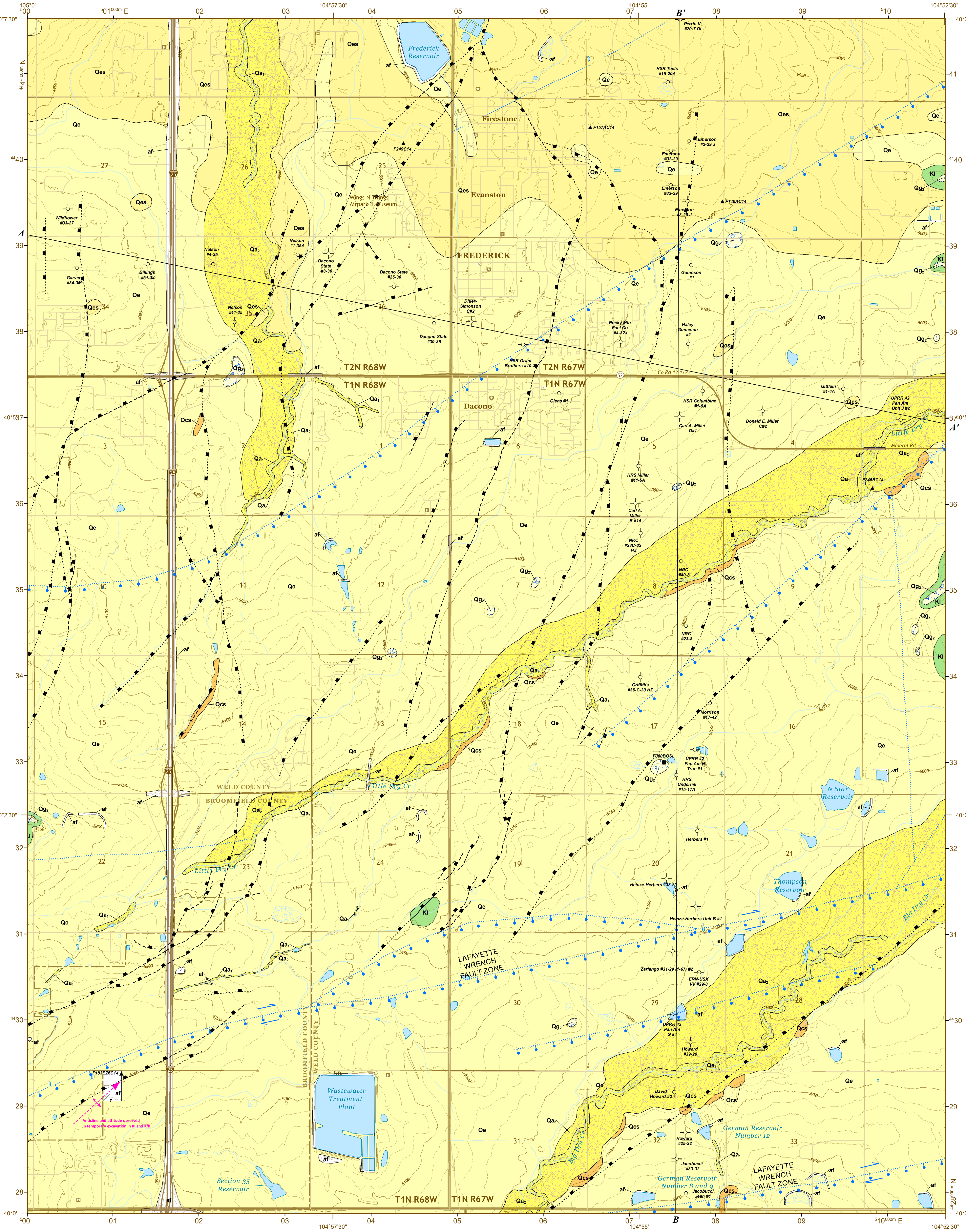
COLORADO GEOLOGICAL SURVEY
COLORADO SCHOOL OF MINES
GOLDEN, COLORADO



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

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Roads..............................U.S. Census Bureau, 2015-2016
Names..............................GNIS, 2016
Hydrography..............................National Hydrography Dataset, 2013
Contours..............................National Elevation Dataset, 2015
Boundaries..............................Multiple Sources; see metadata file, 1972-2016
Public Land Survey System..............................BLM, 2011
Wetlands..............................FWS National Wetlands Inventory, 1977-2014

SCALE 1:24,000

CONTOUR INTERVAL 10 FEET

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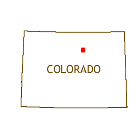

QUADRANGLE LOCATION

Longmont	Gowanda	Platteville
Erie	Frederick	Fort Lupton
Lafayette	Eastlake	Brighton

ADJOINING QUADRANGLES

Geology mapped in 2017
GIS and cartography by Pangaea Geospatial

GEOLOGIC MAP OF THE FREDERICK QUADRANGLE, WELD AND BROOMFIELD COUNTIES, COLORADO

By Stephen M. Keller and Matthew L. Morgan

2018

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af — **Artificial fill (uppermost Holocene) —** 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 average thickness of the unit is less than 20 ft (6 m). Artificial fill may be subject to settlement, slumping, and erosion if not adequately compacted.

ALLUVIAL DEPOSITS

Qa$_1$ — **Alluvium one (upper Holocene)** — Unit Qa$_1$ occupies active channels of Big Dry Creek, Little Dry Creek, and an unnamed north-flowing tributary to Saint Vrain Creek, and underlies terraces that are less than 3 ft (1 m) above the channel and up to 200 ft (60 m) wide. The finer-grained fraction of unit Qa$_1$ sediment ranges from silty clay to clayey silt with fine sand, and contains trace rounded granitic and vein quartz pebbles. Colors are brown (hue 7.5YR), and very dark-gray and very dark grayish-brown (hue 10YR); blue-black mottling is locally present (all colors are per Munsell Color, 1991). The finer-grained fraction of unit Qa$_1$ is noncalcareous to weakly calcareous. Point bars in the active channels are uncommon and consist of medium to coarse sand with rare quartz granules, and coarse to very coarse sand with minor gravel up to very coarse pebble size. The sand is subrounded to rounded and is ~70% quartz along with feldspar, opaques, and trace biotite. Gravel clasts consist of subrounded to rounded granitics, vein quartz, and blue-gray quartzite. The overall colors of Qa$_1$ bars are pale-brown and light brownish-gray (hue 10YR), and the sediment is loose and noncalcareous. Within the quadrangle, this unit is likely not a potential source of sand or gravel, because of the paucity and small size of point bars within the channels. The area mapped as Qa$_1$ is prone to flooding (see Plate 2 section on mineral resources, groundwater, and geologic hazards).

Qa$_2$ — **Alluvium two (Holocene to Upper Pleistocene)** — Unit Qa$_2$ underlies terraces 6 to 26 ft (2 to 8 m) above the three mainstem drainages in the quadrangle. Natural exposures are rare. Terraces underlain by Qa$_2$ are continuous with and correlative with alluvial sand and silt of unit Qss in the Fort Lupton quadrangle adjacent to the east (Soister, 1965). Most sediment of unit Qa$_2$ is fine grained, being either clayey silt or silty clay, the latter having some content of very fine sand. Coarser sediment of the unit is silt to fine sand with trace medium to coarse sand, and fine to medium sand with minor coarse and very coarse sand. Where exposed along Little Dry Creek the unit contains a layer of gravelly medium to very coarse sand with abundant subrounded gravel up to coarse cobble size, including blue-gray quartzite, granitics, vein quartz, and gneiss. The layer is 2.5 to 5 ft (0.8 to 1.5 m) thick and is of unknown lateral extent. Unit Qa$_2$ sand can range from angular to rounded, and gravel content is commonly subrounded. Finer Qa$_2$ locally can contain the following: rare angular Laramie Formation mudstone, siltstone, and coal fragments ranging from very coarse sand to small granules; rare rounded granitics and other crystalline rocks from granule to coarse pebble size; and rare rounded pebble-sized rip-up clasts of alluvial sediment. Some exposures along Big Dry Creek and Little Dry Creek contain distinct layers 1 to 3 ft (0.3 to 1 m) thick; fine-grained layers are laminated to thin-bedded. Carbonate development of Qa$_2$ is variable, with two-thirds of the sampled locations being noneffervescent or very slightly effervescent with hydrochloric acid (using the effervescence class assessment of NRCS, 2018), and the remaining third strongly effervescent. Unit Qa$_2$ is less calcareous than Qe, both by visual observation and by effervescence. Unit Qa$_2$ colors mostly are darker than those of Qe, Qes, and Qg$_2$. Occurrences of fine-grained Qa$_2$ are dark and very dark grayish-brown and very dark-gray (all hue 2.5 Y); dark-brown (hue 7.5 YR); and and other variations of brown (within hue 10YR). Coarser Qa$_2$ mostly is lighter-colored than the finer material, with mostly lighter variations of brown (hues 7.5 YR and 10 YR). At several stream cuts the Qa$_2$ exposures are 5 to 8 ft (1.5 to 2.4 m) in height. The few water well logs in mapped Qa$_2$ areas indicate thickness from 13 to 27 ft (4.0 to 8.2 m). A radiocarbon analysis from Qa$_2$ (sample location F245BC14, 5.7 ft [1.7 m] below ground surface) (Table 1) yielded an age of 4,450 +/- 30 C14 yr (late Holocene). In most of the Frederick quadrangle, unit Qa$_2$ is not a likely potential source of sand and gravel, because the deposit has a high clay and silt content and also because gravel-rich layers are rare. Layers of coarse sand and gravel within unit Qa$_2$ were observed at two locations along Big Dry Creek: immediately south of Weld County Road (CR) 6, and where CR 15 crosses the creek. The area mapped as Qa$_2$ is prone to flooding (see Plate 2 section on mineral resources, groundwater, and geologic hazards).

Qg$_2$ — **Gravel deposit two (Upper to Middle (?) Pleistocene)** — Exposures of unit Qg$_2$ exist as isolated remnants at a limited number of locations near the three mainstem drainages within the quadrangle. In the Erie quadrangle adjacent to the west, the unit is mapped as Verdos Alluvium (Colton and Anderson, 1977), and in the Fort Lupton quadrangle adjacent to the east it is mapped as Rocky Flats Alluvium (Soister, 1965). At its type section in the Littleton quadrangle (Scott, 1962) the Verdos Alluvium is deposited upon the Lava Creek "B" ash, which was dated using $^{40}Ar/^{39}Ar$ to be 641.9 ka +/- 28 ka; the gravel post-dates the deposition of the Lava Creek "B" ash and therefore must be less than 641 ka (M. Morgan personal commun., 2018). Furthermore, the age of Rocky Flats Alluvium ranges from ~400 ka to >2 Ma (Middle Pleistocene to Gelasian) (Riihimaki and others, 2006). In the present report, unit Qg$_2$ is not assigned to either the Verdos or Rocky Flats alluviums. Unit Qg$_2$ has several characteristics in common with other gravel units mapped in areas near the Frederick quadrangle: similarity in appearance, locations at higher elevations along the sides of main stem drainages, and association with inverted topography. Gravel units possibly related to Qg$_2$ are: unit Qg$_2$ of the Johnstown quadrangle (Palkovic and Morgan, 2017) and Berthoud quadrangle (Keller et al., 2017) ~10 miles (16 km) to the north and northwest, respectively; with unit Qg$_2$ of the Milliken quadrangle (Palkovic and Morgan, 2018) ~10 miles (16 km) to the northeast; and with unit Qao and possibly unit Qa$_5$ of the Longmont quadrangle (Madole, 2016) adjacent to the northwest. Natural outcrops are poorly exposed and at several places the only indicator of Qg$_2$ is a hilltop having abundant pebbles and cobbles with white carbonate rinds. The best Qg$_2$ exposure on the quadrangle is in a shallow trench, excavated for the purpose of this map at sample location F080B, ~0.25 miles (0.4 km) north of Weld County Rd. 8 and midway between Rds. 15 and 17. The interval from 0 to 2.9 ft (0 to 0.9 m) below ground surface in this trench is a layer of clayey silt to fine sand with trace larger content of very coarse sand plus gravel up to fine cobble size. Color is very pale-brown (hue 10YR), pebbles and cobbles have partial carbonate rinds, and the matrix is moderately cohesive. From 2.6 to 4.8 ft (0.8 to 1.5 m) there is a layer of silt to fine sand with Laramie Formation mudstone, carbonaceous shale, and coaly fragments up to fine pebble size, and abundant subrounded crystalline pebbles up to coarse pebble size. Color is brown and dark yellowish-brown (hue 10YR) with abundant reddish-brown mottles up to 0.12 inches (3 mm), pebbles have partial carbonate rinds, and the matrix is hard and cohesive. Weathered Fox Hills Sandstone occurs at 4.9 ft (1.5 m). In this trench a Bk horizon is present from 0.9 to 4.8 ft (0.3 to 1.5 m) and contains white carbonate nodules up to 0.6 inches (15 mm) across. At three Qg$_2$ locations (two in sec. 10, T. 1 N., R. 67 W. and one in sec. 12, T. 1 N., R. 68 W.) the deposit is matrix supported and consists of clayey silt to fine sand, silt to very fine sand, and silt to medium sand with minor coarse sand. The gravel fraction ranges from granules to coarse cobbles, and contains subrounded and rounded clasts of granitics, vein quartz, blue-gray quartzite, and rare dark-red sandstone (probably Fountain Formation). Granule-sized purple-brown Laramie Formation ironstone fragments are rare. Some pebbles and cobbles are partially coated with white carbonate rinds. At four locations (two in sec. 7, T. 1 N, R. 67 W.; one in sec. 10, T. 1 N., R. 67 W.; and one in sec. 22, T. 1 N., R. 68 W.) unit Qg$_2$ is a poorly sorted sandy gravel or gravelly sand. The matrix is fine to very coarse sand. The gravel fraction is up to 5.9 inches (15 cm), is subrounded to rounded, and has the composition described above; some larger clasts have carbonate rinds. At two locations (sec. 12, T. 1 N, R. 68 W. and sec. 22, T. 1 N., R. 68 W.) the upper part of unit Qg$_2$ is reworked and intermingled with Qe clayey silt to fine sand.

Unit Qg$_2$ colors are mostly pale- and very pale-brown, light yellowish-brown, yellowish-brown, dark yellowish-brown, brown, grayish-brown (all hue 10YR); less common are white (hue 10YR), light-gray (hue 2.5Y), and bright-white (not in Munsell colors). A Bk horizon is locally well developed, with white carbonate nodules and filaments and (less commonly) pervasive white carbonate. In the rare excavations and road cuts in Qg$_2$ the vertical exposure is 5 to 8 ft (1.5 to 2.4 m) thick. At the Qg$_2$ exposure on the east quadrangle boundary and 0.25 miles (0.4 km) south of Weld County Rd. 16, thickness may be as great as 16 ft (5 m). This unit reportedly has been excavated for gravel at an occurrence along the east boundary of the quadrangle, but this location was inaccessible while mapping. The OSL age of unit Qg$_2$, sampled between 4.4 and 4.8 ft (1.3 and 1.5 m) below ground surface and at the base of the unit, is 29,940 +/- 3,380 yr (Table 1). This OSL age is late Pleistocene, but two features of unit Qg$_2$ indicate that it may be as old as middle Pleistocene: 1) its well-developed Bk horizon at the age-date sample location (F080BOSL); and 2) the inverted topography at the unit's various exposures, most notably along the west and east boundaries of the quadrangle, but also in a line running along higher elevations northwest of Little Dry Creek.

EOLIAN DEPOSITS

Qes — **Eolian sand (upper Holocene to Upper Pleistocene)** — Unit Qes occurs mainly as an east-west-oriented body covering much of the north quarter of the quadrangle. In the Colorado Piedmont (including the Frederick quadrangle) and Great Plains it is mapped as late Quaternary wind-deposited sand (Madole, 2005). Unit Qes is correlative (based upon deposit type and position in the landscape) with unit Qes (eolian sand) of the Fort Lupton quadrangle (Soister, 1965), and probably is equivalent to unit Qes (eolian sand) of the Erie quadrangle (Colton and Anderson, 1977). Unit Qes is exposed in some road cuts and excavations and also can be correlated with sand intervals in geotechnical and water well logs. Unit Qes is distinctly coarser-grained, cleaner (having little clay and silt), and less cohesive than Qe. It consists of fine to medium sand with little clay and silt, and locally contains <5% coarse to very coarse sand, and rare gravel up to fine pebbles. Two locations (sec. 20, T. 2 N, R. 67 W. and sec. 25, T. 2 N., R. 68 W.) consist only of fine sand. Unit Qes is ~75% quartz with subordinate feldspar, opaque minerals, and rare biotite and muscovite, and is predominantly subangular to subrounded. Gravel content consists of angular Laramie Formation mudstone or siltstone granules and rounded granitic clasts up to medium pebble size. Bedding is observed at two excavations (sec. 22, T. 2 N., R. 68 W. and sec. 25, T. 2 N., R. 68 W.), with layers between 1 and 4 ft (0.3 and 1.2 m) thick. Unit Qes is noncalcareous at most locations, and colors are dominated by yellowish-brown, dark yellowish-brown, and brown (all hue 10YR). At most locations Qes sediment is loose to weakly cohesive. The A horizon developed on unit Qes is markedly less developed than that of Qe and Qa$_2$. As much as 4 ft (1.2 m) of unit Qes is exposed at several excavations and road cuts, and 11 geotechnical logs adjacent to the west and east of Firestone indicate that Qes thickness ranges from 5 to 17 ft (1.5 to 5.2 m). Unit Qes is observed to overlie Qe at two excavations, and five geotechnical logs near Firestone also indicate this relationship (i.e. sand correlative with Qes overlying sandy clay correlative with Qe). In the same area, six different geotechnical logs show sand correlative with unit Qes as directly overlying Laramie Formation, with no intervening sandy clay/Qe. A radiocarbon analysis from Qes sand just west of Firestone (sample location F249C14, 3.6 ft [1.1 m] below ground surface) (Table 1) yielded an age of 2,710 +/- 30 C14 yr (late Holocene). A radiocarbon analysis from Qes sand just east of Firestone (sample location F157AC14, 3 ft [0.9 m] below ground surface) (Table 1) yielded an age of 7,540 +/- 30 C14 yr (middle Holocene). This unit is a potential source of sand. The area mapped as Qes may locally contain collapsible soils (see Plate 2 section on mineral resources, groundwater, and geologic hazards).

Qe — **Loess (middle (?) Holocene to Upper Pleistocene)** — Unit Qe covers most of the southern three-quarters of the quadrangle. On the basis of deposit type and position in the landscape, it is continuous with and equivalent to Qe (eolian sediment) of the Longmont quadrangle adjacent to the northwest (Madole, 2016) and Ql of the Fort Lupton quadrangle (Soister, 1965), and is termed loess in both these quadrangles. Also using the above criteria, unit Qe is continuous with and equivalent to both the Qe (eolium) and Qel (loess) of the Erie quadrangle (Colton and Anderson, 1977), but the distinction between eolium and loess was not apparent in the Frederick quadrangle. Unit Qe is massive and fine grained, ranging from clayey silt or silty clay, through silt to very fine sand, to clayey silt to fine sand. Locally the deposit contains rare to abundant angular fragments (fine to medium pebble size) of Laramie Formation mudstone or siltstone and coal or lignite, and fragments of orange and purple-brown Laramie Formation ironstone layers. It also contains rare angular to rounded crystalline clasts up to medium pebble size, with a few as large as coarse pebble size. These are possibly derived from local occurrences of Qg$_2$. At a few locations there are crystalline pebbles having white partial-carbonate rinds, and these pebbles presumably are derived from underlying unit Qg$_2$. Carbonate development in unit Qe ranges from no carbonate (rare), through secondary accumulation consisting of white carbonate nodules and filaments (common), to Bk horizons developed to Stage II of Machette (1985) (at a few exposures). In the Bk horizon there are nodules up to 2 inches (5 cm) across, with many coalesced nodules, and the deposit is moderately cemented. The best-exposed Qe soil profile was at a very large housing development excavation northwest of I-25 and Colorado Hwy. 7. There the A horizon extends to 2.5 ft (0.8 m) below ground surface, a prismatic-weathering Bt horizon extends from 2.5 to 3.5 ft (0.8 to 1.1 m), a Bk horizon with abundant carbonate nodules extends from 3.5 ft to 7.0 ft (1.1 to 2.1 m), and fresher B horizon with less carbonate underlies the Bk. The Bk horizon is distinctively lighter-colored than B-horizon material above and below. Colors of relatively fresh Qe (i.e., lacking significant carbonate accumulation) dominantly are yellowish-brown, dark yellowish-brown, brown, dark-brown, and dark and very dark grayish-brown (all hue 10YR). Light olive-brown, olive-brown, and dark olive-brown colors (all hue 2.5Y) also occur but are rare. The Bk horizon characteristically is very pale-brown, pale-brown, light yellowish-brown, and (rarely) yellowish-brown (all hue 10YR). Natural exposures of unit Qe in the Frederick quadrangle are rare. Its thickness in geotechnical logs ranges from 3 to 23 ft (0.9 to 7 m) but mostly is 7 to 16 ft (2.1 to 4.9 m), and thickness in water well logs ranges mostly from 3 to 60 ft (0.9 to 18.3 m). Unit Qe is not associated with particular topographic features and is present over a broad range of elevations (Madole, 2016).

In the excavation northwest of I-25 and Colorado Hwy. 7, Qe overlies both Laramie Formation and Fox Hills Sandstone. Several detached, deformed, and partially disaggregated blocks and tongues of Laramie Formation, up to 3 ft (0.9) thick and 10 ft (3.0 m) long, are incorporated in the lower part of unit Qe. Qe material is found both above and below the larger Laramie Formation fragments and completely surrounds the smaller fragments. The disturbed Laramie Formation is pervaded with white carbonate-rich zones several inches thick, and these both follow and cut across the Laramie Formation bedding planes. There also are irregular masses of carbonate-rich material, up to 1.5 ft (0.5 m) in diameter, in the Qe and disturbed Laramie Formation. The disturbance may be due to mass wasting. The Fox Hills Sandstone has Qe-filled indentations up to 3 ft (0.9 m) deep and 6 ft (1.8 m) wide, where Qe contains angular Laramie Formation clasts. A lobe of Qe, of unexplained origin, is ~1.5 ft (~0.5 m) wide and extends ~3 ft (~1 m) downward into weathered Fox Hills Sandstone; its contact with the surrounding sandstone is smooth and sharp. An undisturbed Bk horizon overlies the disturbed zone, indicating that the zone is not anthropogenic. A radiocarbon analysis from Qe (sample location F183EZ6C14, at the base of the unit) (Table 1) yielded an age of 4,950 +/- 30 C14 yr (late Holocene). A radiocarbon analysis from Qe (sample location F140AC14, 3.5 ft [1.1 m] below ground surface) (Table 1) yielded an age of 4,420 +/- 30 C14 yr (late Holocene). Unit Qe overlies Laramie Formation throughout much of the quadrangle. Exceptions are a few localized areas along the western quadrangle boundary, west-central portion, and southeast corner, where Qe overlies Fox Hills Sandstone; and several locations where Qe overlies Qg$_2$. Geotechnical logs and one excavation near Firestone indicate Qes overlying Qe. Loess can be prone to hydrocompaction. Unit Qe is not a likely potential source of sand because it has a significant clay and silt fraction. The area mapped as Qe may locally contain collapsible soils (see Plate 2 section on mineral resources, groundwater, and geologic hazards).

MASS-WASTING DEPOSITS

Qcs — **Colluvium and sheetwash deposits, undivided (Holocene to Upper Pleistocene)** — Unit Qcs occurs as discontinuous narrow bands along the dissected south slopes of Big Dry Creek, Little Dry Creek, and an unnamed tributary to St. Vrain Creek. The topographic position of Qcs is the same as unit Qc of the Erie quadrangle adjacent to the west (Colton and Anderson, 1977). Unit Qcs matrix sediment ranges from clayey silt and very fine sand, to fine sand with minor medium to very coarse sand, and the gravel fraction is 5 to 20% of the deposit. Unit Qcs gravel contains many angular fragments of fine-grained sandstone, mudstone, and purple-orange ironstone layers, all presumably derived from the Laramie Formation, and clasts range in size from granules to very coarse pebbles. Other gravel consists of rounded granitic and vein quartz up to coarse pebble size. Colors are pale-brown, light and dark yellowish-brown, dark-brown, grayish-brown (all of hue 10YR). Unit Qcs is very calcareous and at some locations contains white carbonate nodules from 0.04 to 0.12 inches (1 to 3 mm) in diameter. Vertical exposures of Qcs in the Frederick quadrangle are from 2.5 to 4 ft (0.8 to 1.2 m), but thickness in the Erie quadrangle is estimated to be as great as 25 ft (7.6 m) (Colton and Anderson, 1977). Unit Qcs is not a potential source of sand or gravel.

BEDROCK GEOLOGY

Bedrock units (except for Laramie Formation) are shown only in cross sections A-A' and B-B'. Descriptions of the Laramie Formation and Fox Hills Sandstone are taken from Spencer (1986), descriptions of the Pierre Shale are adapted from Scott and Cobban (1965), and descriptions of older units are adapted from the geologic map of the Carter Lake Reservoir quadrangle, 20 miles (66 km) to the northwest, where these units are described in outcrop (Braddock and others, 1988). Thickness values for Laramie Formation and Fox Hills Sandstone are from Spencer (1986). Thicknesses for older units (except for Dakota Group) are from cross sections A-A' and B-B', which are based upon oil and gas well data from the Colorado Oil and Gas Conservation Commission (COGCC). Thickness of Dakota Group is from the geologic map of the Berthoud quadrangle (Keller and others, 2017), 10 miles (16 km) to the northwest.

Kl — **Laramie Formation (Upper Cretaceous)** — The lower 100 ft (30 m) of this unit is light- to medium-gray quartzose sandstone divisible into benches separated by clay, fire clay (refractory clay), shale, or coal seams. The upper 600 ft (183 m) is predominantly claystone, shale, sandy shale, and lenticular beds of sandstone and lignite. Thickness is ~700 ft (213 m). Coal beds in the lower part of the formation are designated Nos. 1 through 7 from lowest to highest, and their maximum thicknesses are from 2 to 12 ft (0.6 to 3.7 m). The Laramie Formation underlies the surficial units throughout the quadrangle, and its basal portion is part of the Laramie-Fox Hills aquifer. Historic coal mining in the formation has caused the ground surface to be prone to local subsidence (see Plate 2 section on mineral resources, groundwater, and geologic hazards).

Kfh — **Fox Hills Sandstone (Upper Cretaceous)** — This unit is a greenish-buff, fine- to coarse-grained, cross-bedded quartzose sandstone in lower part, grading upward to light-yellow and white, massive fine- to medium-grained sandstone. Thickness is 150 to 300 ft (46 to 91 m).

Pierre Shale (Upper Cretaceous) — This unit consists of marine strata of dark-gray shale, siltstone, and fine-grained sandstone. Bentonite beds are common in the lower part of the unit and calcareous concretions are common throughout. The various members of the Pierre Shale contain index fossil ammonite species (Scott and Cobban, 1965).

Kpt/Kpu — **Uppermost transition member and upper shale member** — These members are combined here because they are not distinguished in the COGCC data used for cross sections A-A' and B-B'. They are recognized in outcrop ~8 miles to the west of the Frederick quadrangle (Scott and Cobban, 1965). The uppermost transition member consists of friable sandstone and soft shaly sandstone containing thin-bedded sandy shale and large calcareous sandstone concretions. The underlying upper shale member is a gray, friable, concretionary silty shale. Thickness is 3,400 to 4,050 ft (1,037 to 1,235 m).

Kplr — **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 biotite. Thickness is 50 to 200 ft (15 to 61 m).

Kpm — **Middle Shale Member** — This unit consists of highly friable, greenish-gray claystone, and sandy siltstone containing thin bentonite beds. Thickness is 400 to 450 ft (122 to 137 m). (For oil and gas information on this and underlying units, see Plate 2 section on mineral resources, groundwater, and geologic hazards.)

Kph — **Hygiene Sandstone Member, undivided** — The upper part of this unit is a 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 300 to 470 ft (91 to 143 m).

Kpl — **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 2,150 to 2,350 ft (655 to 716 m).

Kn — **Niobrara Formation, undivided (Upper Cretaceous)** — Unit is very fissile, dark-gray shale containing thin (15 ft, 5 m) micritic limestone layers. Thickness is 200 to 300 ft (61 to 91 m).

Kcgg — **Colorado Group - Carlile Shale, Greenhorn Limestone, Graneros Shale, and Mowry Shale (undivided) (Upper Cretaceous)** — Unit consists of olive-gray silty claystone and sandy claystone; dark-gray limestone and olive-gray, calcareous, silty claystone and siltstone; dark-gray to grayish-black siltstone and claystone; and siliceous shale. Thickness is 250 to 400 ft (76 to 137 m).

Kd — **Dakota Group: South Platte Formation and Lytle Formation (undivided) (Lower Cretaceous)** — Unit consists of gray to light-brown, well-sorted, fine- to medium-grained sandstone; dark-gray carbonaceous shale; gray to light-brown, fine-grained sandstone; and gray to light-brown, coarse-grained, conglomeratic sandstone. Thickness is 300 to 400 ft (91 to 137 m).

Table 1. Age dates in the Frederick quadrangle

Radiocarbon dating (by Beta Analytic, Inc., Miami, Florida, October and November 2017)

Map Unit	Field Sample Number and Map Location	Date Collected	Laboratory Number	Material	Conventional C14 Age (yr BP)
Qel	F140AC14	25-Aug-17	Beta - 474333	Fine to medium sand; bulk carbon	4420 +/- 30
Qes	F157AC14	30-Aug-17	Beta - 474334	Fine to coarse sand; bulk carbon	7540 +/- 30
Qel	F183EZ6C14	4-Sep-17	Beta - 474335	Fine to medium sand; bulk carbon	4950 +/- 30
Qa$_2$	F245BC14	17-Oct-17	Beta - 477466	Clayey silt to fine sand; bulk carbon	4450 +/- 30
Qes	F249C14	17-Oct-17	Beta - 477467	Fine to medium sand; bulk carbon	2710 +/- 30

Optically stimulated luminescence (OSL) dating (by U.S. Geological Survey, Denver, Colorado , March 2018)

Map Unit	Field Sample Number and Map Location	Date Collected	Material	Age (yr BP)
Qg$_2$	F080BOSL	13-Oct-17	Gravelly silt to fine sand	29,940 +/- 3,380

Note: Unit Qg$_2$ Bk horizon development, and inverted topography at Qg$_2$ exposures, indicate an age possibly as old as middle Pleistocene, which is at variance with the OSL date of late Pleistocene.

MAP SYMBOLS

Contact — Approximately located

Ramp fault of Kittleson (1992, 2009) at location mapped by Spencer (1986) — Existence certain, location accurate; rectangles on upthrown side

Ramp fault of Kittleson (1992, 2009) at location mapped by Spencer (1986) — Existence certain, location accurate, location concealed; rectangles on upthrown side

Ramp fault of Kittleson (1992, 2009) at location mapped by Spencer (1986) — Existence certain, location inferred, location concealed; rectangles on upthrown side

High-angle fault of Weimer (1996) — Existence certain, sense of displacement unknown, location concealed

High-angle fault of Weimer (1996) — Existence certain, location concealed; ball and bar on downthrown side

Oblique-slip fault, right-lateral offset, of Weimer (1996) — Existence certain, location concealed; ball and bar on downthrown side

Anticline — Identity and existence certain, location concealed (exposed at time of mapping, now covered with artificial fill)

7 **Strike and dip of inclined bedding** — Showing direction and angle of dip in degrees

A | T **Strike-slip fault (in cross section)** — A, away from observer; T, toward observer

Oil and gas wells

A — A' **Alignment of cross section**

Sample locations for age dates

■ **Optically stimulated luminescence (OSL)**

▲ **Carbon-14**

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