

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

For details on grain size, color, and other characteristics of map units, see Table 1; some general characteristics are presented in the text describing the map units. For details on geologic hazards (e.g., flood potential) of map units, see Plate 2 section on Mineral Resources, Groundwater Resources, and Geologic Hazards. For radiocarbon and optically stimulated luminescence (OSL) ages of select map units, 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), but modified such that each sand category is divided into upper (larger - U) and lower (smaller - L). For example, very coarse (vc) sand is divided into the categories vcl (very coarse - lower) and vcl (very coarse - lower). Size ranges of the upper and lower divisions of very fine through very coarse sand are given in US GeoSupply (2020). Colors are designated with the aid of Munsell soil color charts (Munsell Color, 1991). Description of soil-carbonate morphology is after Machette (1985), and the type of effervescence of sediment or soil observed when treated with dilute hydrochloric acid is according to U.S. Department of Agriculture (2018).

HUMAN-MADE DEPOSITS

**af** **Artificial fill (Upper Holocene)** — Mostly riprap, fill material, and, locally, refuse placed during construction of roads, railroads, buildings, dams, and landfills. The fill deposits generally consist of unsorted clay, silt, sand, and rock fragments. Typically, the unit is less than 6 m thick. Some deposits of artificial fill are not mapped because they are too small to show at map scale. Artificial fill may be subject to settlement, slumping, and erosion if not adequately compacted and (or) if placed on unstable slopes.

ALLUVIAL DEPOSITS

**Qa<sub>1</sub>** **Alluvium one (Upper Holocene)** — Unit Qa<sub>1</sub> occupies active and historically active channels of the Cache la Poudre River and South Platte River. Coarse-grained sediment of the unit typically forms point bars in river channels, with the bars being from several meters to as great as 15 m wide, up to 30 m long, and as high as 0.6 m above stream level. The bar sediment is composed of a loose, poorly sorted mixture of fine sand to cobbles, with a general color pinkish-gray of hue 5YR. Fine-grained sediment is locally present in channel bottoms and banks. It is mostly a dark-brown mixture of clay, silt, and very fine to fine sand. Thickness of unit Qa<sub>1</sub> is not known but may be 2 m or less. Within the Greeley quadrangle, unit Qa<sub>1</sub> is not likely to be a potential source of sand and gravel because of the paucity and relatively small size of point bars. Areas mapped as unit Qa<sub>1</sub> are prone to flooding.

**Qa<sub>2</sub>** **Alluvium two (Upper Holocene)** — Unit Qa<sub>2</sub> occupies the flood plains of the Cache la Poudre River and South Platte River (see cross section D-D'). The unit is locally exposed in cut banks along both rivers and also is exposed in two gravel pits. Unit Qa<sub>2</sub> underlies the lower terrace in both river valleys (the higher terrace is underlain by alluvium three, unit Qa<sub>3</sub>). The unit Qa<sub>2</sub> terrace is 1.5 to 1.8 m above active streams. Sections of Qa<sub>2</sub>, as measured upward from the contact with underlying unit Qa<sub>1</sub>, range from 0.9 to 1.8 m thick and average 1.4 m thick. Unit Qa<sub>2</sub> underlies cut-in-fill terrace deposits and overlies an eroded surface on the valley-fill sediments of unit Qa<sub>1</sub>. Unit Qa<sub>2</sub> bedding is predominantly planar, but locally this unit fills channels 0.6 to 1.5 m deep that are incised into unit Qa<sub>1</sub>. The base of unit Qa<sub>2</sub> is 0.6 m above stream level. Unit Qa<sub>2</sub> consists mostly of dark-colored sand whereas unit Qa<sub>1</sub> consists mostly of light-colored sandy gravel and gravelly sand (see Table 1 for unit colors). Unit Qa<sub>2</sub> is moderately to strongly cohesive whereas unit Qa<sub>1</sub> is weakly cohesive. The stratigraphic relationship of unit Qa<sub>2</sub> overlying unit Qa<sub>1</sub> is supported by radiocarbon ages of both units sampled at the same location in the St. Vrain Creek valley ~40 km to the southwest near Longmont, Colorado (Madole, 2016). On the basis of deposit type and position in the landscape, unit Qa<sub>2</sub> likely correlates with Qa<sub>2</sub> of adjacent and nearby quadrangles (Palkovic and others, 2020; Palkovic and Morgan, 2021; and Keller and others, 2020).

Unit Qa<sub>2</sub> is stratified with beds ranging from 20 to 60 cm in thickness. Deposit types are: 1) fine-grained, lower-energy beds composed of silty clay to medium sand, probably overbank deposits, which are perpendicular in exposures; and 2) coarse-grained, higher-energy beds composed of sand and gravelly sand, probably former active channels, which are subordinate. At the Bucklen Equipment Co. pit (see Plate 1), the fine-grained upper portion of unit Qa<sub>2</sub> has a Bk horizon that is very pale-brown of hue 10YR, with violent effervescence.

A radiocarbon analysis of unit Qa<sub>2</sub> was performed for material at the base of the unit Qa<sub>2</sub> and immediately overlying unit Qa<sub>1</sub> (sample location GR163BC14, 1.2 m below ground surface). This material yielded an age of 3,475-3,366 yr B.P. (calibrated), which is Late Holocene in age. Within the Greeley quadrangle, unit Qa<sub>2</sub> is unlikely to be a potential source of sand and gravel because gravel-bearing layers in the unit are few and thin (<0.5 m thick). Areas mapped as Qa<sub>2</sub> are prone to flooding, as during the September 2013 flood events along the Front Range (see Mineral Resources, Groundwater Resources, and Geologic Hazards in Plate 2).

**Qa<sub>3</sub>** **Alluvium three (Upper Pleistocene)** — Unit Qa<sub>3</sub> is the main alluvial unit in the Cache la Poudre River and South Platte River valleys, where it is partially overlain by less than 3 m of combined Qa<sub>2</sub> and Qa<sub>1</sub>. Unit Qa<sub>3</sub> is only poorly exposed in natural cut banks in the river valleys but is well exposed in gravel pits. On the basis of water-well logs, the depth to bedrock in the two valleys (i.e., the combined thickness of units Qa<sub>1</sub> and Qa<sub>2</sub>) is as great as 18 m (see cross section D-D'); observed thickness was 7 to 12 m in three gravel pits on the north side of the Cache la Poudre valley. Unit Qa<sub>3</sub> underlies a terrace that is 1 to 2 km wide in the South Platte valley, ~1.5 km wide on the north side of the Cache la Poudre valley, and ~3 km wide where the valleys converge. On the basis of lithologic characteristics and position in the landscape, unit Qa<sub>3</sub> correlates with Qa<sub>3</sub> of the Brazeal (Palkovic and Morgan, 2021), LaSalle (Palkovic and others, 2020), and Kersey (Lindsey and Morgan, 2021) quadrangles adjacent to the Greeley quadrangle on west, south, and east, respectively. Unit Qa<sub>3</sub> terraces in the Greeley quadrangle appear to be equivalent to the Broadway Alluvium terrace of the South Platte River as presented by the U.S. Geological Survey in cross section G-G' (spanning the Cache la Poudre River valley on the east side of Greeley) of Lindsey and others (2005). Unit Qa<sub>3</sub> may be equivalent to Broadway Alluvium, although the new Greeley quadrangle unit Qa<sub>3</sub> ages presented below are older than published Broadway Alluvium ages. The elevation of terraces underlain by unit Qa<sub>3</sub> is generally ~9 m above the terraces underlain by unit Qa<sub>2</sub>. The valleys of Graham Seep, Eaton Draw, and Sand Creek, all south-flowing tributaries to the Cache la Poudre River, have little relief at the ground surface. In these valleys, however, a considerable thickness of what appears to be unit Qa<sub>3</sub> underlies unit Qa<sub>2</sub>. This inference is based on water-well logs provided by the Colorado Division of Water Resources (DWR) (2019). Depth to bedrock (i.e., unit Qa<sub>3</sub> thickness) in the Graham Seep paleovalley (buried valley) is as much as 6 m (see cross section B-B') and in the Sand Creek paleovalley is as much as 30 m (see cross section D-D'). Coal seams recorded in water-well logs indicate that the bedrock beneath unit Qa<sub>3</sub> is Laramie Formation. In cross section D-D', alluvium of the Sand Creek paleovalley appears to be continuous and coeval with that of the Cache la Poudre valley, and for this reason the alluvium in all three tributary valleys has been designated as unit Qa<sub>3</sub>.

Unit Qa<sub>3</sub> is stratified and its exposed thickness ranges from 0.3 to ~8 m. Layers of the unit are composed of: 1) gravelly sand and sandy gravel (preponderant); 2) very fine to very coarse sand with little or no gravel (subordinate); and 3) clayey silt or silty clay with minor gravel, possibly overbank deposits (rare). Gravel-pit faces exposed the following: interbedded sand and gravel layers, as well as gravel-filled channels inset in underlying sand and gravel layers; crossbedding in gravel layers; and large (as much as 0.2 m thick and 1.5 m long) rip-up fragments of sand layers incorporated in gravel layers. Unit Qa<sub>3</sub> alluvium exposed at the south end of Eaton Draw consists of 3 m of well-sorted, very fine to fine sand with undisturbed planar bedding at a scale of several mm to several cm. Unit Qa<sub>3</sub> alluvium consists of vertical sequences of superposed longitudinal bars of sand and gravel deposited by braided streams (Madole, 2016). These sequences locally contain finer-grained layers that probably are overbank deposits.

Three samples were collected from unit Qa<sub>3</sub> for optically stimulated luminescence (OSL) dating (see geologic map for sample locations). Sample GR163BOSL, in the Cache la Poudre River valley, was collected in the Bucklen Equipment Co. pit and was at the top of the unit near the contact with overlying unit Qa<sub>2</sub>. The sample yielded an age estimate of 4,920 ± 280 yr (~4.9 ky), which is Middle Holocene in age. This date, however, is too young to be unit Qa<sub>3</sub> and is regarded as suspect. Note that in a similar stratigraphic setting, in Varra Companies Pit 115 in the Gowanda quadrangle, ~15 km southwest of Greeley, a sample for OSL age determination was collected near the top of unit Qa<sub>3</sub> near the contact with overlying unit Qa<sub>2</sub>. This sample yielded an age estimate of ~6.6 ky (Keller and others, 2020). The age was regarded as too young for unit Qa<sub>3</sub>, and a subsequent OSL sample from the same location yielded an age estimate of ~42.5 ky (Keller and others, 2020). Greeley quadrangle sample GR163COSL was collected in the Bucklen Equipment Co. pit at ~1.7 m above the Laramie Formation contact. The sample yielded an age estimate of 48,730 ± 3,135 yr, which is Late Pleistocene in age. Sample GR164COSL was collected from a bluff on the north side of the Cache la Poudre valley for the unit Qa<sub>3</sub> alluvium of Eaton Draw. The sample yielded an age estimate of 70,430 ± 4,460 yr, which is also Late Pleistocene in age. In the river valleys and in the north half of the Greeley quadrangle, unit Qa<sub>3</sub> is an important shallow alluvial aquifer and has been an important sand and gravel resource.

**Qa<sub>4</sub>** **Alluvium three (Upper Pleistocene) overlain by eolian sediment (Lower Holocene and Upper Pleistocene)** — see descriptions for units Qa<sub>3</sub> and Qe.

**Alluvium four (Middle to Upper Pleistocene)?** — The only observed deposit of unit Qa<sub>4</sub> in the Greeley quadrangle lies within the City of Greeley and on the south side of the Cache la Poudre River valley. In an undeveloped lot near an inactive gravel pit, fragments dogs have brought up sandy gravel and gravelly sand. There are also fragments of a carbonate-cemented, nearly indurated material composed of medium sand to gravelly sand. Unit Qa<sub>4</sub> underlies a small terrace ~12 m higher than the valley floor. Deposits that underlie this terrace are shown in cross section F-F' of Lindsey and others (2005), spanning the Cache la Poudre River valley on the west side of Greeley, and the terrace deposits are designated as Louviers Alluvium by Lindsey and others (2005). Also, these terrace deposits are mapped as Louviers Alluvium by Colton (1976). The age of unit Qa<sub>4</sub> is uncertain, and no samples for age determination were collected from unit Qa<sub>4</sub> in the Greeley quadrangle because of the lack of undisturbed exposures for sampling.

**Qe** **Gravel deposit two (Middle (?) Pleistocene)** — In the Greeley quadrangle, observed deposits of unit Qe occur only within the City of Greeley, in which there are very few exposures of undisturbed deposits. Areas mapped as unit Qe on the present map are almost entirely from Colton (1976), who designated the deposits Verdos Alluvium. Kellogg and others (2008) considered the age of older deposits of the Verdos Alluvium to be about 610 to 675 ky. Their age estimate was based upon the presence of the Lava Creek B tephra (age ~640 ky) at the base, within, and at the top of the alluvium. Kellogg and others (2008) estimate the age of younger Verdos Alluvium deposits as 410 to 475 ky. Rühmaki and others (2006) estimate Verdos Alluvium age as several hundred thousand years. As summarized in Berry and others (2019), the maximum age for the Verdos Alluvium is constrained by the underlying Lava Creek B ash, erupted from the Yellowstone Plateau volcanic field at ~631 ka (Matthews and others, 2013, cited in Berry and others, 2019) and is present in Verdos Alluvium at sites along the South Platte River northeast of Fort Morgan; although at many sites the ash is likely to be reworked. The ash is present within and at the top of Verdos Alluvium as well as at the base. All of the above ages are Middle Pleistocene. Water-well logs (Colorado DWR, 2019), geotechnical boring logs (Colorado Geological Survey, 2019; Terracon Consultants, Inc, 2018; VIVID Engineering Group, 2019; Northern Colorado Geotech, 2018), and soil parent materials (Crabb, 1980) all record gravel layers in the immediate subsurface within the areas mapped as Verdos Alluvium by Colton (1976). Only two surface exposures of unit Qe<sub>2</sub> were found during the field work for the present study. One is near the base of an excavation ~2 m deep, where 0.3 to 1 m of unit Qe<sub>2</sub> is exposed. The material is a strongly cemented (similar to calcrete) gravelly sand, ~60% of which is very coarse sand matrix and ~40% is pebble and cobble gravel. This deposit is two cemented and contains too many pebbles and cobbles to permit sampling for OSL dating. The other exposure is in an undeveloped lot in which prairie dogs have brought up abundant subrounded to rounded pebbles and cobbles (same lithologic composition as above) with carbonate coatings, as well as fragments of carbonate-cemented gravel. Unit Qe<sub>2</sub> locally is overlain by unit Qe or unit Qe<sub>3</sub>. Deposits of unit Qe<sub>3</sub> in the City of Greeley are at the same elevation (above mean sea level) as a deposit of Qe<sub>2</sub> ~11 km to the south-southeast in the LaSalle quadrangle (Palkovic and others, 2020), which suggests that the deposits in the two areas are correlative.

EOLIAN DEPOSITS

**Qes** **Eolian sand (Upper Holocene)** — Most of unit Qes in the Greeley quadrangle occurs in two upland areas: one in the northeast quarter of the quadrangle and another in the southeast quarter; the latter occurrence is within the City of Greeley. In parts of the Colorado Piedmont (including the Greeley quadrangle) and the Great Plains, unit Qes is equivalent to sediment mapped as unit Qa<sub>2</sub> in Quaternary wind-deposited sand (as in Madole and others, 2005). On the basis of lithology and position in the landscape, unit Qes correlates with eolian sand in nearby quadrangles (Sostor, 1965; Colton and Anderson, 1977; Keller and Morgan, 2018; and Keller and others, 2020).

Unit Qes was mapped based on exposures in excavations and shallow sample holes as well as from soil parent materials previously identified by soils mapping in southern Weld County (Crabb, 1980). Unit Qes is readily distinguished from unit Qe, an older and compositionally distinct eolian deposit that is thought to be adjacent to and at lower elevations than unit Qes. Unit Qes is distinctively coarser grained, contains much less fines (clay and silt), and is less cohesive than unit Qe. Also, soils formed in unit Qes have a less developed A horizon than soils formed in unit Qe. Visible secondary carbonate is not present in unit Qes but locally is present in unit Qe. Grain-size distributions in unit Qes can be grouped in two types: very fine to medium sand with few fines (silt and clay content) and with trace amounts of granules and pebbles; and fine (fL) to medium sand with few fines, commonly with a very small amount of sand as large as very coarse (vL) sand. In the Greeley quadrangle unit Qes presumably overlies unit Qe. Much of the Greeley quadrangle area that was mapped as Qes by Madole and others (2005) is mapped as Qe in the present study. Unit Qe, as observed in the Greeley quadrangle during the present study, has a significant amount of fines, strong cohesion, and strong effervescence; all of these characteristics are unlike those of the eolian sand of Madole and others (2005). Also, grain-size analyses of unit Qe material performed for geotechnical investigations (Colorado Geological Survey, 2019; Northern Colorado Geotech, 2018; Terracon Consultants, Inc, 2018; and VIVID Engineering Group, 2019) indicate a fines content varying between 21 and 55%, whereas the eolian sand of Madole and others (2005) has a fines content between 4 and 9%.

Sample GR218C14 for radiocarbon analysis was collected at 0.5 m below ground surface from a shallow trench at a residential construction site, and probably is from the upper part of unit Qes. The sample yielded an age of 798 to 690 yr B.P. (calibrated) and is within the age range (0 to 4 ky) for the Late Holocene subdivision of eolian sand of Madole and others (2005). Unit Qes radiocarbon ages in the Frederick and Gowanda quadrangles also fall within this age range (Keller and others, 2017; Keller and others, 2019). Unit Qes locally may be a shallow aquifer and is a potential source of sand. The area mapped as Qes locally may contain collapsible soils.

**Eolian sediment (Lower Holocene to Upper Pleistocene)** — Eolian sediment of unit Qe covers most of the quadrangle north of the Cache la Poudre valley (see cross sections B-B', C-C', and D-D') and much of the City of Greeley, which is south of the valley. On the basis of its position in the landscape, lithologic characteristics in fresh exposures, and secondary carbonate development, unit Qe is similar to unit Qe (eolian sediment, chiefly loess) of the Longmont quadrangle (Madole, 2016). Unit Qe (loess) of the Gowanda quadrangle (Keller and others, 2020), and unit Qe (eolian sediment) of the Johnston quadrangle (Palkovic and Morgan, 2017). Unit Qe in the Greeley quadrangle, however, is about 50 to 79% sand, according to ASTM International grain-size analyses in several geotechnical reports, and thus is designated as eolian sediment (unit Qe does not contain sufficient silt to be categorized as loess). Unit Qe is not associated with particular landforms and can be present over a broad range of elevations (Madole, 2016). In the Greeley quadrangle, exposures of the unit are less than 2 m thick and are observed in road cuts, gravel pits, and excavations. Geotechnical boring logs, however, indicate that the unit can be up to ~10 m thick and water-well logs indicate thicknesses greater than 15 m (see cross sections B-B' and C-C'). Unit Qe overlies unit Qa<sub>3</sub> alluvium deposited by south-draining tributaries to the Cache la Poudre River, and overlies units Qa<sub>3</sub> and Qg<sub>2</sub> in upland areas of the City of Greeley. Unit Qe locally overlies the Laramie Formation in the part of the quadrangle north of the Cache la Poudre River. In the City of Greeley and near the northeast corner of the quadrangle, deposits of unit Qe presumably underlie deposits of unit Qes, but the contact between units Qe and Qes was not observed in the field. Unit Qe locally may contain small unmaped deposits of unit Qes.

Deposits of unit Qe can be grouped into two lithologic types: very fine sand to fine sand, and clayey silt to very fine sand, with the former type more prevalent than the latter. Discernable bedding is absent in both types. Both deposit types are usually strongly effervescent. Visible secondary carbonate occurs locally and ranges from scattered white carbonate nodules <2 mm in diameter to carbonate masses 4 to 6 cm in diameter to BK soil horizons from 0.1 to 0.6 m thick. In ASTM International grain-size analyses from 19 geotechnical borings for three areas in the City of Greeley, the sand content of unit Qe varies between 50 and 79%; and the combined silt and clay content varies mostly between 21 and 55%, with outlying values of ~7, ~72, and 82% (Terracon, 2018; Northern Colorado Geotech, 2018; and VIVID Engineering Group, 2019). Such a large content of fines appears to preclude the sediment from being correlative with the eolian sand of Madole and others (2005) (unit Qes of the present study), the former has a total fines content ranging approximately between 4 and 9%.

BEDROCK GEOLOGY

Within the Greeley quadrangle, the only exposed bedrock unit is the Laramie Formation. Descriptions of the Laramie Formation and Fox Hills Formation are from Spencer (1986), who investigated these units in detail in the Frederick and Eric quadrangles 35 km southwest of the Greeley quadrangle. Descriptions of Pierre Shale members are adapted from Scott and Cobban (1965), supplemented by Braddock and others (1988). Descriptions of older units are adapted from descriptions in the geologic map of the Carter Lake Reservoir quadrangle, 45 km to the southwest, where these units are described in outcrop (Braddock and others, 1988). Thickness values for Laramie Formation and Fox Hills Formation are from Spencer (1986). Thickness values for older bedrock units are from cross section A-A', which was prepared with the aid of oil and gas well drill-hole data from the Colorado Oil and Gas Conservation Commission (COGCC).

**Kl** **Laramie Formation (Upper Cretaceous)** — This unit is exposed in an outcrop on the south side of the Cache la Poudre River valley along the western boundary of quadrangle and in small sumps in several gravel pits in the valley (outcrops in sumps are small and are not mapped). The lower 60 to 90 m of the unit consists of light- to medium-gray quartzose sandstone layers separated by clay, fire clay (refractory clay), shale, or coal seams. The upper 123 to 153 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 are as much as 3.7 m thick. Coal seams reported in water-well logs in the Greeley quadrangle indicate that it is the lower part of the Laramie Formation that underlies surficial deposits in the quadrangle.

**Kth** **Fox Hills Sandstone (Upper Cretaceous)** — Greenish-buff, fine- to coarse-grained quartzose sandstone, crossbedded in the lower part, grading upward to a light-yellow and white, massive, fine- to medium-grained sandstone. Thickness is 46 to 91 m. The Fox Hills Sandstone is not depicted on cross section A-A' because oil and gas wells, and geotechnical borings do not contain sufficient data to distinguish this unit. Some water wells do penetrate the Fox Hills Sandstone as well as the lowermost 60 to 90 m (the coal-bearing interval) of the Laramie Formation, because coal seams are noted in some of the water-well logs. The Laramie-Fox Hills contact, however, cannot be identified in these logs. Therefore, the Fox Hills Sandstone is presumed to be in an interval below the Laramie Formation and above units of the Pierre Shale (combined upper transition member and upper shale member) penetrated by some water wells.

**Pierre Shale (Upper Cretaceous)** — Marine strata composed of dark-gray shale, siltstone, and fine-grained sandstone. Bentonite beds, rich in weathered volcanic ash, are common in its lower part and calcareous concretions are common throughout. The various members of the Pierre Shale contain index fossil ammonite species.

**Kpt-Kpu** **Uppermost transition member and upper shale member, undivided** — These two members are combined in cross section A-A', because they cannot be distinguished in the COGCC data used to prepare the cross section. Both members are observed in outcrop ~45 km southwest of the Greeley quadrangle (Scott and Cobban, 1965). In general, the members consist of friable sandstone and soft shaly sandstone containing thin-bedded sandy shale and large calcareous sandstone concretions. Combined thickness of the two members is 950 m.

**Kplr** **Larimer and Rocky Ridge Sandstone Members and intervening shale, 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 ~45 m.

**Kpm** **Middle shale member** — This unit consists of highly friable, greenish-gray claystone and sandy siltstone, and the unit contains thin bentonite beds. Thickness is ~230 m.

**Kph** **Hygiene Sandstone member, undivided** — The upper part of the unit is a well indurated, light-gray, fine- to medium-grained sandstone composed mostly of quartz, minor feldspar, and minor opaque minerals. The middle part of the unit is a medium-gray siltstone; the lower part is a friable, gray concretionary sandstone. Thickness is 100 to 170 m.

**Kpl** **Lower shale member** — 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 ~580 m.

**Kn** **Niobrara Formation (Upper Cretaceous)** — Very fissile, dark-gray shale containing thin (5 m) micritic limestone layers. Unit is an important oil and gas reservoir in the quadrangle and in much of the Denver Basin (see Plate 2 section on Mineral Resources, Groundwater Resources, and Geologic Hazards). Thickness is ~90 m.

**Kcgg** **Colorado Group - Carlile Shale, Greenhorn Limestone, Graneros Shale, and Mowry Shale, undivided (Upper Cretaceous)** — 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 ~110 m.

MAP SYMBOLS

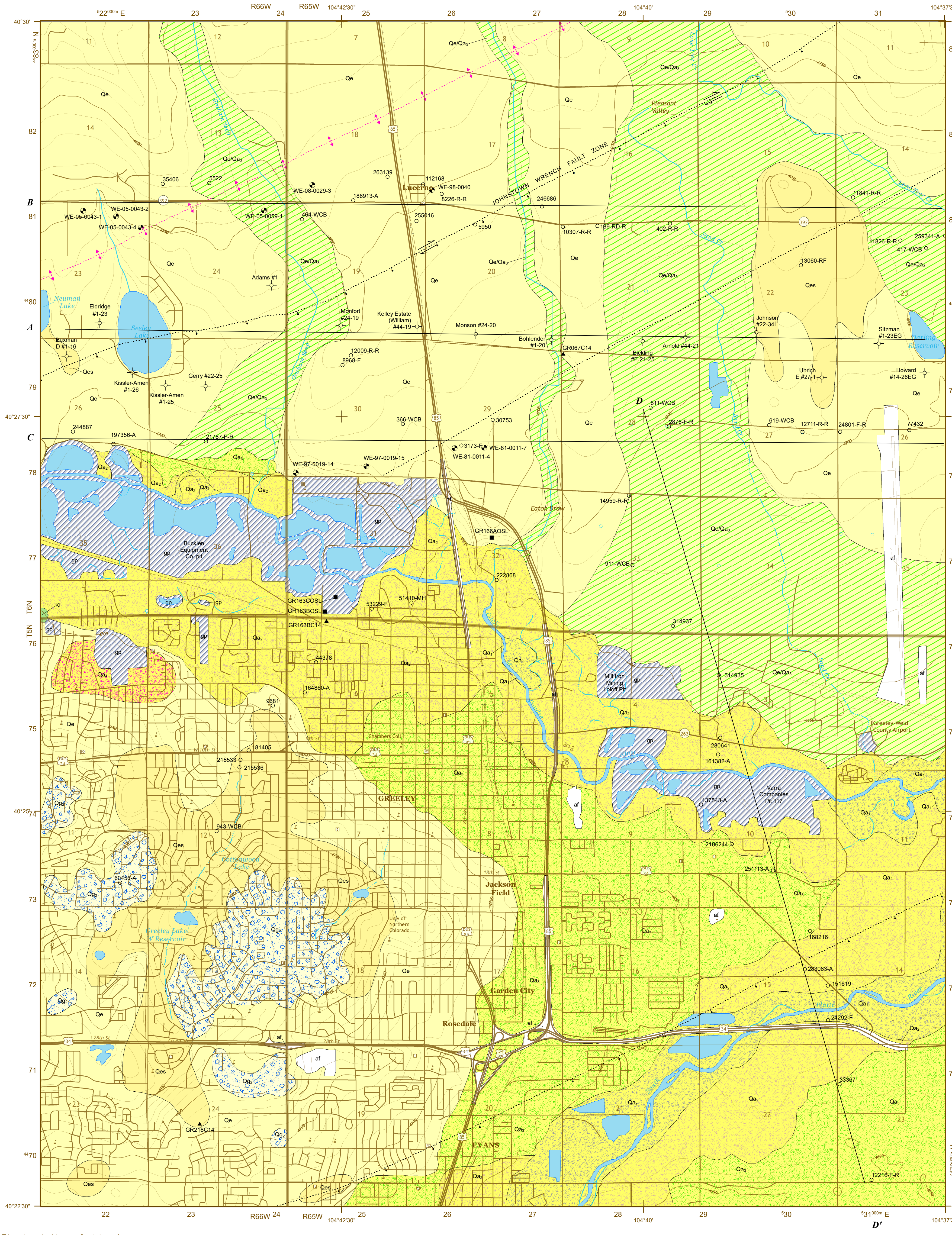
- Contact — Approximately located
- Anticline of Weimer (1996) — Existence certain, location concealed
- High-angle fault of Weimer (1996) — Existence certain, location concealed, sense of displacement is unknown
- High-angle fault of Weimer (1996) — Existence certain, location concealed; ball and bar on downthrown side
- Oblique-slip fault, right-lateral offset, of Weimer (1996) — Existence certain, location concealed; ball and bar on downthrown side
- Strike-slip fault (in cross section) — A, away from observer; T, toward observer
- Oil and gas wells
- Water well
- Soil boring for geotechnical investigation
- Gravel pit — Gravel pit — exposed gravel faces, waste piles of gravel and overburden, and (rarely) exposed bedrock
- Alignment of cross section

Sample locations for age dates

- Optically stimulated luminescence (OSL)
- Carbon-14

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This map is not a legal document. Boundaries may be generalized for this map scale. Private lands within government reservations may not be shown. Obtain permission before entering private lands.

Initial styling of this Map Document was provided by the US Geological Survey. The edited content in this document are either done by or reviewed by the USGS.

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

Roads:..... U.S. Census Bureau, 2010-2016  
Names:..... USGS, 2016  
Hydrography:..... National Hydrography Dataset, 2013  
National:..... National Hydrography Dataset, 1986  
Boundaries:..... Multiple sources, see metadata file, 1972-2016  
Public: Land Survey System, 1972-2016

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GEOLOGIC MAP OF THE GREELEY QUADRANGLE, WELD COUNTY, COLORADO

By Stephen M. Keller and Matthew L. Morgan  
2020

