



DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

For details on grain size, color, and other characteristics of map units, see Plate 2. For details on geologic hazards (e.g., flood potential) of map units, see Plate 2 section on Mineral Resources, Groundwater and Geologic Hazards. For radiocarbon dates, see Table 2. Subdivision of the Quaternary follows the International Chronostratigraphic Chart v. 2020/01 (International Commission on Stratigraphy, International Union of Geological Sciences, 2020). Particle size designation is according to the Udden-Wentworth grain size scale (in Nichols, 2009), modified such that each sand category is divided into upper (lighter) and lower (darker) sub-categories. For example, very coarse (vc) sand is divided into vcU and vcL. Colors are designated according to the Munsell soil color charts (Munsell Color, 1991). Description of soil-carbonate morphology is after Machette (1985).

HUMAN-MADE DEPOSITS

af Artificial fill (Upper Holocene) — Mostly riprap, fill, and refuse placed during construction of roads, railroads, buildings, dams, and landfills. Generally consists of unsorted clay, silt, sand, and rock fragments. The typical thickness of the unit is less than 6 m. Some artificial fill features, such as the barriers between St. Vrain Creek and gravel pits, are not mapped because they are limited in areal extent to show at map scale. Artificial fill may be subject to settlement, slumping, and erosion if not adequately compacted and (or) if it is placed on unstable slopes.

ALLUVIAL DEPOSITS

Qa1 Alluvium one (Upper Holocene) — Unit Qa1 deposits occupy active channels of St. Vrain Creek and three unnamed tributaries. Two of these tributaries drain the northern part of the quadrangle and join the creek in the northeast quarter; one joins the creek in the southwest quarter. In the lower reaches of the first two tributaries, unit Qa1 channels are bounded by cut-in-fill terraces of alluvium of tributaries to St. Vrain Creek (Qa2), less (Qa3), and Fox Hills Sandstone (Kh). In the St. Vrain Creek valley and in the tributary in the southwest quarter, the unit Qa1 active channel is almost everywhere confined on both sides by the banks of the Qa2 cut-in-fill terrace, the surface of which is 1.5 to 1.8 m above the active stream level. On the north side of St. Vrain Creek and 0.8 km west of 1/25 the creek channel is bounded by the upper transition member of the Pierre Shale (Kp1). In T. 3 N., R. 67 W., sec. 16 the creek channel is bounded by colluvium and alluvial deposits (unit Qa3). In St. Vrain Creek the fine-grained fraction of unit Qa1 is present mostly on the channel bottom and consists of a dark brown, of hue 10YR, mixture of clay, silt, and very fine to fine sand. The coarse-grained fraction occurs in point bars in the channel. The bars are as high as 0.6 m above the active stream level and are composed of a loose, poorly sorted, clay-supported mixture of medium sand to cobbles. The sand is poorly sorted and angular to subangular; it consists of ~65% quartz with significant feldspar and minor mica and opaque minerals. The matrix is subrounded to rounded and is dominated by granitic clasts with subordinate vein quartz, quartzite, gneiss, and sandstone. The overall color of the unit is pinkish-gray to light gray. Thickness of the unit is not known because its presumed contact with underlying unit Qa2 could not be observed. Within the quadrangle, unit Qa1 is likely a potential source of sand and gravel, because of the paucity and small areal extent of gravelly point bars. Unit Qa1 is prone to flooding.

Qa2 Alluvium two (Upper Holocene) — Unit Qa2 occupies the flood plains of St. Vrain Creek and also the unnamed north-flowing tributary in the southwest quarter of the quadrangle, as shown on cross sections B-B' and C-C'. The unit is well exposed along several reaches of the creek. It underlies the lowest terrace in the valley, with the terrace surface being 1.5 to 1.8 m above the active stream channel. The unit Qa2 surface appears to be a cut-in-fill terrace. At locations throughout the valley, a thickness of 0.6 to 1 m of unit Qa2 is observed to overlie 0.6 to 0.9 m of a gravel layer of alluvium three (unit Qa3). Unit Qa2 also may locally overlie unit Qa1 in the unnamed tributary in the southwest quarter of the quadrangle, where two geotechnical logs indicate a layer of clayey sand overlies a layer of sand and gravelly sand. The gravelly sand relationship also is observed in the Longmont quadrangle adjacent to the creek, as supported by radiocarbon age data (Madole, 2016). Unit Qa2 probably is overlain by colluvium and alluvial deposits (Qa3) on the north side of the St. Vrain Creek valley near the north quadrangle boundary. On the basis of deposit type and the terrace position on the landscape, unit Qa2 correlates with Qa2 of adjacent nearby quadrangles (Soister, 1965; Madole, 2016; Palkovic and Morgan, 2017; Keller and Morgan, 2017).

Qa3 Alluvium three (Upper Holocene) — Unit Qa3 underlies the flood plains of St. Vrain Creek and also the unnamed north-flowing tributary in the southwest quarter of the quadrangle. It locally overlies both upper transition member of the Pierre Shale (Kp1) and Fox Hills Sandstone (Kh), but mostly overlies the unit Qa2 (Soister, 1965) deposits that cover the adjacent valley sides. Unit Qa3 may be interbedded with unit Qa2 along the valley walls, assuming that the tributaries were flowing during the Qa2 deposition in Late Pleistocene through Holocene time. Eroded unit Qa2 materials contribute to the unit Qa3 (Madole, 2016). In the upper reaches of the tributaries, unit Qa3 forms cut-in-fill terraces less than 0.9 m in height, but the terrace height increases to 1.8 m where the streams approach St. Vrain Creek. Their local base level (Madole, 2016) is the maximum exposed thickness of unit Qa3 in the quadrangle. Madole (2016), describing unit Qa3 in the Longmont quadrangle adjacent to the west, states that twice during Holocene time conditions in the region favored valley widening and alluviation. This resulted in formation of valley fill that subsequently was incised. Unit Qa3 also forms small gently sloping fans where the tributaries enter St. Vrain Creek. Unit Qa3 is a fine-grained silt to fine sand; locally the deposit contains angular granules of Pierre Shale upper transition member (Kp1) mudstone. Color is mostly dark-gray, commonly with bluish-black and rust-colored mottles. Where moist or wet, the matrix is plastic, and where dry it ranges from weakly cohesive to very cohesive. Secondary carbonate development in the form of carbonate nodules was present at only one of the six locations where unit Qa3 was described. At the remaining locations, however, the unit was weakly to strongly calcareous. Part of the area mapped as unit Qa3 is prone to flooding. Because of its clay and silt content, the unit is likely not a potential source of sand. The observed thickness of the unit ranges from less than 0.9 to 1.8 m.

Qa4 Alluvium of tributaries to St. Vrain Creek, undivided (Holocene to Upper Pleistocene) — Unit Qa4 occupies the valley floors of the two unnamed south-flowing tributaries to St. Vrain Creek, both of which are in the northern part of the quadrangle. It locally overlies both upper transition member of the Pierre Shale (Kp1) and Fox Hills Sandstone (Kh), but mostly overlies the unit Qa2 (Soister, 1965) deposits that cover the adjacent valley sides. Unit Qa4 may be interbedded with unit Qa2 along the valley walls, assuming that the tributaries were flowing during the Qa2 deposition in Late Pleistocene through Holocene time. Eroded unit Qa2 materials contribute to the unit Qa4 (Madole, 2016). In the upper reaches of the tributaries, unit Qa4 forms cut-in-fill terraces less than 0.9 m in height, but the terrace height increases to 1.8 m where the streams approach St. Vrain Creek. Their local base level (Madole, 2016) is the maximum exposed thickness of unit Qa4 in the quadrangle. Madole (2016), describing unit Qa4 in the Longmont quadrangle adjacent to the west, states that twice during Holocene time conditions in the region favored valley widening and alluviation. This resulted in formation of valley fill that subsequently was incised. Unit Qa4 also forms small gently sloping fans where the tributaries enter St. Vrain Creek. Unit Qa4 is a fine-grained silt to fine sand; locally the deposit contains angular granules of Pierre Shale upper transition member (Kp1) mudstone. Color is mostly dark-gray, commonly with bluish-black and rust-colored mottles. Where moist or wet, the matrix is plastic, and where dry it ranges from weakly cohesive to very cohesive. Secondary carbonate development in the form of carbonate nodules was present at only one of the six locations where unit Qa4 was described. At the remaining locations, however, the unit was weakly to strongly calcareous. Part of the area mapped as unit Qa4 is prone to flooding. Because of its clay and silt content, the unit is likely not a potential source of sand. The observed thickness of the unit ranges from less than 0.9 to 1.8 m.

Qa5 Alluvium three (Upper Pleistocene) — Unit Qa5 underlies unit Qa1 in the St. Vrain Creek valley, as shown on cross sections B-B' and C-C'. The unit forms a prominent, widespread cut-in-fill terrace occupying most of the valley's southeast side and a portion of its northwest side. The terrace has two surfaces discernible on lidar imagery: the higher surface is the predominant part of the feature and the lower surface only on the southeast side of the valley in the northeast corner of the quadrangle (in T. 3 N., R. 67 W., secs. 9, 10, and 15, and T. 3 N., R. 68 W., sec. 36, NE 1/4). Vertical exposures of unit Qa5 are 0.3 to 1.5 m thick along St. Vrain Creek and are up to ~10 m thick along gravel pits. Along the eastern quadrangle boundary, the upper surface of the Qa5 terrace is a broad flat upland dividing St. Vrain Creek to the west from the South Plate River to the east. The lower surface of the Qa5 terrace is a broad, gently sloping surface that is present in cross section J-J' of Lindsey and others (2005), and thus unit Qa5 may correlate with Broadway Alluvium by virtue of height above stream level. On lidar imagery the upper surface of unit Qa5 is traceable southwest along the southeast boundary of the quadrangle to the east. The lower surface is also traceable along a thin band along part of the northeast valley wall from T. 3 N., R. 67 W., sec. 29 to its far southwest as T-25. The upper surface of unit Qa5 is ~3.0 m above the lower surface and 1 m above the Qa2 terrace. The Qa5 terrace lower surface lies approximately 1.5 to 3.0 m above the Qa2 terrace. The lower surface is at the base of several prominent meander cuts into unit Qa5; the cuts presumably were made by lateral erosion operating during a period of stream incision. Unit Qa5 overlies the Pierre Shale upper transition member (Kp1) at Varra Companies Pit 115. The greatest observed Qa5 thickness was 10.4 m, at the east face of this pit. Unit Qa5 is continuous with and equivalent to unit Qa3 in the Longmont quadrangle adjacent to the west (Madole, 2016). In the Johnson quadrangle adjacent to the north (Palkovic and Morgan, 2017), unit Qa5 is also continuous with river gravel (Qg) and alluvial sand and silt (Qs) in the Plattville quadrangle adjacent to the east. These Plattville map units may be partly equivalent to Broadway or Louviers Alluviums (Soister, 1965).

Seventeen geotechnical logs of water wells in the St. Vrain Creek valley, in the area southwest of T. 3 N., R. 67 W., sec. 31, indicate that depth to bedrock (unit Qa1 plus unit Qa2 thickness) ranges from 3.0 to 9.2 m (Colorado Department of Natural Resources, Division of Water Resources (DWR), 2018). Five geotechnical logs in the same area have bedrock depth values that range from 4.6 to 7.0 m. To the northeast and downstream, between T. 3 N., R. 67 W., sec. 31 and the place name of Gowanda, six water well logs that penetrate the upper surface of the Qa2 terrace indicate bedrock depths between 2.8 and 14.2 m. Near the eastern quadrangle boundary, the depth-to-bedrock values in three water wells that penetrate the upper surface of the terrace range from 13.7 to 17.1 m. The water well data generally indicate that the bedrock floor of the St. Vrain Creek valley decreases in elevation in the downstream direction (westward).

The lower part of unit Qa5, exposed locally along St. Vrain Creek, consists chiefly of poorly sorted gravelly sand and sandy gravel, with the gravel-size fraction making up to 50% of the sediment. The overall color is reddish or pinkish-gray. The sand fraction locally is only weakly calcareous. The deposit is weakly to moderately cohesive.

In the eastern face of the Varra Companies Pit 115, as observed in 2019, is a fresh vertical exposure of 10.4 m of upper unit Qa5. The face consists of three gravel layers interbedded with three sand layers; this sequence is underlain by bluish-gray Pierre Shale upper transition member (Kp1) shale and is capped by a clayey layer. The gravel and sand layers are 0.9 to 1.5 m thick and the clayey layer is 0.9 m thick. The sands are ~65% quartz with subordinate feldspar and opaque minerals, moderately to poorly sorted, angular to subangular, mostly non-calcareous, non-calcareous, and weakly cohesive. Colors are yellowish-brown to dark-brown. The gravel layers are clast-supported gravel and matrix-supported sandy gravel. Color is reddish to pinkish-gray. No carbonate rinds were observed on the clasts, and cut-in-fill channels were observed in the uppermost gravel layer. The capping clayey layer, which possibly is an overbank deposit, is black, hard, very cohesive, breaks into blocks, and has secondary carbonate development in the form of white carbonate nodules less than 0.5 m in size.

Unit Qa1 at the Asphalt Specialties Nelson Mining Resource pit, 1.7 km west of the Varra Companies Pit 115 and at nearly the same elevation, is somewhat different than that at Pit 115. A fresh exposure in 2019 of 6.1 m of upper Qa1, has 3.7 m of coarse gravel overlying Pierre Shale upper transition member (Kp1) shale, with the gravel layer extending from 2.4 to 6.1 m below ground surface. The gravel is overlain by a 0.9-m-thick layer of silty clay or clayey silt, which is overlain by 1.5 m of sand. The gravel layer is bedded at ~0.5 m, has some crossbedding, contains a layer having contorted bedding (probably from self-sedimentation deformation), and contains large rip-up clasts of gray fine to fine sand. No carbonate rinds were observed on the clasts. Overall gravel color is pinkish-gray. The overlying silty clay or clayey silt resembles the black clayey layer at the top of unit Qa1 at the Varra Companies Pit 115; it is medium to dark bluish-gray and has columnar structure. The lower contact of the unit cross-cut the bedding of the underlying gravel layer, indicating that the silty clay or clayey silt probably is a channel filling. The sand overlying the clay layer is poorly sorted, consists of medium sand to small pebbles, is reddish-brown to light gray, and locally is crossbedded.

Four samples were collected, from interbedded sand and gravel mapped as unit Qa1, for optically stimulated luminescence (OSL) dating. All samples were from sand layers in a vertical exposure on the east face of Varra Companies Pit 115 (Plate 1; map, and Plate 2; Table 2). From lowest to highest in elevation the samples were G0670/S, G0670/G, G067E, and G067F; collected at depths of 11.6, 9.8, 7.9, and 3.6 m below ground surface, respectively. Their ages are 151,360 ± 5,800, >56,305, 54,480 ± 5,540, and 42,285 ± 2,720 yr, respectively. Sample G0670/S was overlain by a thin layer of the lowest accessible sand and sample G067F was collected from the uppermost sand layer, underlying the capping clayey layer. The upper three sand layers are approximately the same age range for Broadway Alluvium, which is considered coeval with Pinedale glacial. Pinedale time is considered ~31 ka to about 15 to 13 ka (as summarized in Berry and others, 2019). Broadly alluvium is considered to be 30 to 12 ka (Kellgus and others, 2008), and Colorado Geological Survey OSL ages for unit Qa1 (equivalent to Broadway Alluvium) are ~11 ka in the Berthoud quadrangle (Keller and others, 2017), ~12 ka in the Longmont quadrangle (Madole, 2016), and ~13 ka in the Milliken quadrangle (Palkovic and others, 2018). The ages of the upper three sand layers in Pit 115 are much younger than the range for Louviers Alluvium (120 to 170 ka; Kellgus and others, 2008, and references cited therein). If the Pit 115 OSL ages closely date the times of deposition of the sediments, then the uppermost sand (age 42,285 ± 2,720 yr) may have been deposited during an early advance of Pinedale ice between about 47 and 34 ka (Thompson and others, 2015; Sturcho and others, 1994). The middle sand layer (54,480 ± 5,540 yr) and possibly the lower sand layer (>56,305 yr) are of Early Wisconsin age, a period of time for which there are no known alluvial deposits mapped in the Colorado Piedmont and near Denver (Kellgus and others, 2008) or further north on the western margin of the Colorado Piedmont (Cole and Bradstock, 2009; Workman and others, 2018). The latter two ages are equivalent and should be interpreted with caution, in part, because there are no corresponding glacial deposits of Early Wisconsin age identified in the Front Range that the middle and lower dated deposits can be attributed. In Table 2, these two ages are assigned to unit Qa1 but are queried because they could have collected from an underlying deposit that predates unit Qa1. The age (~151 ky) of the lowest sand layer in Pit 115 is within the age range for Louviers Alluvium (Kellgus and others, 2008, and references cited therein). In the northeast part of the quadrangle, a sample for radiocarbon analysis was collected from a debris flow (?) overlying unit Qa1 (sample location G19C14). The sample yielded an age of 1,244 ± 270 yr B.P. (calibrated). In the St. Vrain Creek valley within the Gowanda quadrangle, unit Qa5 is a shallow aquifer and an important sand and gravel resource.

Qa6 Alluvium four (Upper Pleistocene) — The Qa6 terrace is locally mantled by unit Qa5, as shown on cross sections B-B' and C-C'. From water well data, the underlying Qa6 alluvium is interpreted to be 8.2 to 24.4 m thick (Colorado DWR, 2018). The Qa6 terrace lies along the southwest boundary of the St. Vrain Creek valley, between T. 3 N., R. 67 W., sec. 33 and the unnamed tributary to St. Vrain Creek, and the top of the Qa6 terrace is ~13 m higher than the top of the Qa2 terrace. As indicated in nine water-well logs, unit Qa6 consists of stratified sand, gravel, and silt, and is not exposed at the surface in the Gowanda quadrangle except at the bottom of Varra Companies Pit 115. A little over half of the deposit consists of interbedded sand, sand and gravel, and clayey sand; interbed thickness values range from 3.0 to 10.1 m and average 7.0 m. One-third of the deposit is gravel; gravel layer thickness values range from 1.2 to 3.1 m and average 2.4 m. The remaining part of the deposit is clay or clayey silt; thickness values range from 0.6 to 4.9 m and average 2.1 m. In the Gowanda quadrangle the unit Qa6 terrace is in the same position relative to unit Qa5 as in the Greeley quadrangle; the remnant Qa6 terrace on the south side of the Cote a Poudre River (Keller and Morgan, 2021). The terrace remnant in the Greeley quadrangle is mapped as Louviers Alluvium by Colton (1976). Both the Louviers Alluvium and the unit Qa6 terrace are overlain by unit Qa1. In the Lindsey and others (2005) cross section G-G', presenting alluvium in the Cote a Poudre River valley, the top of the Louviers (unit Qa6) terrace is ~11 m above the top of the Broadway terrace. In the Gowanda quadrangle the terrace of unit Qa6 (overlain by Qa1) is considered to be equivalent to the Louviers Alluvium terrace remnant in the Greeley quadrangle. Sample G0678 (base of Pit 115) yielded an optically stimulated luminescence (OSL) age of 51,360 ± 5,800 yr, which is within the age range of 120-170 ky given for Louviers Alluvium in Kellgus and others (2008). Although, per water-well evidence, there is sand and gravel in the Gowanda quadrangle Qa6 deposits, within the quadrangle there are no active or inactive aggregate pits in the unit. Several pits excavated in the unit Qa6 valley floor extend only as far south as the toe of the unit Qa6 terrace, suggesting that unit Qa6 may not be as suitable an aggregate resource as unit Qa5.

Qa7 Gravel deposit one (Middle Pleistocene T2) — Unit Qa7 constitutes a northeast-trending strip of isolated terraces that underlie hills in the upland along the southeast side of the St. Vrain Creek valley. Also, there are three isolated exposures on the northwest valley wall near the western quadrangle boundary. The eroded top of unit Qa7 is 15.2 to 21.3 m above the creek and 12.2 to 18.3 m above the upper surface of the unit Qa2 terrace (the latter corresponds to the Broadway terrace surface along the South Plate River). Individual outcrops of unit Qa7 are poorly exposed, and at all but one location the only indicators of the deposit are hillocks having abundant pebbles and cobbles with white carbonate rinds on clasts.

The best exposure of unit Qa7 is in a small abandoned pit ~1.2 km west of Firestone. This deposit was estimated in the field to be ~75% matrix and ~25% clasts (gravelly sand); a grain-size analysis of the material yielded 57% gravel, 38% sand, 3% silt, and 2% clay (sandy gravel). Carbonate rinds are common on the clasts and locally are as much as 2 mm thick. The matrix contains many fragments possibly from ionstone concretions in the Laraine Formation (Kl), and some fragments have been incorporated with carbonate rinds. Within the quadrangle, no water wells penetrate the unit (Colorado DWR, 2018) and therefore its thickness is not known; its exposed thickness is ~2.4 m in the pit discussed above. At that location unit Qa7 has been a limited source of sand and gravel in the past, but the paucity and limited extent of unit Qa7 elsewhere in the map area reduces the potential of this unit as a commercial source of sand and gravel.

In the easternmost part of the Gowanda quadrangle, unit Qa5 may correlate with deposits on a hill mapped as Sloum Alluvium (Qs) in the Plattville quadrangle (Soister, 1965); this occurrence is ~0.4 km to the east of the Gowanda quadrangle. Also, several occurrences of unit Qa5 in the Gowanda quadrangle were mapped as Sloum Alluvium by Colton (1976). In the Colorado Piedmont, younger portions of the Sloum Alluvium may have been deposited between about 300 and 220 ka, and older deposits of the unit may have accumulated between 300 and 320 ka (Madole, 1991). In the Masters quadrangle, ~40 km east of the Gowanda quadrangle, Berry and others (2015) mapped an interstratified alluvium (unit Qa1) that correlates with the older Sloum Alluvium of Kellgus and others (2008). Uranium-series ages for unit Qa1 indicate a best age of somewhat older than 382 ka. In the adjacent Plattville quadrangle, close to the southeast corner of the Gowanda quadrangle, Soister (1965) mapped four small hills as Rocky Flats Alluvium (Qrf), and these hills are topographically higher than unit Qa5 in the Gowanda quadrangle. Soister's unit Qrf apparently does not extend westward into the Gowanda quadrangle.

Without a numerical age for unit Qa7 specific to the quadrangle, it is not known with certainty that the unit is correlative with Sloum Alluvium but based upon the mapping of Colton (1976) such correlation is probable. Also, the Gowanda quadrangle occurrences of unit Qa7 resemble the (1) remnants of unit Qa1, thought to correlate with the older Sloum Alluvium of Kellgus and others (2008), on the south side of the South Plate River valley in the Masters and Orchard quadrangles (Berry and others, 2015a, 2015b); 2) unit Qa7 (proposed as Sloum Alluvium) in the northeast corner of the Valley View School quadrangle (Keller and Morgan, 2021); and 3) a putative remnant of unit Qa7 (proposed as Sloum Alluvium) near the South Plate River in the Hardin quadrangle (Palkovic and Morgan, 2021).

Qa8 Fox Hills Sandstone (Upper Cretaceous) — Greenish-buff, fine- to coarse-grained, cross-bedded quartzose sandstone in its lower part, grading upward to a light-gray and white, massive, fine- to medium-grained sandstone (Spencer, 1986). Outcrop described during the mapping consists of interbedded very fine-grained to fine-grained sandstone, which is well sorted, angular to subangular, weakly calcareous, and well indurated. Bedding thickness ranges from laminated, to 1 to 3 cm, to 20 to 60 cm. Colors of weathered sandstone are very pale-brown and yellowish-brown of hue 10YR. Thickness is 4 to 91 m (Spencer, 1986).

EOLIAN DEPOSITS

Qes Eolian sand (Upper Holocene) — Unit Qes occupies most of the quadrangle southeast of the St. Vrain Creek valley. In the Colorado Piedmont, including the Gowanda quadrangle and Great Plains, it is mapped as Late Quaternary wind-deposited sand by Madole and others (2005). On the basis of lithology and position in the landscape, it is continuous with and correlative with colluvium and alluvium and nearby quadrangles (Soister, 1965; Colton and Anderson, 1977; Keller and Morgan, 2018; Palkovic and others, 2018). Unit Qes is moderately well exposed to poorly exposed in road cuts, excavations, and one mine-out cut, but is easily identified even in shallow, hand-dug sample holes. Unit Qes was observed to overlie unit Qa1 in two excavations; the better exposed was in T. 3 N., R. 67 W., sec. 34, S 1/2 (radiocarbon sampling locations G098BC14 and G098C14). This stratigraphic relationship was observed also in some of the geotechnical logs and water well logs in the south-central and southeast parts of the quadrangle. The greatest vertical exposure of unit Qes is 1.8 m in a railroad cut in T. 2 N., R. 67 W., sec. 6, NW 1/4. Geologic logs from 17 water wells that penetrate Qes indicate that the unit is commonly 2.4 to 4.0 m thick, with three values from 6.1 to 7.4 m and two at 1.5 m. Two geotechnical log indicate values of 2.4 and 4.9 m.

Unit Qes is commonly a moderately to well-sorted fine to medium sand. Coarser sand content and poor sorting occur locally in Qa1 and might be attributable to proximity to areas of alluvial sand. Unit Qes is angular to subangular, or subangular to subrounded. Quartz content is approximately 65 to 70% with subordinate feldspar, opaque minerals, and mica. Neither secondary carbonate nor effervescence was observed when treated with dilute hydrochloric acid. The sand is only weakly cohesive. The color is mostly dark to light yellowish-brown. No bedding was seen in unit Qes in the Gowanda quadrangle (although bedding was noted in the adjacent Frederick quadrangle; Keller and Morgan, 2018). The deposit is distinctly coarse-grained, cleaner (i.e., with little clay and silt), and less cohesive than loess (unit QeL), and soils formed in unit Qes have a less-developed horizon than those formed in units QeL and Qa2.

Radiocarbon analysis sample G098BC14 was collected at 1.2 m below ground surface from unit Qes sand in a trench at the east quadrangle boundary in T. 3 N., R. 67 W., sec. 34, S 1/2. The sample was taken at the base of unit Qes, at its contact with underlying unit Qa1, and yielded an age of 2,867 ± 760 yr B.P. (calibrated), which is Upper Holocene. A radiocarbon sample also was collected from the top of QeL, a few centimeters below the Qes/QeL contact. Unit Qes locally is a shallow aquifer and also is a potential source of sand. Unit Qes may locally contain collapsible soils.

Qe Eolian sediment (Lower to Middle Holocene) — Unit Qe covers most of the quadrangle northwest of the St. Vrain Creek valley (see cross sections B-B' and C-C'), and also occurs in several small, discontinuous areas on the southeast of the valley. Unit Qe is a thin mantle, so it is not associated with particular topography and can be present over a broad range of elevations and geomorphic landforms (Madole, 2016). Within the quadrangle, unit Qe commonly overlies the Pierre Shale upper transition member (Kp1) and also overlies the Fox Hills Sandstone (Kh) along the north side of the St. Vrain Creek valley north of Colorado Highway 66, and overlies the Laraine Formation (Kl) in the south part of the quadrangle. Vertical Qe exposures thicker than 1 m are rare. The thickest exposure observed is 2.4 m high, on the south bank of a tributary to St. Vrain Creek and in T. 3 N., R. 67 W., sec. 17, NE 1/4. Bedrock logs from 32 water wells in unit Qe indicate most Qe thickness values range from 1.1 to 10.0 m, with three values from 1.2 to 1.8 m. Ten geotechnical logs in Qe place the lithologic contact beneath unit Qe as between 2.1 and 7.0 m below ground surface. On the basis of lithology and position in the landscape, unit Qe correlates with units QeL and Qe2 in adjacent and nearby quadrangles (Soister, 1965; Colton and Anderson, 1977; Madole, 2016; Keller and others, 2017; Palkovic and Morgan, 2017; Palkovic and others, 2018).

Unit Qe is massive and fine grained. At most locations grain size ranges from clayey silty sand or silty clayey sand to silty sand with minor clay. A grain size analysis of a sample of unit Qe collected in the north-central part of the quadrangle yielded sand at 37% silt, at 34%, and clay at 29%. Matrix material is moderately to very plastic, depending chiefly upon its silt content; the dry material is moderately cohesive to very stiff and hard. Colors of fresh unit Qe (i.e., lacking significant secondary carbonate) are various browns that fall evenly into hues 2.5Y and 10YR.

There are few exposures of unit Qe in the quadrangle, so its contacts with other surficial deposits are rarely observed. In two trenches, however, ~1 m of unit Qe was observed to directly underlie ~1 m of unit Qes. The first trench was in T. 2 N., R. 68 W., sec. 11, SE 1/4, and the second was on the east quadrangle boundary in T. 3 N., R. 67 W., sec. 34, S 1/2. In the second trench, radiocarbon analysis (sample G098C14, 1.3 m below ground surface) was performed on a sample of unit Qe immediately below its contact with the overlying unit Qes. The sample yielded an age of 5,590 ± 545 yr B.P. (calibrated). A radiocarbon sample also was collected from unit Qe, 1.3 m below ground surface, was performed on a sample of unit Qe immediately below its contact with the overlying unit Qes. The sample yielded an age of 5,590 ± 545 yr B.P. (calibrated). It yielded an age of 2,867 ± 760 yr B.P. (calibrated). Several geotechnical logs in T. 2 N., R. 68 W., sec. 14, NW 1/4 indicate silty sand overlying sandy clay, and these materials are likely to be similar to unit Qe. Secondary carbonate development in unit Qe is variable, but commonly is Stage I and II. Unit Qe is non-effervescence to moderately effervescence (U.S. Department of Agriculture, Natural Resources Conservation Service, 2018). Unit Qe is not a likely potential source of sand and gravel because of its clayey and silt fraction. The unit may have collapsible (hydropactive) soils.

MASS-WASTING AND ALLUVIAL DEPOSITS

Qcs Colluvium and sheetwash deposits, undivided (Holocene to Upper Pleistocene) — Unit Qcs forms a discontinuous area on the lower slopes of the northwest side of the St. Vrain Creek valley. The deposit apparently overlies the Fox Hills Sandstone (Kh) and unit Qa1. The few unit Qcs exposures are less than 0.6 m high; they mostly are on the uplope portions of unit Qa2 areas, and thickness of the unit probably increases down slope. Near the west quadrangle boundary, a thin wedge of Qcs (not mapped) is observed to underlie Qa2, suggesting that the two units locally may be interstratified but there are no northern quadrangle boundary. On the basis of lithology and position in the landscape, unit Qcs correlates with unit Qcs (sheetwash alluvium), or Qe (colluvium of adjacent and nearby quadrangles (Soister, 1965; Colton and Anderson, 1977; Madole, 2016; Palkovic and Morgan, 2017; Palkovic and others, 2018; and Keller and Morgan, 2018). Unit Qcs consists of eroded clay, silt, and sand, and bedrock fragments transported downslope from higher elevations by gravity or sheet flow. Matrix is predominant, as much as 90% of the deposit. The color is light brownish-gray or light olive-brown. The large proportion of fines and small proportion of coarse sand and bedrock fragments transported downslope from higher elevations by gravity or sheet flow. Matrix may experience fine-tentacular or sheetwash deposition, and locally are subject to small debris flows.

BEDROCK GEOLOGY

Within the Gowanda quadrangle, the upper transition member of the Pierre Shale (Kp1) and the Fox Hills Sandstone (Kh) are locally exposed in outcrops. The Laraine Formation (Kl) is present in outcrop and locally as residual composed of fragments formed by the weathering and erosion of the unit. All of these exposures are limited in areal extent; individual exposures do not exceed 0.2 km². The description of the Laraine Formation is from Spencer (1986), as the unit was observed in the Frederick and Erie quadrangles adjacent to the south and southeast, respectively. Field descriptions of the Fox Hills Sandstone are supplemented from the same source. Field descriptions of the upper transition member of the Pierre Shale are supplemented by descriptions from Scott and Cobban (1965). Bedrock units older than this member are shown only in cross section A-A'. For these older formations, map-unit descriptions of Pierre Shale members are modified from Scott and Cobban (1965), and descriptions of other units are modified from the geologic map of the Carter Lake Reservoir quadrangle, 23 km northwest of the map area, where these units are described in outcrop (Bradlock and others, 1988). Thickness values for the Laraine Formation and Fox Hills Sandstone are from Spencer (1986). Thicknesses for older units, except for the Dakota Group (Kd), are from cross section A-A', which is based upon oil and gas well data from the Colorado Oil and Gas Conservation Commission (COGCC). Thickness of the Dakota Group is from cross sections A-A' and B-B' (based on COGCC data) in the geologic map of the Berthoud quadrangle (Keller and others, 2017), adjacent to the northwest.

Kl Laraine Formation (Upper Cretaceous) — The lower 30 m of this unit is light- to medium-gray quartzose sandstone divisible into beds separated by clay, fine clay (refractory clay), shale, or coal seams. The upper 183 m is predominantly claystone, shale, sandy shale, and lenticular beds of sandstone and lignite. Total thickness is ~213 m. Multiple coal beds are present in the lower part of the formation and can reach 3.7 m in thickness. The two areas of Laraine Formation along the eastern quadrangle boundary appear to be residual of the unit and are characterized by abundant purple-brown fragments of Laraine Formation ironstone concretions. The Laraine Formation underlies surficial deposits in the area southeast of the St. Vrain Creek valley, and its basal portion is part of the Laraine-Fox Hills aquifer in the southwest mapped area along the eastern quadrangle boundary. Laraine Formation is weathered Laraine Formation. This material is very resistant and includes fragments of salmon-colored clinker and purple and orange ironstone, the latter possibly derived from concretions in the Laraine Formation. Historic coal mining in the map area has caused the ground surface to be prone to local subsidence (see Plate 2 section on Mineral Resources, Groundwater, and Geologic Hazards).

Kh Fox Hills Sandstone (Upper Cretaceous) — Greenish-buff, fine- to coarse-grained, cross-bedded quartzose sandstone in its lower part, grading upward to a light-gray and white, massive, fine- to medium-grained sandstone (Spencer, 1986). Outcrop described during the mapping consists of interbedded very fine-grained to fine-grained sandstone, which is well sorted, angular to subangular, weakly calcareous, and well indurated. Bedding thickness ranges from laminated, to 1 to 3 cm, to 20 to 60 cm. Colors of weathered sandstone are very pale-brown and yellowish-brown of hue 10YR. Thickness is 4 to 91 m (Spencer, 1986).

Kp1 Upper transition member and upper shale member — These two members are combined in cross section A-A' because they are not distinguished in the COGCC data used to prepare the cross section. The separate Kp1 designation, however, is used on the geologic map because this member is known to directly underlie the Fox Hills Sandstone. Both members are recognized in outcrop ~24 km to the southwest of the Gowanda quadrangle (Scott and Cobban, 1965). In general, the unit consists of silty sandstone containing thin, silty sandstone containing thin, silty sandstone and large calcareous sandstone concretions (Scott and Cobban, 1965); the limited outcrops observed during mapping of the quadrangle consist of sandstone or shale and sandstone. Locally the sandstone or shale is either massive or laminated, appears blocky in weathered exposures, and is weakly effervescence. Colors are light olive-brown and dark grayish-brown of hue 2.5Y and light-gray of hue 10YR. Concretions eroded from a cut bank in this member were observed in St. Vrain Creek west of 1/25, and their dimensions were up to 1 m in diameter and 0.4 m thick. The sandstone is either silty to very fine grained or very fine to fine grained, well sorted, non-calcareous, and bedded at a scale of millimeters to centimeters. Colors are light-gray and very dark-gray of hue 2.5Y, light-olive-gray of hue 5Y, and light-olive-brown of hue 10YR. The underlying upper shale member is a gray, light, concretionary silty shale (Scott and Cobban, 1965). Combined thickness of the two members is 1,037 to 1,235 m.

Kp2 Larimer and Rocky Ridge Sandstone Members and intervening unnamed shale units, undivided — The Larimer and Rocky Ridge Sandstone Members are well indurated, light-gray to light-brown, medium-grained sandstones, predominantly composed of quartz and minor feldspar and mica. Thickness is 37 to 49 m.

Kp3 Middle shale member — This unit consists of highly friable, greenish-gray claystone, and sandy siltstone containing thin bentonite beds. Thickness is 122 to 137 m.

Kp4 Hygiene Sandstone Member, undivided — The upper part of this unit is well-indurated, light-gray, fine- to medium-grained sandstone composed mostly of quartz, minor feldspar, and minor opaque minerals. The middle portion of the unit is medium-gray siltstone; the lower part is a friable, gray concretionary sandstone. Thickness is 122 to 137 m.

Kp5 Lower shale member — This unit consists of dark olive-gray shale, and sandy shale containing limestone and ironstone concretions; bentonite beds are common in the lower part of the unit. Thickness is 655 to 792 m.

Kn Niobrara Formation, undivided (Upper Cretaceous) — Unit is very fissile, dark-gray shale containing thin (5 m) micrite limestone layers. It is an important oil and gas resource in the quadrangle (see Plate 2 section on Mineral Resources, Groundwater, and Geologic Hazards). Thickness is 61 to 76 m.

Kco Colorado Group - Carlie Shale, Greenhorn Limestone, Graneros Shale, and Mowry Shale (undivided) (Upper Cretaceous) — Unit consists of olive-gray silty claystone and sandy claystone; dark-gray to grayish-black siltstone and calcareous, silty claystone and siltstone; dark-gray to grayish-black siltstone and claystone; and siltstone. Thickness is 79 to 131 m.