



## GEOLOGIC MAP OF THE SEVERANCE QUADRANGLE, WELD COUNTY, COLORADO

By Alexander E. Marr, Emily A. Perman, and Kassandra O. Lindsey  
2025

### DESCRIPTION OF MAP UNITS

A summary of the geologic history, mineral and groundwater resources, and geologic hazards can be found on Plate 2. Division of geological time follows the International Chronostratigraphic Chart (International Union of Geological Sciences, 2023). For grain size categories, refer to the Udden-Wentworth grain-size in Nichols (2009). Descriptions of the soil colors and carbonate development are based on Munsell (1991) and Machette (1985), respectively. Relative amounts of calcium carbonate (CaCO<sub>3</sub>) are interpreted based on the degree of effervescence in soil or sediment when treated with diluted (10%) hydrochloric acid (HCl) according to the U.S. Department of Agriculture (2018).

### SURFICIAL DEPOSITS

#### HUMAN-MADE DEPOSITS

af

**Artificial fill (uppermost Holocene)** — The unit is comprised of mostly fill material, riprap, and refuse in the construction of dams, roads, buildings, and landfill. Deposits are generally made of unsorted clay, silt, sand, and rock fragments. Typically, the unit is less than 6 m thick. Artificial fill may be subjected to settlement, slumping, and erosion if not adequately compacted.

#### FOLIAL DEPOSITS

Qe

**Folial sediment (Holocene to Upper Pleistocene)** — The unit is composed of very pale brown to yellowish-brown and light olive brown (10YR and 2.5Y) massive, loose to stiff, moderately to well-sorted, very fine- to medium-grained sand with minor to trace coarse and very coarse-grained sand. Sand grains are mainly subrounded to rounded and are comprised of 75–80% quartz, 14–25% feldspar and other minerals, and 0–5% opaque minerals. Unit Qe may contain local bedrock fragments. West of the Weld County West (WCR) 27 and 72 junction, the authors observed fossiliferous sandstone fragments within an exposure of unit Qe from the weathering of underlying unit Kp bedrock in the edge of a slope pit. The bedrock fragments ranged in length from 3 mm to 5 cm. In an irrigation ditch wall west of WCR 76 and 27 junction, a boulder-sized bedrock fragment (unit Kp), about 0.5–1 m in diameter, was observed in unit Qe. Unit Qe likely includes local sheetwash deposits, especially on the edges of valleys and on relatively steep slopes. Unit Qe ranges from about 2 to 14 m thick in Cross Section B (Plate 2), in part due to inclusion of weathered bedrock residuum and sheetwash or colluvial deposits.

Unit Qe has moderate to strong effervescence. Secondary carbonate development ranges from absent to Bk horizons as much as 1.2 m thick, containing carbonate nodules within the fine-grained material that are < 1 mm in diameter (Stage 1). In addition to carbonate horizons, older Qe units may also have Bk horizons that can range approximately from 10–60 cm thick.

Locally, some deposits may have a higher fines (silt and clay) content. Based on grain size analyses from geotechnical reports throughout the Severance area, the fines content in unit Qe ranges from 21–40%. While the average fines content ranges from around 30–40%, this unit can be classified as loess when it is > 60% (Mads and others, 2014).

The age of unit Qe in the Severance quadrangle area is mostly Holocene but can be as old as Upper Pleistocene. Two radiocarbon (<sup>14</sup>C) samples of this unit (SV019C14 and SV032C14, see Table 1) were collected in this investigation and yielded age estimates of 8,700 ± 30 and 7,440 ± 30 calibrated years before present (cal. yrs BP), respectively. Other dates for colluvial sediment from the surrounding Greeley, Windsor, and Timnath quadrangles range from about 820–9,280 cal. yrs BP (Keller and Morgan, 2020; Keller and Marr, 2024; Perman and others, 2025). On the eastern shore of Black Hollow Reservoir, unit Qe is silty, fine- to medium-grained sand about 1.6 m thick and overlies the Pierre Shale (unit Kp). At the base of unit Qe are rare gravel as large as 2.5 cm pebbles. A 60 cm-thick Bt soil horizon has developed into this unit with columnar structure. At the same location, multiple clastic dikes, resembling ice wedges, are present where the overlying unit Qe infilled wedge-shaped spaces in the underlying unit Kp, forming sand wedges ranging in size from about 4–30 cm in width. Ice wedges, formed by periglacial processes, have been reported in Wyoming, including the Laramie and Cheyenne areas (Moore, 1981; Nielsen, 1985) and at the Anton Escarpment about 200 km southeast of the Severance quadrangle (Noc, 2010). Two OSL samples from unit Qe were taken from the eastern shore of Black Hollow Reservoir (see Table 2): one near the contact of overlying unit Qe and unit Kp (SV086OSL1), and one from a sand wedge (SV086AOSL1). The sample from the overlying Qe (SV086OSL1) yielded an age of 13,860 ± 645 SAR-OSL years and the sand wedge (SV086AOSL1) yielded an age of 13,755 ± 685 SAR-OSL years. However, both samples have an overdispersion percentage > 20%, indicating that this estimate may not be the true deposition age and may have been reworked due to partial solar resetting and/or multiple grain populations (Baylor University, 2025). Ages of the ice wedges from the Anton Escarpment indicated that there were three distinct periods of periglacial ice-wedge formation which occurred from 27.5–18 ka, 20–16 ka, and older wedges with dates around 42.5 and 130 ka based on OSL dates (Noc, 2010). Depending on the silt and clay content, this deposit can contain expansive and/or collapsible soils, which can impact future and existing buildings and infrastructure if not properly mitigated.

#### ALLUVIAL DEPOSITS

Qa

**Alluvium, undivided (Holocene)** — Unit Qa is mapped in The Slough, Coalbank Creek valleys, and overlaps portions of the “Eaton” paleovalley (named by Robson and others, 2000a) based on lidar imagery, and 0.61 m (2 ft) contours from digital elevation map (DEM) imagery. In the Severance quadrangle, unit Qa is locally covered and intermixed with colluvial sediment (unit Qc).

Overlying the “Eaton” paleovalley by WCR 88 and 29, the alluvium is a grayish-brown (10YR), well-sorted, silty clay or clayey silt sand with moderate effervescence. The sand content is roughly 40–50% and fine-grained. Further downstream by WCR 86, from an excavated pond, the unit is more gravel rich, comprising 20–30% of the deposit. Grains range in size from granules to 3.5 cm pebbles and are subangular to subrounded. Some of the pebbles have thin carbonate coating (< 1 mm-thick) that are most likely reworked from units Qg and Qgs. Based on water wells (CO DWR, 2023), the alluvium overlying the “Eaton” paleovalley is about 9 to 12 m thick but be up to 18 m-thick.

In the Coalbank Creek valley, unit Qa is a moderately well- to poorly sorted pale brown and brown (10YR) gravelly sand with local high fines content. The sand is very fine- to coarse-grained and either does not effervesce or effervesces slightly with HCl. The gravel comprises 20–30% of the deposit. Clasts are typically subangular to rounded and range in size from granules to 3 cm pebbles but can be as large as 17 cm cobbles in length. Gravel clasts are primarily comprised of granitic rocks, gneiss, with quartz, white quartzite, and possible black quartzite from Coal Creek (see Lindsey and others, 2005). Some of the gravel has carbonate coatings and could also possibly be reworked from units Qg and Qgs. Water well logs from CO DWR (2023) show that the thickness of alluvium in Coalbank Creek is about 8–9 m. According to Colton (1978), the alluvium in Coalbank Creek correlates to the Piney Creek Alluvium which has been mapped as unit Qg, in other nearby Colorado Geological Survey maps. In the surrounding Greeley, Windsor, and Timnath quadrangles, the ages of unit Qa range from 1,010–4,360 calibrated year BP (Keller and Morgan, 2020; Keller and Marr, 2024; Perman and others, 2025).

In The Slough valley, south of the town of Severance, unit Qa occurs along the cutbank of the modern channel as a pale brown (10YR), moderately well sorted, silty gravelly sand with none to slight effervescence when wet. The sand content is roughly 40–50% and fine-grained. The sand is very fine- to coarse-grained and either does not effervesce or effervesces slightly with HCl. The gravel comprises 20–30% of the deposit. Clasts are typically subangular to rounded and range in size from granules to 3 cm pebbles but can be as large as 17 cm cobbles in length. Gravel clasts are primarily comprised of granitic rocks, gneiss, with quartz, white quartzite, and possible black quartzite from Coal Creek (see Lindsey and others, 2005). Some of the gravel has carbonate coatings and could also possibly be reworked from units Qg and Qgs. Water well logs from CO DWR (2023) show that the thickness of alluvium in Coalbank Creek is about 8–9 m. According to Colton (1978), the alluvium in Coalbank Creek correlates to the Piney Creek Alluvium which has been mapped as unit Qg, in other nearby Colorado Geological Survey maps. In the surrounding Greeley, Windsor, and Timnath quadrangles, the ages of unit Qa range from 1,010–4,360 calibrated year BP (Keller and Morgan, 2020; Keller and Marr, 2024; Perman and others, 2025).

In The Slough valley, south of the town of Severance, unit Qa occurs along the cutbank of the modern channel as a pale brown (10YR), moderately well sorted, silty gravelly sand with none to slight effervescence when wet. The sand content is roughly 40–50% and fine-grained. The sand is very fine- to coarse-grained and either does not effervesce or effervesces slightly with HCl. The gravel comprises 20–30% of the deposit. Clasts are typically subangular to rounded and range in size from granules to 3 cm pebbles but can be as large as 17 cm cobbles in length. Gravel clasts are primarily comprised of granitic rocks, gneiss, with quartz, white quartzite, and possible black quartzite from Coal Creek (see Lindsey and others, 2005). Some of the gravel has carbonate coatings and could also possibly be reworked from units Qg and Qgs. Water well logs from CO DWR (2023) show that the thickness of alluvium in Coalbank Creek is about 8–9 m. According to Colton (1978), the alluvium in Coalbank Creek correlates to the Piney Creek Alluvium which has been mapped as unit Qg, in other nearby Colorado Geological Survey maps. In the surrounding Greeley, Windsor, and Timnath quadrangles, the ages of unit Qa range from 1,010–4,360 calibrated year BP (Keller and Morgan, 2020; Keller and Marr, 2024; Perman and others, 2025).

Qg<sub>1</sub>

**Gravel deposit one (Middle Pleistocene?)** — Unit Qg<sub>1</sub> was observed exclusively along the eastern shores of Black Hollow Reservoir. At this location, unit Qg<sub>1</sub> was initially deposited within a paleogeographic stream channel where an ancestral creek scoured and incorporated portions of the underlying Kp and PkNbh layers into the deposits. The unit consists of pale brown to light yellowish gray (2.5Y), moderately to poorly sorted gravelly sand with interbedded layers of sandy silt and clay. The sand grains are predominantly very fine to medium, with minor amounts of coarse to very coarse grains, and are subangular to subrounded.

Gravel content constitutes between 5% and 60% of the unit, ranging in size from granules to 12.5 cm cobbles in diameter, with most clasts measuring approximately 5 cm in diameter. The gravel is primarily subangular to subrounded and comprised of dark-colored metamorphic and igneous rocks, brown sandstone, and granitic rocks; some clasts are comprised entirely of igneous rocks. Bedding on the millimeter scale was observed within The Slough valley. Silt developed into this unit have included Stage I-II CaCO<sub>3</sub> morphology. Carbonate nodules up to 5 mm in diameter, filaments up to 2 cm-long and 1 mm-thick, and discontinuous, lobate-shaped filaments up to 4 cm-long are present in the matrix. Some clasts have carbonate coatings up to about 1 mm-thick, and the matrix effervesces weakly to violently.

Three samples were collected for OSL analyses (see Table 2). Two samples were collected from a single exposed face about 1.1 and 0.76 m below ground surface near the top of the deposit. A third sample was collected from a different exposure 50 m to the east. The highest sample from the first site (SV085B2-OSL1) was collected near the bottom of a 0.6 m thick gravelly sand layer below a 10 cm thick Bt soil horizon and yielded an infinite age of greater than 30.4 ka SAR OSL years. The second sample (SV085B3-OSL2) was collected about 0.3 m below the highest sample and yielded an age of 73,810 ± 7,820 SAR OSL years. The results of these are stratigraphically reversed. The third sample site (SV085A3-4OSL1) nearby was collected from about 1 m below the surface in a 80 cm thick gravelly sand layer below a 30 cm thick Bt soil horizon and yielded an age of 7,685 ± 210 SAR OSL years.

Given the observed Stage I-II carbonate development overlying the sample, the 7,685 ± 210 yrs. age estimate is likely too young. The 73,810 ± 7,820 yrs. age estimate seems more reasonable due to the degree of soil development (presence of Bk and Bt horizons), and position above The Slough valley (about 13 m). Even though the result is infinite, the >304 ka estimate could also be supported by these observations. In the Valley View School quadrangle (40 km southwest), an OSL age estimate was collected in unit Qg<sub>1</sub> yielding a result of ~341 ka (Keller and Marr, 2023). This unit is possibly correlative to the Slocum Alluvium which was mapped by the USGS in the past. In the Denver area, Slocum Alluvium is estimated to date about 300 and 220 ka, and possible older deposits are around 390 and 320 ka (Kellogg and others, 2008). Apart from the >304 ka estimate, the age results yielded from samples collected near Black Hollow Reservoir are younger. However, these samples also have an overdispersion percentage >20% (Table 2).

Qgs<sub>1</sub>

**Gravel deposit two (Middle Pleistocene)** — The unit is composed of very pale brown to light brown and white (10 YR and 7.5 YR), poorly to very poorly sorted, very fine- to very coarse-grained sand with gravel with minor fines. Sand grains are mainly subangular to subrounded and comprise 75% quartz, 25% feldspar and other minerals, and < 1% opaque minerals. Gravel clasts range from angular to well rounded but are generally subrounded. The lithology of the clasts includes granitic rock, brown sandstone, gneissic rock, and possible igneous concretions. While the gravel content observed during this investigation ranges from approximately 3–50%, Colton and Finch (1974) conducted a grain size analysis of unit Qgs<sub>1</sub> in the northern part of the Severance quadrangle. Their analysis estimates the unit is 40–70% sand and 30–40% sand, and 10–30% clay and silt. Clasts range in size from granules to 16 cm cobbles but can be as large as 37 cm boulders. By the WCR 84 and 25 junction, a soil developed into a silty gravelly sand deposit has a moderately to strongly cemented Bk horizon with Stage III to IV carbonate morphology. Secondary carbonate nodules in the matrix are as much as 3 mm in diameter and gravel clast coatings were observed at least 1 mm-thick. The thickness of unit Qgs<sub>1</sub> ranges from 2–9 m in the greater Fort Collins area (Workman and others, 2018). The unit is locally overlain by unit Qe and has been heavily modified by pedogenic processes.

Qg<sub>2</sub>

Unit Qg<sub>2</sub> is the oldest mapped surficial deposit in the Severance quadrangle. Colton (1978) mapped this unit as Verdos Alluvium on the basis of height above local major and overlying unit Kf is gradational. Like the contact between units Kf and Kf, historically, the contact between the upper part of unit Qg<sub>2</sub> (also known as the Pierre Transition Member) and unit Kf was difficult to define. According to Lovering and others (1972), in the contact was defined by being 75 m below unit Kf, and Scott and Cobban (1965) stated that the contact was unmappable. In the Bracwell quadrangle, the author included the Transition Member within the Fox Hills Sandstone due to the difficulty of delineating the contact (Palukovic, 2020). Lake units Kf and Kf, the contact in this map between units Kf and Kf was defined using the contact from Shelton and Rogers (1975) (see unit Kf).

Two detrital zircon samples were collected from near the upper portion of unit Kf, near the Kf/Kf contact: one along WCR 86 (SV001DZ, see Table 3), which yielded a youngest age population of 74.9 ± 1.7 Ma (n = 3; MSWD = 0.56; youngest single grain of 70.8 ± 4.3 Ma), and one along WCR 25 (SV012DZ, see Table 3), which yielded a youngest age population of 67.6 ± 2.1 Ma (n = 5; MSWD = 0.62; youngest single grain of 63.7 ± 3.5 Ma). Additionally, another detrital zircon sample (SV021DZ, see Table 3) was collected near the base of unit Kf from a site near the center of the quadrangle, by WCR 80, near the Kf/Kf contact. This sample yielded a youngest age population of 73.3 ± 1.6 Ma (n = 13; MSWD = 0.93; youngest single grain of 69.4 ± 3.4 Ma). The 74.9 ± 1.7 Ma and 73.3 ± 1.6 Ma dates are within the ages of the Fox Hills Sandstones at Limon, Colorado, which yielded a youngest age population of 76.6 ± 1.2 Ma (youngest single grain of 74 ± 2 Ma and 72.2 ± 1.0 Ma (youngest single grain of 67 ± 3 Ma) (Morgan and others, 2023; Morgan and O’Keefe, 2023).

Water well logs from CO DWR (2023) in Cross Section A indicate that the unit is up to 33 m-thick, while Shelton and Rogers (1975) report that the unit is up to 18 m-thick, and Workman and others (2018) estimate it to be up to 24 m-thick.

Kp

**Pierre Shale (Upper Cretaceous)** — The unit is composed mainly of medium- to dark-gray shale with an upward gradation to silstone and silty sandstone that make up the upper Pierre Shale Transition Zone Member (Shelton and Rogers, 1975). The unit is mostly covered by Quaternary-aged sediments and residuum, but it is exposed on the bluffs on the eastern shores of Black Hollow Reservoir where it is overlain by units Qe, Qgs<sub>1</sub>, and PkNbh. At this location, unit Kp is composed of alternating dark grayish-brown to olive gray (5Y and 2.5Y) shale and pale brown to light yellowish-brown (2.5Y) silstone and fine-grained sandstone layers. Bedding ranges from planar lamination to wavy beds up to 1 cm thick. The unit is friable and breaks into platy and blocky fragments. Some of the sandy beds are discontinuous. Calcium carbonate content varies from none to slight with effervescence with HCl and have 1–2 mm carbonate veinlets. Locally, iron oxide coatings are present. At Black Hollow Reservoir, this unit dips at 4° east. Spiderolitic concretions as large as 60 cm in diameter were observed and are common in the upper Pierre Transition Zone Member (Scott and Cobban, 1965). In addition, indurated portions of the shale have cone-in-cone structures about 5 cm-thick. The unit also has sandy gypsum lenses about 3–6 cm-thick with yellow to orange, very fine- to medium-grained sand and smaller white lenses of fine sand about 1 mm thick. Gypsum crystals are present and form 1 mm to 3 cm thick plates and weather to an acicular habit. “Swallowtail” twins and gypsum “flowers” are also present. Indurated, pale brown, carbonate cemented, fine- to medium-grained sandstone beds locally contain burrows and fossil shells as large as 5 cm. Fragments of these indurated sandstones are present in the overlying colluvial deposits (unit Qc) throughout the western portion of the quadrangle. Unit Kp was also observed in an irrigation ditch along WCR 21 where it is mostly thin, gray shale beds interlayered with indurated, fine-grained, discontinuous sandstone beds. Total unit thickness is approximately 2,055–2,208 m.

**Colluvium and sheetwash deposits, undivided (Holocene to Upper Pleistocene)** — Unit Qc occurs along the valley sides of The Slough and Coalbank Creek in the northern part of the quadrangle, where bedrock is shallow. It is also present west of the WCR 25 and Hwy 14 junction, where it occupies a bowl-shaped landform. The unit is not well exposed, however, it forms distinct colluvial fans and aprons at the base of the bedrock and base of unit Qg<sub>1</sub> as seen in lidar imagery.

Colluvium within unit Qc consists of bedrock fragments and local gravel derived from unit Qg<sub>1</sub> that have been transported downslope by gravity. In the Coalbank Creek valley, sheetwash deposits are moderately sorted, brown, very fine to medium sand with minor gravel, as well as poorly sorted, pale brown silt sand. Gravel within this deposit ranges in size from granules to 3 cm pebbles, with larger local cobbles and boulders. A radiocarbon sample, SV104C14 (see Table 1), was taken from unit Qc fan in the Coalbank Creek Valley, yielding a <sup>14</sup>C conventional age of 500 ± 30 years.

In The Slough valley, based on water wells from CO DWR (2023), the sheetwash deposits consist of brown and light yellowish-brown sandy clay.

Kn

Unit Qes may include sediments from minor gullies and rills, local bedrock residuum, reworked colluvial sediments, and may grade into or interfinger with units Qa and Qe. Based on CO DWR (2023), the thickness of unit Qes typically ranges from 5–7 m but can be as thick as 11 m. Qes is mapped as unit Qe. Qes are locally susceptible to small debris flows and swelling or collapsing soils. This unit may also serve as a local source of sand and gravel for fill material.

Qcso

**Old colluvium and sheetwash deposits, undivided (Upper Pleistocene)** — Unit Qcso occurs on the western side of the Coalbank Creek valley in the north part of the quadrangle. Unlike unit Qc, it does not form distinct fans and aprons. The unit was delineated based on its smoother surface observed in lidar imagery, in contrast to the surrounding bedrock, which has a more irregular surface.

The unit consists of sheetwash deposits that are light brownish gray to very pale brown, moderately to poorly sorted, silty clay or clayey silt sand. The sand ranges from very fine to coarse, with minor gravel up to 1 cm in size. Larger gravel is scattered throughout the unit, ranging from granules to 30 cm boulders, with an average size around 6 cm. Soil developed on the unit consists of Bk Stage I: carbonate development, with scattered calcic carbonate filaments, clasts with <1 mm thick rills, and strong effervescence.

Bedrock residuum (unit Kf) was observed from an animal burrow, suggesting that the unit most likely has residuum at a shallow depth. CaCO<sub>3</sub> cemented sandstone boulders (from unit Kf) were also observed in the ravine near the center of the unit. Unit Qcso may include reworked colluvial sediments. The thickness is estimated to be 1–2 m, although the exact thickness of unit Qcso is not known, as no water wells are located in its vicinity. Areas mapped as unit Qcso are locally susceptible to small debris flows and swelling or collapsing soils. This unit may serve as a local source of borrow sand.

Qu

**Quaternary undivided (Holocene to Pleistocene)** — Shown in cross section only. Alluvium and colluvial deposits of the Severance quadrangle undivided. This unit locally may contain residuum from underlying bedrock (Robson and others, 2000a and b).

### BEDROCK GEOLOGY

**Conglomeratic sandstone of Black Hollow Reservoir (Upper Cretaceous (Palaeogene?))** — The unit is composed of very pale brown (10YR) and pale yellow (2.5Y), poorly sorted conglomerate sandstone with a matrix dominated by coarse- to very coarse-grained sand with minor very fine- to medium-grained sand. Sand grains are mostly rounded to well rounded with about 75% quartz, 24% feldspar and other minerals, and 1% opaque minerals. Gravel clasts are predominantly subrounded to well rounded and range in size from granules to 3–5 cm pebbles with rare cobbles up to 11 cm. Clasts are primarily potassium feldspar granitic rocks, dark, fine-grained metamorphic rocks, and iron concretions. The unit is moderately to strongly indurated with a calcium carbonate cement (strong to violent effervescence with HCl). The unit is cross-bedded to massive; cross-beds range from a cm to tens of cm in scale. Unit KfPbh was only mapped along the eastern shore of the Black Hollow Reservoir where it is underlain by unit Kp.

The exposure at Black Hollow Reservoir is approximately 1 m-thick and 17 m-long. Due to its small area, unit KfPbh is represented as a point on Plate 1. At the unit’s contact with the underlying unit Kp, a meter thick KfPbh layer was precipitated from groundwater flow. Although not in situ, boulders possibly equivalent to this unit were observed about 230 m to the east of the Black Hollow outcrop and another boulder was observed in a ravine within unit Qcso about 3 km to the east. A detrital zircon sample (SV085CZD, see Table 3) from the Black Hollow outcrop yielded a youngest age population of 71.3 ± 1.5 Ma (number of concordant analyses [n] = 6; mean-square weighted deviation [MSWD] = 0.77; youngest single grain of 67.8 ± 2.9 Ma). In the Milliken quadrangle (35 km south of Black Hollow Reservoir), a lithologically similar unit was mapped mapping at Wilk’s Mount. Detrital zircons collected from this site (n = 58) yielded an age estimate of 28 Ma (Palukovic and others, 2018). Another lithologically similar unit was mapped and dated in the south-central part of the Timnath quadrangle (12 km southwest of Black Hollow Reservoir) where a detrital zircon age (n = 102) yielded an age estimate of 27.5 ± 1.4 Ma (Perman and others, 2025). While the ages at the Timnath and Milliken quadrangles may correlate to the Ogallala Formation (possibly began accumulating in the Oligocene or early Miocene) at its western extent (Klein and others, 2016; Morgan and others, 2023; Morgan and O’Keefe, 2023; Kainz and others, 2023), the age at Black Hollow Reservoir is about twice as old (youngest date 67.8 ± 2.9 Ma). Based on the absence of ~28 Ma zircons, it is possible that unit KfPbh has an age that is pre-Ogallala and may be similar to the Arkare Formation, White River Formation, or older. It is also possible that the apparent age difference reflects a sampling limitation at Black Hollow Reservoir, where younger zircons (<28 Ma) were simply not encountered in the analyzed population. Although very unlikely, it is important to point out the possibility that the age results from this study could be accurate, which would suggest unit KfPbh may be Cretaceous in age. According to Raynold (2021), the age of the Arapahoe Conglomerate, part of the Denver Formation D1 Sequence found mainly in the Denver area, has an age estimate around 67 Ma. The Denver Formation D1 Sequence was deposited during the Laramide Orogeny uplift of the Rocky Mountains when precipitation was high, resulting in the formation of large fan deposits (Leier and others, 2005) and river systems that generally flowed north from the Denver area (DeChesne and others, 2011). It is possible that unit KfPbh may have been deposited during this period.

**Laramie Formation (Upper Cretaceous)** — The unit is composed of light- to dark-gray, interbedded silstone, silty sandstone, and carbonaceous shale. The lower portion of the unit consists of light- to medium-gray, quartzose sandstone beds that are separated by shale beds and coal seams. The upper portion consists of claystone, shale, sandy shale, lignite, and lenticular sandstone beds (Shelton and Rogers, 1975).

In a few areas in the quadrangle as well as throughout the Colorado Piedmont, the contact between units Kf and Kf is difficult to distinguish due to its gradational and shingled stratigraphy (Odouli, 1966; Briscoe, 1972; DeChesne and others, 2011). In the Severance quadrangle, the contact between units Kf and Kf is from Shelton and Rogers (1975) which was modified from previous work (Mather and others, 1928; Briscoe, 1972;

North of the Greeley Arch (see Geologic History and Structure on Plate 2), the total thickness of the Laramie Formation is about 488–545 m (Weimer, 1977; Kirkham and Lagwig, 1979). However, water well logs from CO DWR (2023), plotted on Cross Section A (Plate 2), indicate the unit is about 46–61 m thick in the Severance quadrangle. These measurements concur with those of Shelton and Rogers (1975).

**Fox Hills Sandstone (Upper Cretaceous)** — The unit is comprised of white, pale yellow, pale brown (5Y and 2.5Y), very fine- to fine-grained sandstone with minor silt. The sandstone is friable, breaks along bedding planes, weakly to moderately indurated, and predominantly massive but has some weak bedding and cross-bedding ranging from 1–10 cm thick. Iron oxide staining is locally present along bedding planes. The unit generally does not have any calcium carbonate accumulation and does not effervesce; however, carbonate fillings are present in the fractures and veinlets as thick as 5 mm. Ophiomorphus burrows, perforated wood, fossil shell fragments, and local mm-scale ripple mud clasts are present in the unit. Locally, unit Kf is comprised of indurated, very fine- to fine-grained sandstone. In the Bracwell quadrangle, this facies consist of highly resistant, dark brown to dark-gray, fine-grained sandstone cemented by silica and crops out in oblong lenticular bodies (Palukovic, 2020). This indurated sandstone may also be locally cemented by calcium carbonate (see unit Qcso).

While most of the unit is covered by residuum and Quaternary-aged sediments over much of the quadrangle, it is exposed in the Coalbank Creek valley in the northern part of the quadrangle and dips to the east at 4°. The contact of unit Kf with the underlying unit Kp and overlying unit Kf is gradational. Like the contact between units Kf and Kf, historically, the contact between the upper part of unit Qg<sub>2</sub> (also known as the Pierre Transition Member) and unit Kf was difficult to define. According to Lovering and others (1972), in the contact was defined by being 75 m below unit Kf, and Scott and Cobban (1965) stated that the contact was unmappable. In the Bracwell quadrangle, the author included the Transition Member within the Fox Hills Sandstone due to the difficulty of delineating the contact (Palukovic, 2020). Lake units Kf and Kf, the contact in this map between units Kf and Kf was defined using the contact from Shelton and Rogers (1975) (see unit Kf).

Two detrital zircon samples were collected from near the upper portion of unit Kf, near the Kf/Kf contact: one along WCR 86 (SV001DZ, see Table 3), which yielded a youngest age population of 74.9 ± 1.7 Ma (n = 3; MSWD = 0.56; youngest single grain of 70.8 ± 4.3 Ma), and one along WCR 25 (SV012DZ, see Table 3), which yielded a youngest age population of 67.6 ± 2.1 Ma (n = 5; MSWD = 0.62; youngest single grain of 63.7 ± 3.5 Ma). Additionally, another detrital zircon sample (SV021DZ, see Table 3) was collected near the base of unit Kf from a site near the center of the quadrangle, by WCR 80, near the Kf/Kf contact. This sample yielded a youngest age population of 73.3 ± 1.6 Ma (n = 13; MSWD = 0.93; youngest single grain of 69.4 ± 3.4 Ma). The 74.9 ± 1.7 Ma and 73.3 ± 1.6 Ma dates are within the ages of the Fox Hills Sandstones at Limon, Colorado, which yielded a youngest age population of 76.6 ± 1.2 Ma (youngest single grain of 74 ± 2 Ma and 72.2 ± 1.0 Ma (youngest single grain of 67 ± 3 Ma) (Morgan and others, 2023; Morgan and O’Keefe, 2023).

Water well logs from CO DWR (2023) in Cross Section A indicate that the unit is up to 33 m-thick, while Shelton and Rogers (1975) report that the unit is up to 18 m-thick, and Workman and others (2018) estimate it to be up to 24 m-thick.

Kp

**Pierre Shale (Upper Cretaceous)** — The unit is composed mainly of medium- to dark-gray shale with an upward gradation to silstone and silty sandstone that make up the upper Pierre Shale Transition Zone Member (Shelton and Rogers, 1975). The unit is mostly covered by Quaternary-aged sediments and residuum, but it is exposed on the bluffs on the eastern shores of Black Hollow Reservoir where it is overlain by units Qe, Qgs<sub>1</sub>, and PkNbh. At this location, unit Kp is composed of alternating dark grayish-brown to olive gray (5Y and 2.5Y) shale and pale brown to light yellowish-brown (2.5Y) silstone and fine-grained sandstone layers. Bedding ranges from planar lamination to wavy beds up to 1 cm thick. The unit is friable and breaks into platy and blocky fragments. Some of the sandy beds are discontinuous. Calcium carbonate content varies from none to slight with effervescence with HCl and have 1–2 mm carbonate veinlets. Locally, iron oxide coatings are present. At Black Hollow Reservoir, this unit dips at 4° east. Spiderolitic concretions as large as 60 cm in diameter were observed and are common in the upper Pierre Transition Zone Member (Scott and Cobban, 1965). In addition, indurated portions of the shale have cone-in-cone structures about 5 cm-thick. The unit also has sandy gypsum lenses about 3–6 cm-thick with yellow to orange, very fine- to medium-grained sand and smaller white lenses of fine sand about 1 mm thick. Gypsum crystals are present and form 1 mm to 3 cm thick plates and weather to an acicular habit. “Swallowtail” twins and gypsum “flowers” are also present. Indurated, pale brown, carbonate cemented, fine- to medium-grained sandstone beds locally contain burrows and fossil shells as large as 5 cm. Fragments of these indurated sandstones are present in the overlying colluvial deposits (unit Qc) throughout the western portion of the quadrangle. Unit Kp was also observed in an irrigation ditch along WCR 21 where it is mostly thin, gray shale beds interlayered with indurated, fine-grained, discontinuous sandstone beds. Total unit thickness is approximately 2,055–2,208 m.

**Niobrara Formation (Upper Cretaceous)** — Shown in cross section only. Fossilic, dark-gray shale with thin layers of micritic limestone. Unit is an important oil and gas resource in the Denver Basin. Total thickness is approximately 76–100 m.

**Colorado Group (Upper Cretaceous)** — Shown in cross section only. Units comprising the Colorado Group include the Codell Sandstone (silty, shaley, fine-grained sandstone), Carlile Shale (near-shore sandstone and shale), Graneros Shale (shale with interbedded sandstone), and Greenhorn Limestone (shale, limestone, and chalky shale). Two wells penetrate the underlying Dakota Group: 05-123-23201 and 05-123-26741. Based on these wells, unit Kegg combined approximate thickness is about 140–242 m.

### ACKNOWLEDGMENTS

The authors would like to thank the following for their assistance with this investigation. Ralph Shroba (Colorado Geological Survey geologist and U.S. Geological Survey Scientist Emeritus) was a peer reviewer and provided constructive comments and information to the authors. Steven L. Forman of Baylor University, Waco, Texas performed the optically stimulated luminescence (OSL) analyses. Beta Analytic, Inc. Miami, Florida performed radiocarbon analyses. Dr. Mark Schmitz of Boise State University performed the detrital zircon analyses and provided the concordant analyses of the data. Michael O’Keefe (Colorado Geological Survey) provided helpful discussions about the mineral resources within the Severance area. Jonathan White (Colorado Geological Survey Emeritus) provided valuable information and suggestions for the map. Joanna Redwine (Colorado Geological Survey STATEMAP Program Manager) and Matthew Morgan (State Geologist and Colorado Geological Survey Director) reviewed the final product and provided valuable feedback. David “Barney” Barnett of Panagaea Geospatial, produced the final map plates and GIS files. Benjamin Teschner and Rachel Turner from the Colorado State Land Board permitted the authors to do fieldwork within the property owned by the S.B. Nicola Watson and Lindsey Radcliffe-Coombs (Town of Severance) also permitted the authors to do fieldwork within the municipality of Severance. Finally, the authors would also like to thank Ryan Woodland of Woodland Home Marketplace, and other landowners in the Severance quadrangle who permitted the authors to visit and work on their properties.

### MAP SYMBOLS

- Water well — Division of Water Resources permit number shown on map
- Oil and gas well — Label is the American Petroleum Institute (API) Unique Well Identifier. Label does not include preceding State (05) and County Code (123 for Weld County).
- Geotechnical soil borehole
- <sup>14</sup>C age date sample site