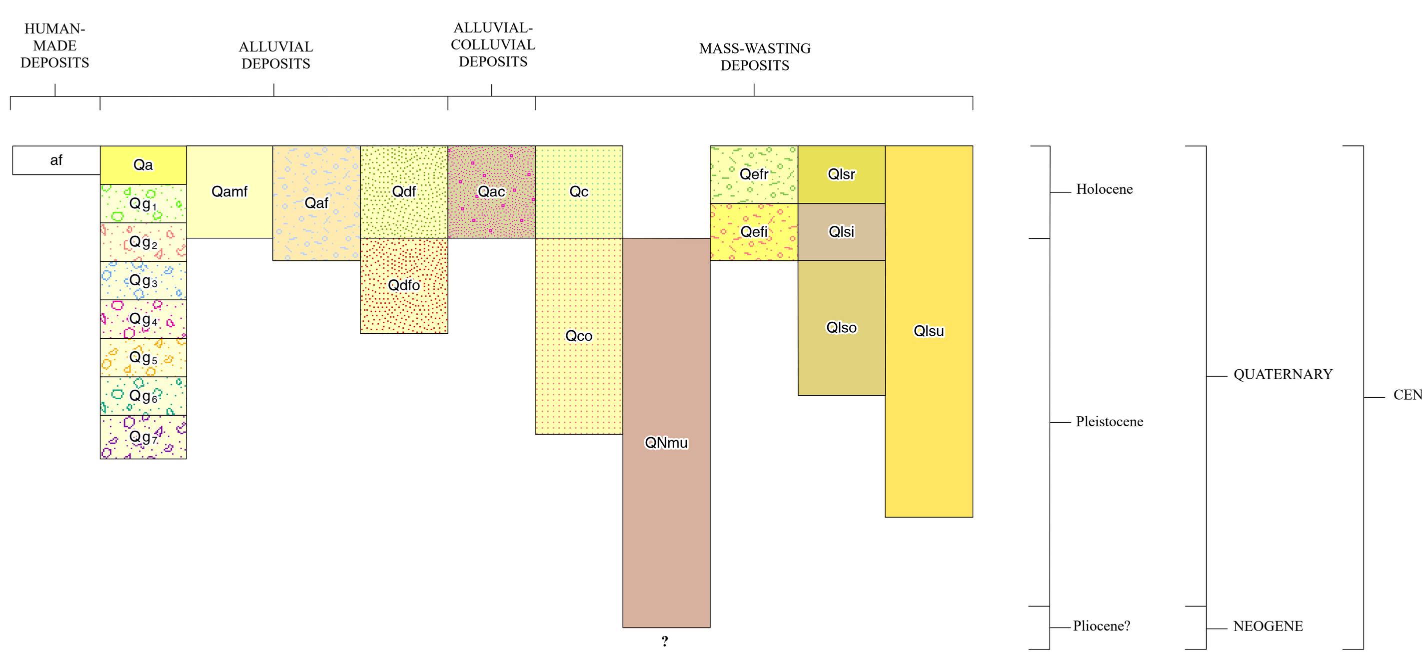
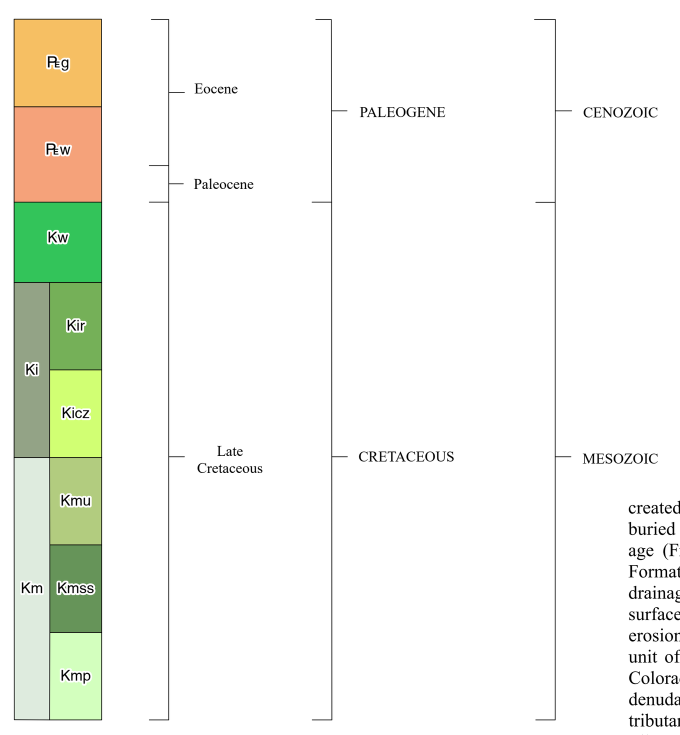
CORRELATION OF MAP UNITS

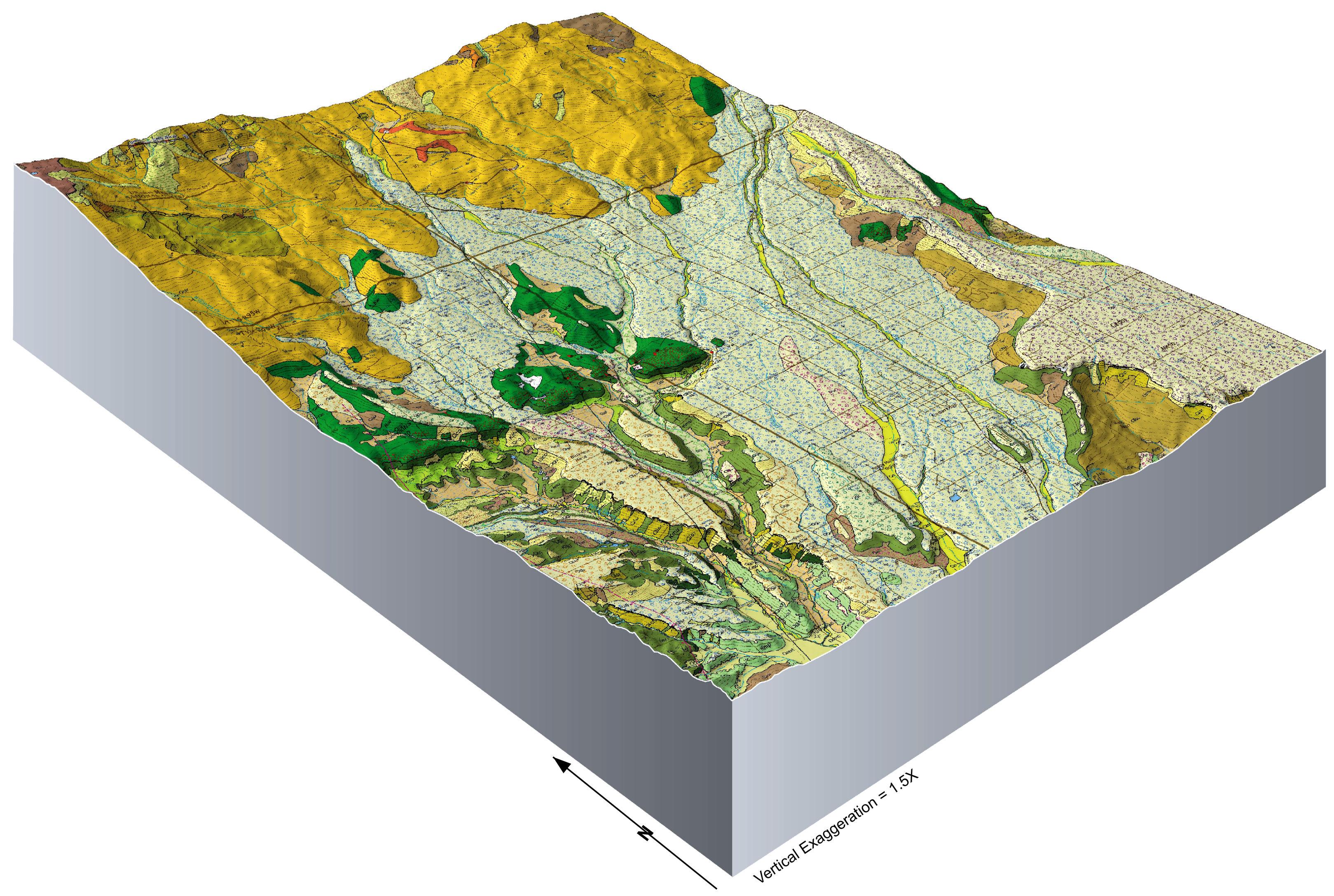
SURFICIAL DEPOSITS



BEDROCK UNITS



3-D OBLIQUE VIEW



PHYSIOGRAPHIC SETTING

The Cedaredge quadrangle lies in Delta County, Colorado, approximately 20 km northeast of the town of Delta. The town of Cedaredge is in the lower central part of the quadrangle along the north-to-south aligned State Highway (SH) 65 that bisects the map area before meandering up into steeper slopes towards Grand Mesa. These steeper slopes in the upper third of the map area are part of the southern flank of Grand Mesa and are characterized by higher elevations and hummocky, south-facing slopes underlain by landslide deposits with abundant basaltic surface boulders. The upper hummocky terrain transitions southward to lower-gradient mid-elevation bouldery mesa surfaces near Cedaredge. The highest elevation of Cedaredge quadrangle is 2,986 m above mean sea level (AMSL) at the northwest map corner within higher elevation landslide terrain in the Grand Mesa National Forest. The lowest is 1,662 m AMSL at its southern boundary where Ward Creek exits the quadrangle. The annual precipitation in the map area (National Centers for Environmental Information) ranges from 91 cm along the northern map area where alpine forest is predominant, through a mid-elevation semi-arid pinyon-juniper woodland climate of the high alluvial mesas, and to a low of 31 cm at the more arid, lower elevation, southwest flank of the map area where sparsely vegetated shale ("adobe") badlands occur. Average temperatures in Cedaredge are correspondingly about 6°C cooler than at Delta along the Gunnison River and the Grand Junction/Grand Valley area at the confluence with the Colorado River.

GEOLOGIC SETTING

The early Cenozoic and Late Cretaceous evolution of western Colorado is recorded in the transition from marine to terrestrial rocks exposed in the map area. The basal bedrock unit exposed in the map area is the upper members of the Late Cretaceous Mancos Shale. This marine shale was deposited during the transgression of the Cretaceous Western Interior Seaway (WIS). Regressive and transgressive sequences of the western shoreline of the WIS formed the sediments of the Iles Formation in shoreface and nearshore environments. Of note is the 30-m high gray-white cliffs of the Rollins Sandstone Member that is a prominent stratigraphic marker bed in the area. As the paleoshoreline regressed to the east, broad floodplain environments were created. Sand, mud, and organic-rich swamp sediments, transported from west to southwest sources, formed the Late Cretaceous Williams Fork Formation. Commercial coal deposits in the Cameo-Wheeler coal zone were formed. Uplifts during the Laramide orogeny, of Late Cretaceous and Paleogene ages, occurred along the Southern Rocky Mountain orogenic belt in central Colorado, as well as structural intermountain basins such as the Piceance Basin. The resultant uplift-driven erosion of the highlands of the orogenic belt shed a thin deposit of sand and coarse pebble-to-cobble gravel that become the sandstone and conglomerate of the Ohio Creek Formation. Later, beginning in the Paleocene, packages of clastic sediments accumulated to form the Wasatch Formation. Differential uplift during the Laramide orogeny created broad, closed, structural basins that contained freshwater lakes. The Wasatch Formation sediments were buried by a package of lacustrine and lake-shoreface sediments that formed the Green River Formation of Eocene age (Franczyk and others, 1992). After limited deposition of terrestrial sediments that buried the Green River Formation during the Late Miocene, drainage integration led to the establishment of the paleo Colorado River drainage basin on a subdued landscape. Basaltic lava of the Grand Mesa Volcanic Field (GMVF) flowed onto this surface during the Neogene (Cole and others, 2017). The GMVF is composed of basaltic rock that is resistant to erosion compared to the underlying softer Neogene and Paleogene bedrock that include the Goodenough (informal unit of Cole and others, 2013), Green River, and Wasatch formations. In late Neogene, epeirogenic uplift of the Colorado Plateau occurred, possibly coupled by mantle buoyancy and erosional-isostatic rebound by regional denudation from late Neogene and Quaternary river incision by the paleo-Colorado River and its Gunnison River tributary (Aslan and others, 2019). A few thousand meters of regional downcutting by the Colorado River and its tributaries, accompanied by topographic inversion of the resistant GMVF basalt, formed Grand Mesa.

Major Quaternary events included continuing incision and regional lowering of the landscape, Pleistocene glaciation on Grand Mesa, and mass wasting. The latter continued through the Holocene to the present day. The major mechanism of topographic lowering is continual ground instability and mass-wasting processes on the flanks of Grand Mesa. Slump blocks, scarps, disturbed and broken ground, heave and pressure ridge features, and linear earth-flow pathways are typical of the upper slopes that surround the Grand Mesa rim (Baum and Odom, 1996; White and Palkovic, 2018; Chesnutt and others, 2018; and White and Palkovic, 2019). In the map area, SH 65 is relatively straight northward until the roadway begins to meander up into this steeper landslide terrain towards Grand Mesa. Many areas in the steeper landslide terrain are actively moving and the Colorado Department of Transportation must mitigate landslide damage seasonally to maintain the roadway. Points are shown on the map where road damage was observed by the author during the 2019 mapping season. The source materials for much of the landslide deposits are basaltic blocks that have retrogressively slumped from the GMVF mesa rim, the underlying weak clay-rich Neogene and Paleogene rocks, and basaltic bouldery till and glacio-fluvial outwash of Pleistocene age.

Punctuated periods of erosion and alluvial deposition during the Middle to Late Pleistocene shed rocky alluvial sediments from the landslide terrain, likely related to glacial and interglacial epochs. This material was deposited in broad aprons of bouldery alluvial-fan gravel and rocky debris-flow deposits below the landslide terrain. Subsequent erosion and ground-surface lowering has resulted in the formation of many gravel-capped mesas. The most distinctive, highest, and oldest gravel in the map area caps Cedar Mesa, which distinctly displays alluvial-fan morphology on topographic maps and lidar imagery. The most expansive deposit is the Cedaredge/Orchard City mesa gravel at and near Surface Creek, referred to as the Surface Creek Surface. The mesa tread begins near the northeast corner of the map area, is present within the entire map area, and extends an additional 12.2 km beyond the southern boundary to a paleo-confluence with the Gunnison River (Noe and Zawaski, 2013). The amount of erosion and alluviation was not uniform in the entire map area. These mesa-forming gravel deposits likely filled pre-existing valleys with alluvial sediments that are surprisingly thick (100 m). Water-well driller's log data (CO Division of Water Resources) are shown as points on the map with the reported thickness of the basaltic gravel indicated. Ward Creek and its tributaries along the western margin of the map area has been more erosive during the Late Pleistocene and has incised more deeply than Surface Creek, exposing the sandstone beds, coal beds, and coal-fire clinker of the Iles and Williams Fork formations, and forming isolated, linear gravel-capped mesa remnants that overlie the Mancos Shale. All the mesas and mesa remnants have longitudinal profiles with gradients that slope southward towards the Gunnison River Valley, except for the western boundary of the map area where mesa profiles from the Flowing Park Lobe of Grand Mesa dip eastward towards Ward Creek.

The structural geology of the Cedaredge quadrangle reflects the regional development of Late Cenozoic basins and the general formation dip at a gentle grade away from the Uncompahgre Uplift towards the Piceance Basin to the northeast. Structural data was difficult to obtain, because of the extent of Quaternary surficial deposits that cover the underlying bedrock, as well as the subsidence and collapse deformation that resulted from coal seam fires in the Cameo coal zone that formed the clinker zones in exposed Williams Fork strata. Excellent exposure of a naturally extinguished coal fire exists at the Benson Brothers Red Shale Pit where visible coal seams transition to notably thinned, white ash beds where the subsurface fire ended.

The major structural feature in the map area is a monoclinal fold, expressed as a northwest-trending zone of steeply dipping strata in the Mancos Shale near the southwest corner of the quadrangle. The monocline is likely fault cored at depth. Steep westward dips of bedrock on the monocline limb is traceable southward to the Gunnison River and west flank of Smith Mountain where strata has been stripped away by erosion and the fault is exposed at the surface (Noe and Zawaski, 2013). In the southwest corner of the map area, the monocline continues to be expressed by measured dips of up to 37° in a band of strata that includes the Sharon Springs Member (Kmss) of the Mancos Shale. Northward, the monocline is obscured by mesa gravels. Where sandstone strata of the Iles and Williams Fork formations are exposed in the Dirty George Creek valley, the monoclinal dips are less steep and take the form of an asymmetrical fold gently plunging northward with the westward limb dipping to the northwest from 9 to 15°. This author found no surface expressions of faults, no perceived strata offsets, nor deformation-band damage zones typically seen in faulted sandstone. Hail (1972) also did not show faults on his map. However, Dunrud (1989) mapped several inferred faults in his study of the coal-bearing strata exposed in the Cedaredge area; many indicated as structure-contour offsets drawn at the top of the Rollins Sandstone (Kir) in areas covered by thick surficial deposits, and so they were likely inferred from coal exploration well logs. No oil and gas wells occur in the near-surface coal bearing strata. Regionally, the map area lies upon the trend of the ancestral Pennsylvanian-Permian Uncompahgre Mountains where the entire package of Paleozoic rocks have been eroded away prior to deposition of Mesozoic rocks. An oil and gas well log (Hawkins #1) indicate the nonconformity between the Triassic Chinle Formation and Precambrian crystalline rocks occurs at a depth of 790 m near the southwest corner of the map area in the Ward Creek valley.

WATER RESOURCES

The southern flank of Grand Mesa north of the Cedaredge quadrangle contains major watersheds that flow into the map area. The upper watersheds along the high flanks (about 3,200 m AMSL) receive high (about 125 cm) annual precipitation stored in winter snowpack. This is an important water resource, both for domestic and agricultural use, recognized by Delta County (Kolm and van der Heijde, 2014). Almost all pastures, orchards, vineyards, and crop farmland is irrigated. Many small reservoirs and agricultural diversions (ditches and aqueducts) in and near the map area are administered by the Grand Mesa Water Users Association. Almost all privately owned completed water wells draw water from unconsolidated deposits, some in landslide deposits, but most from the gravel alluvium on the mesas, or along terraces treads in incised valleys. Selected water wells from the DWR water-well database are shown on the map. Surface Creek provides water to the Town of Cedaredge and other user groups such as the Upper Surface Creek Domestic Water Users Association. The underlying rock units do not produce much water. Seasonal recharge of ground water in the gravel mesas occurs from the Surface Creek and Ward Creek watersheds that extend north of the map area.

MINERAL RESOURCES

Oil and gas, coal, coalbed methane, and clinker shale are potential mineral resources in the Cedaredge quadrangle. Coal resources exist in the basal part of the Williams Fork Formation within the map area (Lee, 1912), which were developed in the early- to mid-1900s. The Palisade coal seam mined at the Book Cliffs and above the town of Palisade pinches out eastward and is not present in the map area (Gill and Hail, 1975). The Cameo-Wheeler coal zone and related red clinker beds outcrop in a band directly above the Rollins Sandstone. The outcrop trends west to east near the middle of the map area from extensive exposures in Dirty George Creek and Ward Creek valleys, and outcrops in the risers between Cedaredge Mesa (Surface Creek Surface), Cedar Mesa, and Cactus Park at the center-east border of the map area. The coal-bearing units dip northward. Oil and gas well logs (Colorado Oil and Gas Commission COGIS) place the top of the Cameo coal zone about 990 m deep at the northern boundary of the map area. The Cameo coal zone was actively prospected, and coal was produced in this area. Coal beds, up to 4 m thick, have been reported (Lee, 1912). Dunrud (1989) reported coal-resource test borings identifying multiple coal seams. Several coal mines historically operated near Cedaredge above the Rollins Sandstone cuesta. All have been closed and the mined land reclaimed. Those disturbed and reclaimed surface zones are shown on the map. Within the coal-mining district, there has been small quarries that mine red clinker rock. As of late 2019, one commercial pit is still active – the Benson Brothers Red Shale Pit.

There has been some oil and gas drilling activity within the map area and well completions in Cretaceous rocks, but there is currently no production. Within the Mancos Shale, the Niobrara Member may have oil and gas potential using horizontal well drilling and hydraulic fracturing (fracking) completion techniques. Except for the red clinker quarry mentioned earlier, the aggregate resource value of the extensive gravel deposits is limited because they commonly have layers of mud and poorly sorted debris-flow gravel that contain high percentages of clay and silt. There are a few borrow pits in the map area. There are gravel pits along the southern boundary of the map area where the gravel layers are increasingly riverine and better sorted. Opportunities may exist for the quarrying or harvesting of weathered and pitted boulders suitable for landscaping that are commonly in the map area, particularly within drainage areas. Boulders are also commonly raked out to the sides of agricultural fields and screened out of foundation and borrow-area excavations on the many mesas of the map area.

FOSSIL RESOURCES

The marine Mancos Shale is fossiliferous and marine mollusks and gastropods can be found and collected. The author observed *inoceramid* fragments in the Prairie Canyon Member of the Mancos Shale (Kmp) near the southern map boundary, and *inoceramid* and burrowing trace fossils in the Rollins Sandstone (Kir). The Lee (1912) report of the Grand Mesa coal field contains mapped fossil collection sites, fossil photographs that includes *Halymenites* trace fossils, and fossil descriptions and species identifications of mollusks and gastropods in the upper Mancos Shale (Kmu) and the Cameo coal zone of the Williams Fork Formation (Kw). In the same general area along Dirty George Creek at the Hawkins Ranch, Gill and Hail (1975) measured a section of the Kicz and Kir units. They reported a fossil assemblages that indicated the *Didymoceras stevensoni* zone (about 70.1 Ma) of the Western Interior ammonite zonal sequence (Cobban and others, 2006) within the Cozzette Sandstone (Kicz).

A scientifically important, museum-quality marine vertebrate fossil was discovered in the map area. A nearly complete, 11-m long, partially articulated skeleton of a new mosasaur species, *Prognathodon stadtmani* (Kass, 1999), was discovered in 1975 by a Cedaredge teenager and quarried by Brigham Young University (BYU) personnel from the exposed upper Mancos shale (Kmu) on the Cedar Mesa Road incline east of Cedaredge. The site was below the large "C" made of painted white rocks on the slope facing Cedaredge. Faunal fossil assemblage recovered at the site places the strata in the *Scaphites hippocrepis* zone (Kass, 1999) of the Western Interior ammonite zonal sequence (81.71 ±0.34 Ma; Cobban and others, 2006). The complete fossil of this large adult mosasaur is a major display in the BYU Museum of Paleontology in Provo, Utah. A cast of the skull is also displayed at the Cedaredge Welcome Center.

Terrestrial fossils, including dinosaurian tracks and rare bone fragments have also been recovered and reported within Williams Fork (Kw) Formation and the Cameo coal zone. The author observed fossil wood, woody stem, and leaf fragments during the 2019 mapping season. Lee (1912) collected fossils and his report includes the collection sites on the accompanying map, and pictures of leaf fossils that are associated with the coal zone. Of notable interest is extensive trackways that were discovered in the States Coal Mine in the 1930s. The operator, Mr. Charles G. States and his miners noticed hundreds of "blisters" on the mine ceiling sandstone that were, in fact, individual dinosaur track casts that included large theropod tracks, 123 cm in width. In 1937, a sandstone bed with some of the largest track casts, of a short 3-track dinosaurian stride, were removed and collected by the American Museum of Natural History in New York City (Brown, 1938). The tracks were of such interest that, prior to World War II, the National Park Service was considering creating a national monument at the mine (National Park Service Archive, 1940). Unfortunately, this resource is now lost. According to the States family that still owns the property (W. Boyd, written commun., 2020) mined coal was temporarily stored in the tunnel and in 1952, a coal fire occurred in the stockpile and the ceiling collapsed. That fire continues today (Rushworth and others, 1989).

GEOLOGIC HAZARDS

Potential geologic hazards in the map area are primarily the risk of landslides and other ground movements, but there are also areas susceptible to rockfall, debris-flow flooding, and coal-mine subsidence hazards. The Mancos Shale also contains bentonite and other expansive clay minerals. Clayey surficial deposits (soils) derived from the shale may be expansive (swelling soils). The marine shale may also be high in sulfates and possibly corrosive to unprotected concrete and steel. Site-specific geotechnical investigations including bore holes and soil testing should be conducted for structures planned in the Mancos Shale or in clayey soils derived from it.

Landslides are ubiquitous throughout the northern part of the map area. Lands within the northern mapped landslide areas, underlain by the weak clay-rich Neogene and Paleogene rocks, are predominantly undeveloped and unoccupied public lands or private ranch land. Several areas in this terrain are actively moving. The Colorado Department of Transportation must seasonally address landslide damage to maintain SH 65. Points are shown on the map where recent road damage was observed during the 2019 mapping season. Light development in 14-ha parcels (35 acre) has occurred within the landslide terrain along High Park Road in the northwest part of the map area. In the lower terrain, most mesa flanks or risers underlain by Mancos Shale are also susceptible to landsliding. The mesa tops are irrigated and where the gravel is underlain by shale, irrigation water percolates to the water table and moves laterally along the contact between the permeable gravel and the impermeable shale. Many ancient to recent landslides have been mapped along the flanks of mesas along Ward Creek and the riser of Cedar Mesa where wet ground conditions previously occurred on the steeper slopes. The near-vertical scarps of these landsides are fresh and the layers of exposed gravel and underlying weak shale can be observed. Areas of mapped landslides and earthflows should be considered susceptible to future ground movements. Careful geological and geotechnical investigations should be completed for any site within mapped landslide areas if there are land-use changes and permanent and (or) occupied structures are planned. Those investigations would also be warranted for prospective buyers of real estate within mapped landslides, especially if there are existing residential structures, or they are being planned. Earth flows and debris flow/ flash flooding can have long runouts (over 3.2 km). Careful planning and siting of structures is also important in the vicinity of creek floors and drainage swales. This map only shows existing landslides and earthflows, and does not reflect future risk or recurrence intervals. Future landsliding could occur in any susceptible area along the flanks of Grand Mesa and the gravel-mantled mesas in the map area. Those ground movements can range from slow near-imperceptible creep, of the type that continually damages SH 65, to dangerous, potentially catastrophic, high velocity, rock avalanche-type flows.

Rockfall hazards exist at steep rocky cutslopes of SH 65, and certain county roads (Green Valley Road and R Road) where they climb steep risers from Ward Creek and the Cedar Mesa Road incline. Rockfall hazards also occur along the base of high, near-vertical sandstone cliffs (e.g., Rollins Sandstone) or any cliffy slope with a steep grade that exceeds the angle of repose. Debris flow and hyperconcentrated flash flooding may also be hazards where drainage channels lie within steep terrain, and where they outlet onto alluvial or debris-flow fans.

Several historic underground coal mines exist in the map area. Coal-mine subsidence may be a factor for future construction that may be planned overlying underground workings. As mentioned previously, an underground coal-mine fire has been reported and likely still smoldering at the States Coal Mine (Rushworth and others, 1989; W. Boyd, written commun., 2020).

PREVIOUS GEOLOGIC MAPPING

The preparation of this map was aided by the review of previous geologic mapping conducted in the area. The geology of the Cedaredge quadrangle was previously mapped at limited, small-scale extents by Lee (1912) in a 1:125,000-scale plate that accompanied his report on the Grand Mesa coal field; at 1:250,000 scale by Williams (1964); at 1:100,000 scale by Ellis and Gabaldo (1989); and at 1:50,000 scale by Dunrud (1989) along the exposed band of coal-bearing rocks. A 15-minute quadrangle (scale 1:48,000) that includes the Cedaredge area was mapped by Hail (1972). Quaternary surficial units were previously mapped at a small scale by Cole and Sexton (1981). Geology has been mapped on adjacent 1:24,000-scale quadrangles as part of this multi-year mapping program of the Grand Mesa region; including the Lands End (White and Palkovic, 2018), Mesa Lakes (Chesnutt and others, 2019), and Hells Kitchen (White and Palkovic, 2019) quadrangles. To the south of the map area are geologic maps of the North Delta (Noe and others, 2015a), Orchard Mesa (Noe and Zawaski, 2013), and Lazear (Noe and others, 2015b) quadrangles. The 1:24,000-scale quadrangle locations are shown on the Plate 1 index map.

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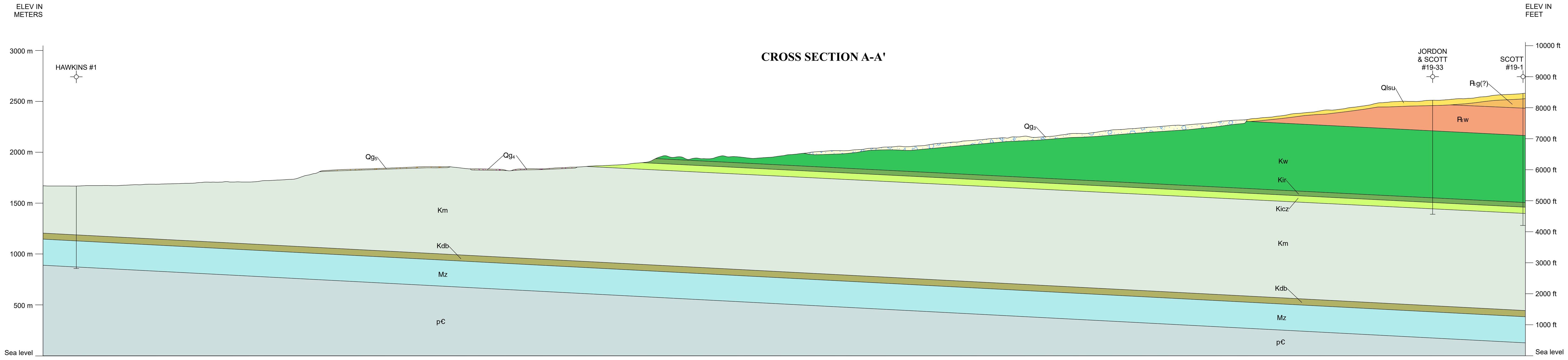
CROSS SECTION A-A'



GEOLOGIC MAP OF THE CEDAREDGE QUADRANGLE, DELTA COUNTY, COLORADO
CORRELATION OF MAP UNITS, 3-D OBLIQUE VIEW, GEOLOGIC SETTING, AND CROSS SECTION

By Jonathan L. White
2023
Although assigned an OFR number in 2020, this report was published in 2023.

COLORADO GEOLOGICAL SURVEY
COLORADO SCHOOL OF MINES