COLORADO GEOLOGICAL SURVEY
COLORADO SCHOOL OF MINES
GOLDEN, COLORADO

GEOLOGIC MAP OF THE SEVERANCE QUADRANGLE, WELD COUNTY, COLORADO
CORRELATION OF MAP UNITS, 3-D OBLIQUE, GEOLOGIC HISTORY, AND CROSS SECTIONS
OPEN-FILE REPORT 24-03
PLATE 2 OF 2
DOI: https://doi.org/10.58783/cgs.of2403.abnf2846

CORRELATION OF MAP UNITS

3-D OBLIQUE VIEW OF GEOLOGIC MAP

GEOLOGIC HISTORY AND STRUCTURE

The Severance quadrangle is located about 100 km (62 mi) northeast of Denver and within the Front Range Urban Corridor. The quadrangle lies within the eastern part of the Colorado Piedmont, a physiographic province bounded by the Rocky Mountains to the west and High Plains to the north and east (Fenneman, 1931; Leonard, 2002; Smith and others, 2016). Fluvial erosion and geomorphic evolution of the ancestral South Platte River and its tributaries during the Pliocene have removed most of the Paleogene and Neogene rocks in the northern Colorado Piedmont (Madole, 1991). The result is a scoured region that is topographically lower than the surrounding physiographic provinces. The elevation range within the Severance quadrangle is about 1447-1615 m (4749-5297 ft) with a total relief of 167 m (548 ft). South of the quadrangle, incision along the Cache la Poudre River and its three tributaries: The Slough, Coulbank Creek valleys, and the "Eaton" paleovalley (named cosined from Robson and others (2006a)) contribute to the relatively low relief in the area. These three of tributaries were possibly part of an ancient tributary system to the Cache la Poudre River that flowed roughly north to south in the quadrangle. These streams had a higher competence, and formed wide stream valleys. Over time, the stream competence decreased, resulting in paleovalleys with low flowing underfit streams (Robson and others, 2006a).

The Severance quadrangle lies along the western part of the Greeley Arch, a structural saddle that separates the Cheyenne Basin to the north and Denver Basin to the south (Dechesne and others, 2011). The quadrangle is on an asymmetrical, oval-shaped, structural basin extending as far east as southwest Nebraska and southeast Wyoming to the north reaching of Pueblo, Colorado (Tweto, 1975). Though none are present at the ground surface in the mapped area, the oldest bedrock units underlying the Denver Basin are Pennsylvanian in age (300 Ma) and were deposited during the uplift of the Ancestral Rocky Mountains. The three oldest units mapped in this quadrangle were deposited when the Western Interior Seaway covered the Denver Basin area 100-60 Ma). During this time, the Pierre Shale (unit Kp) was deposited in a shallow marine environment. Uplift of the Laramide Orogeny initiated the modern Rocky Mountain uplift about 70 Ma. Sediments deposited in regressing seas and near-shore environments now comprise of the Fox Hills Sandstone (unit Kfh) and Laramie Formation (unit Kl). Most of the bedrock dips gently to the east at around 4°.

Compression during the Laramide Orogeny formed the Windsor Wrench Fault Zone and associated synclines and anticlines (Stone, 1969; Stone, 1985; Weimer, 1996). The anticline crosses the mapped area in the northwest (Plate 2), and the Windsor Wrench Fault Zone is a right-lateral, oblique-slip fault zone that strikes from near Boulder northeastward, through the Severance quadrangle, and continues northeastward towards Briggsdale (about 16 km east of the quadrangle). Although the fault zone itself and folds that are shown in Cross Section A (Plate 2) are northeast-trending, they also produce bedrock and surface folds that extracted oil from the Pennian Lyons Sandstone in the Severance quadrangle: New Windsor, Black Hollow, and Peirce. These oil fields were developed within anticlines in Paleocene rocks (Rigby and Cox, 2007). The Black Hollow oil field developed in the north-central portion of the quadrangle. Faults within the Pierce and Black Hollow fields have minor vertical separation of less than 50 m (Stone, 1985). Structural elements on this map are taken from Weimer (1996) and Stone and Dechesne (2010). Cross Section B (Plate 2) intersects two synclines, which were previously mapped by Weimer (1996). The east-vergent, westernmost fold is asymmetrical and more easily recognized than the broad easternmost fold.

During the Paleogene and Neogene, sediment eroded from the uplifting Rocky Mountains was deposited to the east, within the newly formed Denver Basin lowland. By the Lower-Middle Pliocene, the dominating processes switched from aggradation to erosion owing to increased precipitation and broad uplifts in the Rocky Mountains (Dallet and others, 2012; Marder and others, 2021). Erosion mostly removed the Paleogene and Neogene rocks in the western portion of the Denver Basin, leaving only Cretaceous rocks exposed; however, there are isolated outcrops of Cenozoic units preserved throughout the Colorado Piedmont.

The "Conglomeratic Sandstone of Black Hollow Reservoir" is the youngest mapped bedrock unit in the Severance quadrangle (unit PgNds). This unit is exposed on the eastern shores of Black Hollow Reservoir. Initially, this unit was correlated to a lithologically similar unit in the proximal Tennath and Milliken quadrangles, 12 and 35 km away, respectfully (Salkovic and others, 2018; Pernan and others, 2025). However, results from detrital zircon analyses suggest unit PgNds may be significantly older than whose other units and may be correlative. Alternatively, additional analyses may be needed to confirm the accuracy of the detrital zircon results to represent the age of deposition of unit PgNds. Considering this unexpected result, several possible regional correlations are presented below.

Detrital zircon ages from the Tennath and Milliken sites yielded 27.5 ± 1.4 Ma and 28 Ma, respectively. These results suggest that relic Cenozoic deposits in the Tennath and Milliken quadrangles may be correlative with, or were deposited coevally with, the Ogallala Formation at its western extent, where deposition possibly began in the Oligocene or early Miocene (Smith and others, 2016; Morgan and others, 2023; Morgan and O'Keeffe, 2023; Kaine and others, 2023). In contrast, detrital zircon results from the Severance site yielded a much younger maximum depositional age of 71.3 ± 1.5 Ma (n = 6, MSWD = 0.77), with the youngest single grain dated at 67.8 ± 2.9 Ma. Because unit PgNds contains no zircons younger than 28 Ma, it may predate the Ogallala Formation and instead correlate with the Arikaree Formation, White River Formation, or older deposits. A second possibility, though more speculative, is that unit PgNds is not correlative with similar deposits elsewhere in the region but instead represents sedimentation by north-trending river systems during Rocky Mountain uplift in the Laramide Orogeny, as described by Soreson and others (2011). A final possibility is that unit PgNds represent age difference artifacts in sample.

Surficial deposits mantle most of the bedrock throughout the quadrangle. Since the beginning of the Pleistocene, the Colorado Piedmont has undergone cyclic periods of erosion and deposition. Pleistocene deposits in the Severance quadrangle consist of fluvial terrace deposits, eolian sand sheet deposits, and alluvial scouring and aggradation of relatively recent channel bottoms throughout the Colorado Front Range (Wood and Pike, 1940; Hunt, 1954; Scott, 1963). The surficial deposits mapped in the Severance quadrangle are Holocene and Upper Pleistocene eolian silt/clay and sand (unit Qe), alluvium and mass-wasting deposits (units Qa, Qcs, Qaxs), and older Middle Pleistocene gravel deposits (units Qg, Qgo, and Qgx).

Units Qg, Qgo, and Qg are coarse-grained, fluvial gravel units that were deposited by eastward flowing, high-energy streams during late glacial and (or) interglacial periods during the Middle Pleistocene. These units are mapped mainly in the highlands between The Slough and Coulbank Creek valleys in the northwest portion of the quadrangle and also south of the Pierce oil field. Deposits of the "Eaton" paleovalley on the eastern side of the quadrangle, Unit Qg, forms high ridges in the northern part of the quadrangle and is generally poorly preserved, has Stage III-IV carbonate development, and has been extensively mantled by younger deposits. Based on elevation (60 to 75 m) above modern streams (i.e. Cache la Poudre River), Colton (1978) mapped the deposits as unit Qg, as Verdos Alluvium (~675-410 ka) within the Severance quadrangle. Unit Qg, was only observed on the eastern shores of Black Hollow reservoir. Optically stimulated luminescence dating, along with soil development, indicates an age broadly correlative with the Slocum Alluvium (~300–220 ka) and similar deposits identified near Valley View School quadrangle (Keller and Marr, 2023). The coarse, gravelly character has made these units relatively resistant to erosion, resulting in the inverted topography where Qg, mantles underlying units.

Since the middle Pleistocene, the Cache la Poudre River has flowed near its modern course (Workman and others, 2018). Tributary valleys such as The Slough, Coulbank Creek, and the "Eaton" paleovalley once carried greater discharge and sediment load than today, as indicated by their valleys and thick sand and gravel deposits. During the Holocene, these streams shifted to lower-energy regimes, depositing alluvium (unit Qa) and localized colluvial and sheetwash deposits (units Qcs and Qaxs) along valley margins. Radiocarbon dating indicates that these deposits formed within the last several thousand years, with some as recent as the last millennium.

Eolian deposits (Qe) are the dominant surficial unit in the Severance quadrangle, derived primarily from stream-valley alluvium and local bedrock sources (Muhs and others, 1996). These deposits accumulated mainly during the Late Pleistocene, particularly under strong northwesterly winds associated with the Pinedale glaciation (Madole and others, 2005) and continued into the Holocene. Radiocarbon and OSL dating confirm that much of the eolian activity occurred between about 14,000 and 7,500 years ago, though Black Hollow soil development, indicates an age broadly correlative with the Slocum Alluvium (~300–220 ka) and similar deposits identified near Valley View School quadrangle (Keller and Marr, 2023). The coarse, gravelly character has made these units relatively resistant to erosion, resulting in the inverted topography where Qg, mantles underlying units.

Units Qs, Qg, and Qgx are coarse-grained, fluvial gravel units that were deposited by eastward flowing, high-energy streams during late glacial and (or) interglacial periods during the Middle Pleistocene. These units are mapped mainly in the highlands between The Slough and Coulbank Creek valleys in the northwest portion of the quadrangle and also south of the Pierce oil field. Deposits of the "Eaton" paleovalley on the eastern side of the quadrangle, Unit Qg, forms high ridges in the northern part of the quadrangle and is generally poorly preserved, has Stage III-IV carbonate development, and has been extensively mantled by younger deposits. Based on elevation (60 to 75 m) above modern streams (i.e. Cache la Poudre River), Colton (1978) mapped the deposits as unit Qg, as Verdos Alluvium (~675-410 ka) within the Severance quadrangle. Unit Qg, was only observed on the eastern shores of Black Hollow reservoir. Optically stimulated luminescence dating, along with soil development, indicates an age broadly correlative with the Slocum Alluvium (~300–220 ka) and similar deposits identified near Valley View School quadrangle (Keller and Marr, 2023). The coarse, gravelly character has made these units relatively resistant to erosion, resulting in the inverted topography where Qg, mantles underlying units.

MINERAL RESOURCES, GROUNDWATER, AND GEOLOGIC HAZARDS

The Severance quadrangle is located in the western part of the Denver Basin and Weld County. The quadrangle contains the following mineral resources: oil and gas, coal, uranium, and sand and gravel. The Severance quadrangle lies in the northwest margin of the Wattenberg oil field which is a productive oil and gas field that is mostly in Weld and Adams Counties. The Wattenberg oil field in the United States and ninth largest gas field based on proved reserves (EIA, 2021). According to O'Keeffe (2025), Weld County has an estimated total production value of over $12 billion in oil and gas production and produced over 133 million oil barrels in 2023. Oil and gas infrastructure is dominate in the central and southern portions of the quadrangle. The Niobrara Formation (unit Kn) is the principal production horizon in the Wattenberg Field. Other formations with production horizons include the Shannon/Hygiene Sandstone (combined member of the Pierre Shale (unit Kp)), the Codell Sandstone (upper part of the Cretaceous Carlile Shale (unit Kcg)), the Muddy (or J sandstone) (within the Dakota Group), and the D sandstone (Dakota Group) (Fishman, 2005). Three oilfields that produced primarily from the Permian Lyons Sandstone are within the Severance quadrangle: Severance, Black Hollow, and Pierce (Rigby and Cox, 2007). Oil and natural gas cumulative production from Severance oilfield bedrock units and local artifacts (Gallardo and Reid, 1961; Higley and Cox, 2007). Oil and natural gas cumulative production from these fields were 11.8 million barrels and 0.330 million cubic feet of gas in Black Hollow and 11.5 million barrels in Pierce (Higley and Cox, 2007). Cretaceous formations also serve as important reservoir rock in oil in these fields: the Black Hollow field produces oil from the Niobrara Formation (unit Kn) and Codell Sandstone (unit Kcgg); the New Windsor field produced oil from the Terry, Hygiene/Shannon members of unit Kp, and Codell Sandstone (unit Kcgg) (Higely and Cox, 2007).

The Laramie Formation (unit Kl), which underlies the central and eastern portion of the quadrangle, is an important coal source in the Denver Basin. The quality of coal in the Laramie Formation ranges from lignite to subbituminous (Cappa and Tetlbur, 2022). Coal from the Laramie Formation north of Greeley was limited because the coal deposits are relatively thin and discontinuous (Kirkham and Ladwig, 1979; Roberts, 2007). The average heat of combustion of coal mined north of Greeley ranges from 7,200 to 8,000 British thermal units per pound (lbs/lb) (Kirkham, 1978; Kirkham and Ladwig, 1979).There are no historical coal mines reported in the Severance quadrangle; however, Shelton and Rogers (1975) stated that the eastern part of the quadrangle has limited potential for coal development. Coal productive areas continue to the east of the mapped area in the Eaton area (6 km east of the quadrangle).

Units Qs, Qg, Qcs, and Qcso are potential sources of local sand and gravel. There are no active industrial gravel quarries in the Severance quadrangle. A single historic quarry is shown in Coulbank Creek excavated into unit Qcs (1960 USGS topographic map and Schwochow and others, 1974). Due to the high content of both fines and calcium carbonate present in units Qg,, Qcs, Qcso, the deposits are not considered suitable sources for concrete aggregate and may only be suitable for fill material (Schwochow and others, 1974).

Uranium was discovered in Weld County in 1969, primarily in the Fox Hills Sandstone and Laramie Formation (units Kfh and Kl, respectively) (Reade, 1978). Most of the historical uranium mining occurred in the Gilcrest and the Briggsdale areas, located about 89 km to the northeast of the Severance quadrangle. In the past, the uranium ore was low grade (varies from 150,000 to 1,000,000 lbs U3O8) and were commercially significant in the 1970s because of high demand from the nuclear industry (Reade, 1978). There are no active or historic uranium mines in the Severance quadrangle, although areas with potential for yielding uranium are present (Shelton and Rogers, 1975). North of the Severance quadrangle is a proposed exploration project called the Centennial Project with conceptual designs to extract in-situ uranium. The original owner of the project, Powertech (USA) Inc., controlled about 9,015 acres of fee mineral ownership and 7,263 acres of surface ownership (SRK Consulting, 2010). The project extends from the Colorado/Wyoming border (about 42 km) to the northern boundary of the Severance quadrangle. In the project area, the uranium ore occurs in the Fox Hills Sandstone (unit Kfh) as rolling-front deposits in the form of small pods to elongated lobes. Ore mineralogy is mainly uraninite, coffinite, and carnotite with some vanadium (SRK Consulting, 2010). As of 2023, enCore Energy Corp. owns the Centennial Project and there is no update on production within the project area (https://miningfeeonline.com/projects/7230/profile.aspx?pid=12383).

The Laramie-Fox Hills aquifer is a bedrock aquifer in the Denver Basin. It consists of two relatively thick sandstone units in the basal portion of the Laramie Formation (unit Kl) and the entire Fox Hills Sandstone (unit Kfh) (Topper and others, 2003). The aquifer is as much as 107 m thick, but the water pumped zones are rarely thicker than approximately 60 m and is generally under artesian pressure (Topper and others, 2003). The aquifer exists primarily in the eastern part of the Severance quadrangle where Unit Kl is absent in the central section of the quadrangle but both units Kl and Kfh are absent in the western part. While the Pierre Shale (unit Kp) is generally a confining layer, the upper sandy transition member can yield small quantities of groundwater (Hershey and Schneider, 1964; Hewitt, 1972). This part of the Pierre Shale has historically been known as the "Upper Pierre Aquifer" (Kirkham and others, 1980). Sand and gravel deposits in units Qg,, Qs, Qg, Qa, and sand-rich Qe may be local groundwater sources. According to CO DWR (2023), the maximum well depth in the Severance quadrangle is 270 m (885 ft) and the average well production is about 95 l/min (gpm) or 25 l/min (gpm).

The Pierre Shale and Laramie Formation (units Kp and Kl, respectively) are known to contain swelling clays that can impact building and infrastructure if not properly engineered and mitigated (Hart, 1974). Swelling clays were encountered in the 6th throughout the Front Range (Tuck and others, 2016). From 1960 to 2023, there was only one recorded earthquake around the Severance quadrangle area with a magnitude of 2.6 in 2016 south of the town of Eaton (USGS Online Earthquake Catalogue, 2023).

REFERENCES

Arnold, L.J., and Roberts, R.G., 2009, Stochastic modelling of multi-grain equivalent dose (De) distributions: Implications for OSL dating of sediment mixtures: Quaternary Geochronology, v. 4, no. 3, p. 204-230. https://doi.org/10.1016/j.quageo.2008.12.001

Berry, M.E., Slate, J.L., and Taylor, E.M., 2019, Pleistocene and Holocene landscape development of the South Platte River corridor, northeastern Colorado: U.S. Geological Survey Scientific Investigations Report 2019-5020, 22 p. https://doi.org/10.3133/sir20195020

Briscoe, H.J., Jr., 1972, Stratigraphy and aquifer characteristics of the Fox Hills sandstone in the Greeley area, Weld County, Colorado: M.S. thesis, Colorado School of Mines, 78 p. https://hdl.handle.net/11124/14063

Bryan, K., and Ray, L.L., 1940, Geologic antiquity of Lindenmeier site in Colorado: Smithsonian Miscellaneous Collections, v. 99, p. 65-86. http://hdl.handle.net/10088/25895

Cappa, J.A., and Tetlbur, H., 2002, Evaluation of mineral and mineral fuel potential of Weld County, State Mineral Lands administered by the Colorado State Land Board: Colorado Geological Survey Open-File Report 02-23, p. 11-12. https://coloradogeologicalsurvey.org/publications/evaluation-mineral-fuel-potential-weld-colo/

Clark, B.W., and Rold, L., 1961, New Windsor field, Weld County, Colorado, p. 202–205, in Parker, J.M., ed., Colorado-Nebraska oil and gas fields: Rocky Mountain Association of Geologists.

CO DWR (Colorado Division of Water Resources), 2023, Driller's logs incorporated with water-well permits. https://dwr.colorado.gov/services/data-information/gis

CO ECMN (Colorado Energy and Carbon Management Commission), 2023, Colorado Oil and Gas Commission data download: Colorado Oil and Gas Commission, monthly production by county. https://ecmc.state.co.us/data4.html#/production

Colton, R.B., 1978, Geologic map of the Boulder-Fort Collins-Greely area, Front Range Urban Corridor, Colorado: U.S. Geological Survey Miscellaneous Investigations Map I-855-G, scale 1:100,000. https://pubs.usgs.gov/imap/i855g/

Colton, R.B., and Fitch, H.R., 1974, Map showing potential sources of gravel and crushed-rock aggregate, in the Boulder-Fort Collins-Greeley area, Front Range Urban Corridor, Colorado: U.S. Geological Survey Miscellaneous Investigations Map I-855-D, scale 1:100,000. https://pubs.usgs.gov/publication/i855D

Dechesne, M., Reynolds, R.G., Barkmann, P.E., and Johnson, K.R., 2011, Notes on the Denver Basin geologic maps: Bedrock geology, structure, and isopach maps of the Upper Cretaceous to Paleocene Strata between Greeley and Colorado Springs: Colorado Geological Survey Open File Report 11-01, 35 p. https://coloradogeologicalsurvey.org/publications/maps-denver-basin-colorado/

Dallet, R.A., Whittaker, A.C., Swinehart, J.B., Armitage, J.J., Sinclair, H.D., Blair, Andrea, and Allen, P.A., 2012, Abrupt landscape change post-6 Ma on the central Great Plains, USA: Geology, v. 40, no. 10, p. 871–874. https://doi.org/10.1130/G33219.1

EIA (Energy Information Administration), 2021, Colorado state profile and energy estimates: U.S. Energy Information Administration. https://www.eia.gov/state/?sid=CO

Federal Emergency Management Agency (FEMA), 2023, FEMA's National Flood Hazard Layer (NFHL) Viewer. https://hazards-fema.maps.arcgis.com/apps/webappviewer/index.html?id=8ba0bf1994a44dd7933b925baebed

Fenneman, N.M., 1931, Physiography of western United States: New York, McGraw-Hill Book Co, 534 p. https://archive.org/details/physiographyofwe00fenn/page/n7/mode/2up

Fishman, N.S., 2005, Overview of studies related to energy resources, northern Front Range, Colorado, p. 1-6, in Fishman, N.S. ed., Ch. A: Energy resource studies, northern Front Range, Colorado: U.S. Geological Survey Professional Paper 1698, 182 p. https://pubs.usgs.gov/pp/2005/1698/

Forman, S.L., Tow-Todd, V., Machesky, C., Marin, L., Wost, L.A., and Morey, G., 2022, Late Quaternary aeolian environments, luminescence chronology and climate change for the Monahans dune field, Winkler County, West Texas, USA: Aeolian Research, v. 58, 100828. https://doi.org/10.1016/j.aeolia.2022.100828

Galbraith, R.F., and Roberts, R.G., 2012, Statistical aspects of equivalent dose and error calculation and display in OSL dating: An overview and some recommendations: Quaternary Geochronology, v. 11, p. 1-27. https://doi.org/10.1016/j.quageo.2012.04.020

Galbraith, R.F., and Green, P.F., 1990, Estimating the component ages in a finite mixture: International Journal of Radiation Applications and Instrumentation, v. 17, p. 197-206. https://doi.org/10.1016/1359-0189(90)90035-V

Hart, S.S., 1974, Potential swelling soil and rock in the Front Range Urban Corridor, Colorado: Colorado Geological Survey Environmental Geology 7. https://coloradogeologicalsurvey.org/publications/potentially-swelling-soil-rock-front-range-urban-corridor-colorado/

Hershey, L.A., and Schneider, P.A., Jr., 1972, Geologic map of the lower Cache la Poudre River basin, northcentral Colorado: U.S. Geological Survey Miscellaneous Geological Investigation Map I-687, scale 1:62,500. https://pubs.usgs.gov/publication/i687

Hershey, L.A., and Schneider, P.A., Jr., 1964, Ground-Water investigations in the lower Cache la Poudre River Basin, Colorado: US Geological Survey Water-Supply Paper 1805-X, 22 p. https://pubs.usgs.gov/publication/wsp1805X

Higley, D.K., and Cox, D.O., 2007, Oil and gas exploration and development along the Front Range in the Denver Basin of Colorado, Nebraska, and Wyoming in Petroleum systems and assessment of undiscovered oil and gas in the Denver Basin Province, Colorado, Kansas, Nebraska, South Dakota, and Wyoming: U.S. Geological Survey, Digital Data Series, DDS-69-P, 45 p. https://pubs.usgs.gov/dds/dds-069/dds-069-p/REPORTS/69_P_CH_2.pdf

Hunt, C.B., 1954, Pleistocene and recent deposits in the Denver area, Colorado: U.S. Geological Survey Bulletin 996-G, p. 91-140. https://pubs.er.usgs.gov/publication/b996G

Kaine, S.J., Abbott, L.D., Flowers, R.M., Olsson, A., Fernandez, S., and Metcalf, J.R., 2023, Cenozoic exhumation across the High Plains of southeastern Colorado from (U-Th)/He Thermochronology: Lithosphere, v. 2023, 310, 26 p. https://doi.org/10.2113/2023/lithosphere_2023_310

International Union of Geological Sciences, 2023, International Commission on Stratigraphy, version 2023/09. https://stratigraphy.org/chart#latest-version

Keller, S.M., and Marr, A.E., 2024, Geologic map of the Windsor quadrangle, Larimer and Weld Counties, Colorado: Colorado Geological Survey Open File Report 22-05, scale 1:24,000. https://pubs.usgs.gov/publication/i3025.htm

Keller, S.M., and Marr, A.E., 2023, Geologic map of the Valley View School quadrangle, Weld County, Colorado: Colorado Geological Survey Open File Report 21-02, scale 1:24,000. https://coloradogeologicalsurvey.org/publications/geologic-map-valley-view-school-quadrangle-weld-colorado/

Keller, S.M., and Morgan, M.L., 2020, Geologic map of the Greeley quadrangle, Weld County, Colorado: Colorado Geological Survey Open-File Report 20-05, scale 1:24,000 https://coloradogeologicalsurvey.org/publications/geologic-map-greeley-quadrangle-weld-colorado/

Kellogg, K.S., Shroba, R.R., Bruce, B., and Premo, W.R., 2008, Geologic map of the Denver West 30' x 60' quadrangle, north-central Colorado: U.S. Geological Survey Scientific Investigations Map 3000, scale 1:100,000 https://pubs.usgs.gov/sim/3000/

Kirkham, R.M., and Ladwig, L.R., 1980, Energy resources of the Denver and Cheyenne Basins, Colorado—Resource characteristics, development potential, and environmental problems: Colorado Geological Survey Environmental Geology 12, 258 p. https://coloradogeologicalsurvey.org/publications/energy-resources-denver-cheyenne-basin-colorado-characteristics-development-environmental/

Kirkham, R.M., O'Leary, W., and Warner, J.W., 1981, Hydrogeologic and stratigraphic data pertinent to uranium mining, Cheyenne Basin, Colorado: Colorado Geological Survey Environmental Geology 16, 76 p. https://coloradogeologicalsurvey.org/publications/hydrogeologic-stratigraphic-data-uranium-mining-cheyenne-basin-colorado/

Kirkham, R.M., and Ladwig, L.R., 1979, Coal resources of the Denver and Cheyenne Basins, Colorado: Colorado Geological Survey Resource Series 5, 76 p. https://coloradogeologicalsurvey.org/publications/coal-resources-denver-cheyenne-basins-colorado/

Kirkham, R.M., 1978, Coal mines and coal analyses of the Denver and Cheyenne Basins, Colorado: Colorado Geological Survey Open-File Report 78-9, 104 p. https://coloradogeologicalsurvey.org/publications/coal-mines-coal-analyses-denver-cheyenne-basins-colorado/

Loist, A.L., DeCillis, P.G., and Pelletier, J.D., 2005, Mountains, monsoons, and megadams: Geology, v. 33, p. 289–292. https://doi.org/10.1130/G21228.1 https://pubs.er.usgs.gov/publication/pp421A

Leonard, E.M., 2002, Geomorphic and tectonic forcing of the Cenozoic warping of the Colorado Piedmont: Geology, v. 30, no. 7, p. 595-598. https://pubs.geoscienceworld.org.mines.idm.oclc.org/gsa/geology/article-pdf/30/7/595/3473476/i0091-7613-30-7-595.pdf?casa_token=

Liang, P., and Forman, S.L., 2019, LDAC: An Excel-based program for luminescence equivalent dose and burial age calculations: Ancient TL, v. 37, p. 21–40. https://doi.org/10.26034/fr.ati.2019.156

Lindsey, D.A., Langer, W.H., and Knepper, D.H., Jr., 2005, Stratigraphy, lithology, and sedimentary features of Quaternary alluvial deposits of the South Platte River and some of its tributaries east of the Front Range, Colorado: U.S. Geological Survey Professional Paper 1705, 70 p. https://doi.org/10.3133/pp1705

Lovering, T.S., Anstad, D.A., Lovinger, C.S., and Hynes, J.H., 1932, Fox Hills Formation, northeastern Colorado: American Association of Petroleum Geologists Bulletin, v. 16, no. 7, p. 702-703. https://doi.org/10.1306/3D932AAC-16B1-11D7-8645000102C1865D

Machette, M.N., 1985, Calcic soils of the southwestern United States, p. 1-21, in Soils and Quaternary geology of the southwestern United States, D.L. Weide (ed.): Geological Society of America Special Paper 203. https://doi.org/10.1130/SPE203-p1

Madole, R.F., 1991, Colorado Piedmont, in Wayne, W.J., ed., Quaternary geology of the Northern Great Plains, Chap.15 of Morrison, R.B., ed., Quaternary nonglacial geology--conterminous United States: Geological Society of America, The geology of North America, v. K-2, p. 456-462.

Madole, R.F., VanSistine, D.P., and Michael, J.A., 2005, Distribution of late Quaternary wind-deposited sand in eastern Colorado: U.S. Geological Survey Scientific Investigations Map 1725, 49 p., scale 1:700,000. https://pubs.usgs.gov/sim/2005/2879/

Marder, E., Gallen, S.F., and Puyngalia, F.J., 2023, Late Cenozoic deformation in the U.S. southern Colorado Front Range revealed by river profile analysis and fluvial terraces: Geological Society of America Bulletin, v. 136, n. 7-8, p. 3067-3085. https://doi.org/10.1130/B36440.1

Mather, F.K., Gilbdy, J., and Lind, R.G., 1925, Contributions to economic geology (short papers and preliminary reports), 1927, Part II, Mineral fuels. Geology and oil and gas prospects of northeastern Colorado: U.S. Geological Survey Bulletin, 796-B, 124 p. https://pubs.usgs.gov/publication/b796B

Matthews, N. E., Vazquez, J. A., and Calvert, A. T., 2015, Age of the Lava Creek supereruption and magma chamber assembly at Yellowstone based on $^{40}Ar/^{39}Ar$ and U-Pb dates of sanidine and zircon crystals: Geochem. Geophys. Geosyst., v. 16, p. 2508–2528. https://doi.org/10.1002/2015GC005881

McComas, M. R., 1966, Environmental control of inorganic water quality near Severance, Colorado: M.S. thesis, Colorado State University, 52 p.

Meurs, B., Jr., 1981, Peripheral wedges and the late Pleistocene environment of Wyoming's intermontane basins: Quaternary Research, v. 15 (2), p. 171-198. https://doi.org/10.1016/0033-5894(81)90101-6

Morgan, M.L., and O'Keefe, M.K., 2023, Data tables of detrital zircon U-Pb geochronology and trace element concentrations of select Cretaceous, Paleogene, and Neogene rocks, Denver Basin and Northeastern Colorado (Data) - v20231110: Colorado Geological Survey ON-004-04D https://coloradogeologicalsurvey.org/publications/front-range-detrital-zircon/

Morgan, M.L., O'Keefe, M.K., Mahanna, A.A., and Keller, S.M., 2023, Detrital zircon age estimates of select Upper Cretaceous to Neogene rocks, Denver Basin and northeastern Colorado: Colorado Geological Society of America Abstracts with Programs, v. 55, no. 5.

Muhs, D.R., Cattle, S.R., Crouvi, O., Rousseu, D.D., Sun, J., and Zarate, M.A., 2014, Loess records, p. 411-441, in Knippertz, P., Stuut, J.B.W., eds., Mineral Dust: Springer Netherlands, Dordrecht, 509 p. https://link.springer.com/chapter/10.1007/978-94-017-8978-3_16

Muhs, D.R., Aleinikoff, J.N., Stafford, T. W., Jr., Stone, John, Mahan, S., and Crowland, Scott, 1996, Late Quaternary loess in northeastern Colorado; Part I--Age and paleoclimatic significance: Geological Society of America Bulletin, v. 111, n. 12, p. 1861-1875. https://pubs.geoscienceworld.org/gsa/gsabulletin/article-abstract/111/12/1861/183433/Late-Quaternary-loess-in-northeastern-Colorado

Muhs, D.R., Stafford, T.W., Cowherd, S.D., Mahan, S.A., Kihl, R., Maat, P.B., Bush, C.A., Nehring, J., 1996, Origin of the late Quaternary dune fields of northeastern Colorado: Geomorphology, v. 7, p. 129-149. https://doi.org/10.1016/0169-555X(93)90010-3

Munsell Color, 1991, Munsell soil color charts, 1994 edition revised, Newburgh, NY, Macbeth Division of Kollmorgen Instruments Corp.

Murray, A.S., and Wintle, A.G., 2003, The single aliquot regenerative dose protocol: potential for improvements in reliability: Radiation Measurements, v. 37, p. 377-381. https://doi.org/10.1016/S1350-4487(03)00053-2

Nichols, G., 2009, Sedimentology and stratigraphy (second edition): Wiley-Blackwell, Chichester (United Kingdom), 419 p.

Nissen, T.C., 1985, Field and laboratory studies of selected peripheral wedge-pull-pans in Southern Wyoming: M.S. thesis, University of Wyoming, 175 p. http://mines.idm.oclc.org/login?url=https://www.proquest.com/dissertations-theses/field-laboratory-studies-selected-peripheral/docview/303457010/se-2?accountid=28366

Noe, Dic C., 2010, Anton oncampment paleoseismologic investigation. Washington County Colorado Geological Survey National Earthquake Hazards Reduction Program (NEHRP), External Research Program, award 07HQGR0090, 23 p.https://earthquake.usgs.gov/cfusion/external_grants/report/07HQGR0090.pdf

Odonchi, K., 1966, Geology of northwestern Larimer and northwestern Weld Counties, Colorado: M.S. thesis, Colorado School of Mines, 146 p., 5 plates. https://hdl.handle.net/11124/16574

O'Keeffe, M.K., 2025, Colorado mineral and industry activities 2023-2024: Colorado Geological Survey Information Series 87, 32 p. https://coloradogeologicalsurvey.org/publications/colorado-mineral-energy-industry-activities-2024/

Pelkuwki, M.J., Lindsey, K.L., and Morgan, M.L., 2018, Geologic map of the Milliken quadrangle, Weld County: Colorado Geological Survey Open File Report 18-02, scale 1:24,000. https://coloradogeologicalsurvey.org/publications/geologic-map-milliken-quadrangle-weld-colorado/

Pernan, E.L., Lindsey, K.L., and Marr, A.E., 2025, Geologic map of the Tennath quadrangle, Larimer and Weld Counties, Colorado: Colorado Geological Survey Open File Report 24-01, scale 1:24,000 (in publication).

Pernan, E.L., and Hutton, J.T., 1994, Cosmic ray contributions to dose rates for luminescence and ESR dating: Large depth sand long-term time variations: Radiation Measurements, v. 23, p. 497- 500. https://doi.org/10.1016/1350-4487(94)90086-8

Ramsey, C.B., 2009, Bayesian analysis of radiocarbon dates: Radiocarbon, v. 51, p. 337-360. https://www.cambridge.org/core/journals/radiocarbon/article/abs/bayesian-analysis-of-radiocarbon-dates/E6223B7BF8917F39D7188DEA7D7114

Reynolds, R.G., Cretaceous stratigraphy of Colorado Geological Survey Map Series 54. https://coloradogeologicalsurvey.org/publications/cretaceous-stratigraphy-colorado/

Reimer, P.J., Baird, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Ramsey, C.B., Buck, C.E., Cheng, H., Edwards, R.L., Friedrich, M.,Grootes, P.M., Guilderson, T.P., Haflidason, H., Hajdas, I., Hatte, C., Heaton, T.J., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, C.S.M., and Van der Plicht, J., 2013, IntCal13 and Marine13 radiocarbon age calibration curves, 0–50,000 years cal BP: Radiocarbon, v. 55, no. 4, p. 1869-1887. https://www.cambridge.org/core/journals/radiocarbon/article/intcal13-and-marine13-radiocarbon-age-calibration-curves-050000-years-cal-bp/F395C13451F4328D0c8418C6FE4E2BE090

Reade, H.L., 1978, Uranium deposits: Northeastern Denver Julesburg Basin, Colorado: Rocky Mountain Association of Geologists – 1978 Symposium, p. 161-171. https://archives.datapages.com/data/rmag/free/Reade/free/Reade.htm

Roberts, S.B., 2007, Coal in the Front Range Urban Corridor - An overview of coal geology, coal production, and coalbed methane potential in selected areas of the Denver Basin, Colorado and the potential effects of historical coal mining on development and land use practices, in Proceedings of the 2007 Symposium: Science and Systems and assessment of undiscovered oil and gas in the Denver Basin Province, Colorado, Kansas, Nebraska, and Wyoming, U.S. Geological Survey Digital Data Series DDS-69-P, 49 p. https://pubs.usgs.gov/dds/2005/1698/508-Angel.html#ancillary337347304

Robson, S.G., Arnold, L.R., and Heiny, J.S., 2006a, Geohydrology of the shallow aquifers in the Greeley-Nunn area, Colorado: U.S. Geological Survey Hydrologic Atlas 746-A. https://pubs.usgs.gov/publication/ha746A

Robson, S.G., Arnold, L.R., and Heiny, J.S., 2006b, Geohydrology of the shallow aquifers in the Fort Collins-Loveland area, Colorado: U.S. Geological Survey Hydrologic Atlas 746-B. https://pubs.usgs.gov/publication/ha746B

Scott, G.R., 1962, Geology of the Littleton quadrangle, Jefferson, Douglas, and Arapahoe counties, Colorado: U.S. Geological Survey Bulletin 1121-L, scale 1:24,000. https://doi.org/10.3133/b1121L

Scott, G.R., 1963, Quaternary geology and geomorphic history of the Kassler quadrangle, Colorado: U.