

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af

**Artificial fill (Uppermost Holocene)** — Mostly fill material, refuse, and riprap placed during construction of roads, railroads, buildings, dams and landfills. Fill material and refuse generally consists of unsorted clay, silt, sand, and rock fragments, while riprap commonly consists of boulder sized or larger rock fragments. The average thickness of the unit is less than 6 m. Artificial fill may be subject to settlement, slumping, and erosion if not underlain by compacted and/or placed on steep slopes. Extensive areas of artificial fill exist locally in residential and commercial developments in the Greeley area; however, these fill deposits are usually less than 1.5 m thick and are difficult to delineate in some areas.

ALLUVIAL DEPOSITS

Qa<sub>1</sub>

**Alluvium one (Upper Holocene)** — Pinkish-gray, pink, or reddish-yellow (7.5 YR 7/2 and 7.5YR 7/3) (Globe, 2005), moderately to well sorted, poorly consolidated, very fine-grained sand with gravel. Gravel-sized material ranges from subangular to well rounded and dominantly consists of quartz, quartzite, granitoid rocks and schist. Unit Qa<sub>1</sub> underlies the Poudre River and low-lying terraces 0-1.5 m above the active channel. Low-lying terraces of Qa<sub>1</sub> and adjacent floodplain deposits are typically vegetated and consist chiefly of clay and silt. Unit Qa<sub>1</sub> is typically confined by alluvium two (Qa<sub>2</sub>), with a few notable exceptions: a prominent bluff of Fox Hills Sandstone (Kh) bounds Qa<sub>1</sub> locally on the south side of the Poudre River, and alluvium three (Qa<sub>3</sub>) bounds Qa<sub>1</sub> in places north of the Cache la Poudre River, on the east side of the quadrangle. A sample from NW ¼ SE ¼ sec. 35, T. 6 N., R. 67 W. contained 39.4 % gravel, 54% sand, 4.2% silt, and 2.4% clay. The Unified Soil Classification System (USCS) (Howard, 1986) designation is a poorly graded sand with silt and gravel (SP-SM). Channel-bar deposits are present adjacent to and within the Cache la Poudre River, and are composed chiefly of pinkish-gray (7.5 YR 7/2) sandy gravel with lenses of clay and silt. On the nearby Berthoud quadrangle (Keller and others, 2017), a bulk carbon-14 sample taken from a depth of 1 m below a ~1.5 m-high terrace of the Little Thompson River (a tributary of the South Platte River) yielded a 14C age of at least 1,525 to 1,350 cal yr BP (1,530 ± 30 14C yr BP), indicating the unit is at least Late Holocene in age where sampled. Unit Qa<sub>1</sub> is generally correlative, by virtue of height above stream level, soil characteristics, and radiometric dates on nearby quadrangles with the post-Piney Creek Alluvium (Colton, 1978). In the Bracewell quadrangle, portions of unit Qa<sub>1</sub> have been mined for construction aggregate and remaining channel bars and gravel-rich facies may be sources of aggregate resources. Locally, this unit may have been cut or graded by earth-moving equipment, and may be overlain by artificial fill in the upper 1-2 m, especially in the eastern part of the quadrangle. Unit Qa<sub>1</sub> is generally correlative with the Federal Emergency Management Agency (FEMA) mapped floodway zone AE (FEMA, 2020), is prone to flooding, and may have a high seasonal or annual water table due to its proximity to modern streams and low height above stream level. Unit Qa<sub>1</sub> is generally 0 to 3 m thick in the quadrangle, as interpreted from the Colorado Division of Water Resources (DWR) borehole drillers logs (Colorado Division of Water Resources, 2019).

Qa<sub>2</sub>

**Alluvium two (Upper Pleistocene)** — Dark-brown (7.5 YR 3/2) (Globe, 2005), poorly to moderately sorted, moderately consolidated, weakly stratified, silty to clayey very fine-grained sand. Unit Qa<sub>2</sub> is bounded by a bluff composed of the Fox Hills Sandstone (Kh), eolian sediment (Qe), and the Laramie Formation (Kl) on the south side of the river, whereas the unit is bounded by alluvium three (Qa<sub>3</sub>) on the north side of the river. Unit Qa<sub>2</sub> underlies stream-terrace deposits that are approximately 1.5 m above the modern stream level of the Cache la Poudre River. A soil profile approximately 2 m in height formed in unit Qa<sub>2</sub> was described near SW ¼ NW ¼ sec. 32, T. 6 N., R. 66 W. The soil is the overlain by 0-0.3 m fill and consisted of the following: soil horizon from top to bottom (Birkland, 1999): 0-3.0 m salt-enriched Bz horizon, dark-brown (7.5 YR 3/1) clay to very fine-grained sand that has a moderate amount of silt and clay; 0.6-1.3 m C horizon, dark-brown (7.5 YR 3/2) clayey silt and sand; 1.3-2 m C horizon, dark-brown (7.5 YR 3/2) clayey silt and sand with orange streaks. Humic organic material is common in the Bz horizon and stage 1 stringers of calcium carbonate (Machette, 1985) are locally present in the lower part of the soil (A. Stenhardt and M. Moore, Natural Resources Conservation Service, written commun., 2019). Two optically stimulated luminescence (OSL) analyses from the nearby La Salle quadrangle (Palkovic and others, 2019) were taken from unit Qa<sub>2</sub> near NW ¼ sec. 35, T. 5 N., R. 66 W. The first sample yielded an OSL age estimate of 3,090 years BP (Central Age Model), whereas the second sample yielded an OSL age estimate of 3,020 ± 260 years (Central Age Model). In the nearby Berthoud quadrangle, Keller and others (2017) reported two carbon-14 ages from unit Qa<sub>2</sub> that range from 1,350 to 2,490 cal yr BP (1,530 ± 30 to 2,390 ± 30 14C yr BP). Unit Qa<sub>2</sub> is generally correlative, by virtue of height above stream level and radiometric dates, with the upper part of the Piney Creek Alluvium described by Hunt (1954) in the Piedmont along the Front Range of Colorado. In the Bracewell quadrangle, many active and reclaimed quarries are present within this map unit. Unit Qa<sub>2</sub> locally overlies alluvium three (Qa<sub>3</sub>), which is the main target for aggregate resources. In map view, it may appear that unit Qa<sub>2</sub> is the target of quarrying operations; however, the underlying unit Qa<sub>3</sub> is typically processed in quarry operations on the Bracewell quadrangle. In the western end of the unit extent, specifically in secs. 34-36, T. 6 N., R. 67 W., alluvial sheetwash and/or colluvium may be present in unit Qa<sub>2</sub> in the small gullies adjacent to the Fox Hills sandstone. Portions of the unit lie within FEMA mapped floodway zone AE (FEMA, 2020). Unit Qa<sub>2</sub> ranges from 7 to 13 m thick, with an average thickness of 9 m. Unit Qa<sub>2</sub> is generally thicker in the eastern part of the quadrangle on the basis of DWR borehole data (Colorado Division of Water Resources, 2019).

Qa<sub>3</sub>

**Alluvium three (Middle and Upper Pleistocene)** — Pinkish-gray (7.5 YR 6/2) (Globe, 2005), poorly sorted, poorly consolidated, medium sand to gravel, with a matrix of fine- to medium-grained sand. Unit Qa<sub>3</sub> underlies terraces approximately 10-21 m above adjacent streams, and occupies a broad, flat, subdued terrace on the north side of the Cache la Poudre River. Clasts in unit Qa<sub>3</sub> are generally subrounded to well rounded, and range in size from 1-10 cm. Clast types include granitoid rocks (dominantly granite and granodiorite), gneiss, schist, quartzite, and vein quartz. Unit Qa<sub>3</sub> is bordered to the south by unit Qa<sub>2</sub>, and to a lesser extent by unit Qa<sub>1</sub>. It is bordered to the north by eolian sediment (Qe). The northern contact is defined by the occurrence of NW-SE trending linear sand dunes of unit Qe that are visible on lidar imagery. Eight DWR boreholes were used to determine the approximate extent of unit Qa<sub>3</sub> in the shallow subsurface and suggests that unit Qa<sub>3</sub> locally underlies unit Qe, especially on the north side of the Poudre River near secs. 25 and 36 of T. 6 N., R. 67 W., and secs. 31-33 of T. 6 N., R. 67 W. Two OSL samples were collected on Bracewell from SW ¼ sec. 30, T. 6 N., R. 66 W. (Plate 2, Table 1). BW064a, collected 2 m below ground surface, yielded an OSL age estimate of 28,225 ± 2350 years (Central/Minimum Model SAR age), whereas BW064b, collected 3.2 m below ground surface, yielded an OSL age estimate of 39,600 ± 1940 years (Central/Minimum Model SAR age). In the adjacent Miliken quadrangle, which borders the Bracewell quadrangle to the south, sample Mi120 in unit Qa<sub>3</sub> yielded an OSL age estimate of 13,220 ± 30 years. These ages roughly correspond to the 30-12 ka date range for the Broadway Alluvium commonly provided by previous authors (Workman and others, 2018; Kellogg and others, 2008; Madole, 1986, 1991; Holliday, 1987; Nelson and others, 1979; Madole and Shroba, 1978). Stage 1 to stage II (Machette, 1985) pedogenic carbonate is common in the soil profile and locally forms discontinuous rinds on gravel clasts. Locally, finer grained sand is cemented onto the underside of gravel clasts due to abundant secondary carbonate accumulation. Unit Qa<sub>3</sub> is generally correlative, by virtue of height above stream level, soil characteristics, and radiometric dates with the Broadway Alluvium (Colton, 1978) and units T3 and T4 of Schwochow and others (1974). Unit Qa<sub>3</sub> has been quarried extensively on the quadrangle and remaining Qa<sub>3</sub> deposits may be a source of aggregate resources. In active quarry areas, some operations may have excavated through overlying Qa<sub>2</sub> material to extract the underlying Qa<sub>3</sub>, which is generally a more desirable deposit for aggregate resources. Unit Qa<sub>3</sub> locally contains valley side sheetwash alluvium, especially in sec. 23, T. 6 N., R. 67 W. Eight boreholes registered with Colorado DWR that terminate in unit Qa<sub>3</sub> indicate that the thickness of the unit ranges from 5-13 m in the quadrangle, with an average thickness of 9 m (Colorado Division of Water Resources, 2019).

Qa

**Alluvium, undivided (Holocene and Upper Pleistocene)** — Pale-brown or beige of hue 10 YR (Globe, 2005), weakly stratified, moderately to loosely consolidated, silty to clayey sand with thin beds and lenses of sandy pebble gravel. The deposit occurs along an ephemeral stream that bisects unit Qe in the southern half of the quadrangle. Unit Qa is used where the identification of the specific alluvial units was not possible due to poor exposure or lack of access. Mapping of unit Qa in Bracewell largely relies on DWR borehole data and lidar imagery. Unit Qa is approximately 4 m thick on the basis of the interpretation of a single DWR borehole in the unit, located in sec. 4, T. 5 N., R. 66 W. (Colorado Division of Water Resources, 2019).

Qg<sub>1</sub>

**Gravel deposit two (Middle Pleistocene)** — Pink (7.5 YR 8/3) (Globe, 2005), poorly sorted, poorly consolidated, matrix-supported gravel with a silty sand matrix that underlies abandoned alluvial terraces 20-90 m above modern streams. Clasts may be subangular but are generally subrounded, and predominantly composed of granitoid rocks, quartzite, vein quartz, and schist. This unit, discontinuous, stage I to stage II calcium carbonate rinds coat some gravel clasts. This unit is locally overlain by unit Qe. In some areas, the only evidence of unit Qg<sub>2</sub> may be gravel in a matrix that otherwise appears to be eolian. Additionally, the downslope edges of Qg<sub>2</sub> deposits locally contain gravelly colluvium derived from the original Qg<sub>2</sub> deposit, and are mapped as Qg<sub>2</sub>. In the southeastern part of the Bracewell quadrangle, a northwest-southeast trending line of unit Qg<sub>2</sub> exists, and continues into the adjacent Greeley quadrangle (Keller and Morgan, 2020). In areas with poor exposure or lack of access, mapping of this unit largely relied upon the interpretation of DWR borehole logs, lidar imagery, and geologic mapping at 1:100,000 scale (Colton, 1978). Unit Qg<sub>2</sub> is correlative, based on its height above stream level, with the Verde Alluvium (Colton, 1978). Unit Qg<sub>2</sub> is a potential source of sand and gravel. One DWR borehole exists in unit Qg<sub>2</sub> in the quadrangle, which indicates a thickness of 4 m (Colorado Division of Water Resources, 2019). However, the thickness of unit Qg<sub>2</sub> typically ranges from 3 to 15 m in the Greeley area (Keller and Morgan, 2020; Palkovic and others, 2019; Palkovic and others, 2018).

EOLIAN DEPOSITS

Qe

**Eolian sediment (Middle Holocene to Upper Pleistocene)** — Reddish-yellow to yellow (7.5 YR 7/6 to 10 YR 7/6) (Globe, 2005), well-sorted silty quartz sand with a trace amount of lithic fragments. Sand-sized fragments are generally very fine to fine, but may range up to medium-grained sand. Quartz grains comprising unit Qe are generally subangular to subrounded. A sample from the Bracewell quadrangle collected in SE ¼ SW ¼ sec. 20, T. 5 N., R. 66 W. contained 78.3% sand, 11.5% silt, and 10.2% clay. According to the USCS (Howard, 1986) this sample is a 'silty sand' (SM) and is nonplastic. In the nearby La Salle quadrangle (Palkovic and others, 2019), a sample from NW ¼ SE ¼ sec. 3, T. 4 N., R. 65 W. contained 89.8% sand, 4.6% silt, and 5.6% clay. The unit is a 'poorly graded sand with silt' (SP-SM) and is nonplastic (Howard, 1986). A third sample, collected at NE ¼ SE ¼ sec. 8, T. 3 N., R. 65 W. (~1 km south of the La Salle quadrangle southern boundary, in the Milton Reservoir quadrangle; Palkovic and others, 2019) contained 93.3 % sand, 1.6 % silt, and 5.1 % clay. It has a USCS classification of 'poorly graded sand with silt' (Howard, 1986). Despite the high sand content of these three samples, varying amounts of fines (silt and clay) may exist locally, especially in the eastern part of the Bracewell quadrangle. Unit Qe is poorly exposed in the southern part of the mapped area and in agricultural areas north of the Cache la Poudre River. On the La Salle quadrangle (Palkovic and others, 2019), two bulk carbon-14 samples (LS035a and LS035b) were taken from the same stratigraphic interval in NW ¼ SE ¼ sec. 33, T. 4 N., R. 66 W. Sample LS035b, taken 2.7 m below ground surface yielded a carbon-14 age of 9,523 to 9,431 cal yr BP (8440 ± 30 14C yr BP) and sample LS035a, taken 2.75 m below ground surface, yielded a 14C age of 10,691 to 10,488 cal yr BP (9,350 ± 40 14C yr BP). Previous authors (Kellogg and others, 2008; Muhs and others, 1999; Scott and Lindvall, 1970) cite three episodes of windblown sand deposition in northeastern Colorado; one from 27 to 11 ka, one between 11 and 4 ka, and one from 1.5 ka to present. In many areas on the Bracewell quadrangle, the unit may be cut, filled or graded from earthwork associated with residential, commercial and agricultural development. Reworked eolian sand locally exists as colluvial or sheetwash deposits in this unit, and are mapped as Qe. Extensive eolian dunes are present north of the Cache la Poudre River on lidar imagery. Similar linear dune forms may be present south of the Cache la Poudre River, but are subdued and/or modified due to residential development in the Greeley area. Throughout the mapped area, deposits of loess (windblown sediment that is >60% silt; Muhs and others, 2014) may be locally present, and are largely identified on the presence of silt and clay in DWR borehole logs surrounded by a vast expanse of eolian sand. Previous authors (Workman and others, 2018; Kellogg and others, 2008; Muhs and others, 1999; Forman and others, 1995) state two episodes of loess deposition in northeastern Colorado from 20 to 14 ka and 13 to 10 ka. The exact boundaries of the loess deposits are difficult to delineate due chiefly to the residential and agricultural development in the area, and the subdued geomorphic signature of loess deposits on lidar imagery. Additionally, small, unmapped deposits of Qg<sub>2</sub> and colluvium/sheetwash may exist in unit Qe. Unit Qe may be subject to deflation and wind erosion in areas that are poorly vegetated and may be prone to hydrocollapse. Locally, the unit may be a source of industrial sand. In the southern part of the Bracewell quadrangle, Qe ranges in thickness from 2-12 m, with an average thickness of 7 m. In the northern part of the quadrangle, thickness ranges from 3-18 m, with an average thickness of 10 m. Thicknesses in both parts of the quadrangle were estimated from interpretation of DWR borehole data (Colorado Division of Water Resources, 2019).

BEDROCK GEOLOGY

Kl

**Laramie Formation (Upper Cretaceous)** — Light-gray to yellowish-gray, well-indurated quartz sandstone interbedded with dark-gray, fissile, friable, well-laminated shale and lenticular seams of carbonaceous shale and lignite. The contact with the underlying Fox Hills Sandstone is conformable, and the Laramie Formation may locally interfinger with the Fox Hills Sandstone. Exposure of the Laramie is limited on the quadrangle, but may range from 0-30 m thick.

Kh

**Fox Hills Sandstone (Upper Cretaceous)** — Light-brown, brown, or golden-brown, buff, friable, poorly to moderately indurated, dominantly massive but sometimes crossbedded, very fine- to fine-grained arenite to subarkose sandstone. Facies composed of dark-brown to dark-gray oblong, lenticular bodies of hard, highly resistant, silica-cemented, fine-grained sandstone are present throughout the unit, as well as locally thin planar-bedded-laminated (bed thickness ~0.5-1 cm) zones of shale, especially to the east near the Signature Bluff Natural Area (sec. 32, T. 6 N., R. 66 W.). These thin, planar bedded zones of shale may be Laramie Formation, because the transgressions and regressions of the Western Interior Seaway during Fox Hills time produced a "stepping character" of the Fox Hills shoreline, referred to as "shingle stratigraphy" (Dechesne and others, 2011). Due to this "shingle stratigraphy", the upper and lower contacts of the Fox Hills Sandstone are gradational and can be difficult to determine in both outcrops and wells. Outcrops of the Fox Hills Sandstone in Bracewell are generally abundant along the south side of the Cache la Poudre River. Although common in the Fox Hills Sandstone elsewhere in northeastern Colorado (Palkovic and others, 2018), no Ophiomorpha burrows, ripple marks, or brachiopods were observed on the Bracewell quadrangle. Rounded clasts of crystalline rocks commonly mantle the Fox Hills outcrops in the map area, and likely represent a lag gravel from ancient alluvium deposited by the Cache la Poudre River. Historically, the contact between the Upper part of the Pierre Shale, known as the Pierre Transition Member, and the Fox Hills Sandstone is defined by Lovering and others (1932) as being 75 m below the base of the Laramie Formation, whereas Scott and Cobban (1965) state that the contact between the two units is unapparent in the area between Denver and Loveland. Due to the difficulty of delineating the upper transitional member of the Pierre Shale, this member is included in the Fox Hills in map view, as well as in cross section B-B. The unit is approximately 90-150 m thick.

Kp

**Pierre Shale (Upper Cretaceous)** — Regionally extensive unit of marine strata present in much of eastern Colorado. The unit is primarily composed of dark-gray shale and siltstone, with as many as six sandstone members that are well defined on geophysical borehole logs. The Pierre Shale is conformably underlain by the Smoky Hill Shale Member of the Niobrara Formation and is conformably overlain by the Fox Hills Sandstone (Scott and Cobban, 1965). Shown in cross section only. Total thickness is approximately 1,800-2,100 m.

Kn

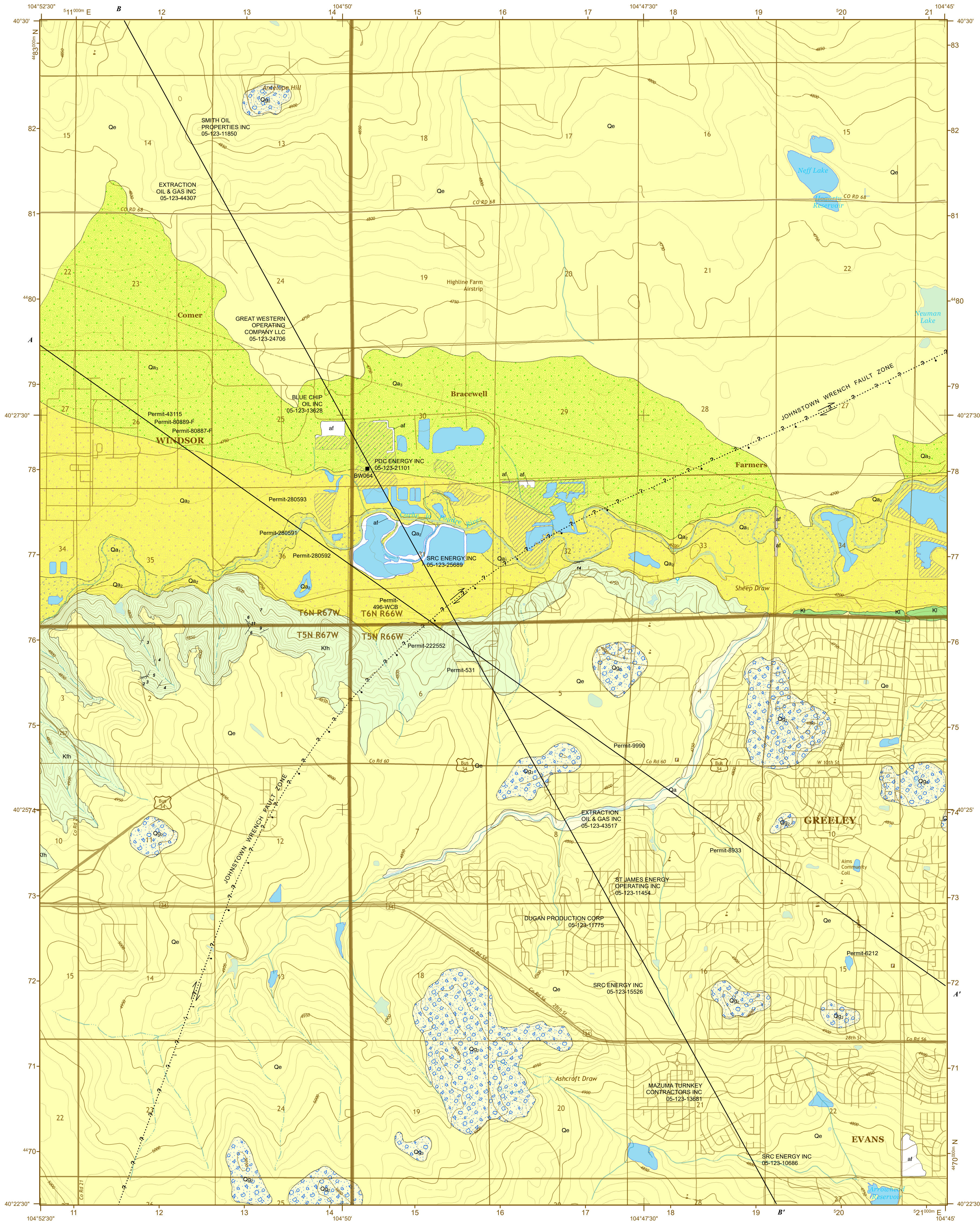
**Niobrara Formation (Upper Cretaceous)** — Unit consists chiefly of shale, marl, chalk and limestone. Shown in cross section only. Approximately 60-100 m thick.

Kcgg

**Colorado Group – Carlile Shale, Greenhorn Limestone, Graneros Shale, and Mowry Shale, undivided (Upper Cretaceous)** — Unit consists chiefly of shale, limestone, marl and chalk. Shown in cross section only. Approximately 120-140 m thick.

MAP SYMBOLS

- Contact — Approximately located
- Oblique-slip fault, right-lateral offset, of Weimer (1996) — Existence questioned; line, location concealed; ball and bar on downthrown side (where sense of displacement is known)
- Inclined bedding — Showing strike and dip
- Oil and gas well (Well name shown on map)
- Water well (Division of Water Resources permit number shown on map)
- Alignment of cross section
- Disturbed ground (uppermost Holocene) — Areas where mining operations have removed much of the original deposit and reclamation of the landscape has not occurred.



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

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Roads: 2006-2012, TomTom  
Names: 2006-2012, TomTom  
Hydrography: National Hydrography Dataset, 2011  
Contours: National Elevation Dataset, 1998  
Boundaries: Census, BLM, USGS, 1972-2012  
Public Land Survey System: BLM, 2011

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GEOLOGIC MAP OF THE BRACEWELL QUADRANGLE, WELD COUNTY, COLORADO

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