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Projection: Transverse Mercator
Datum: North American 1983
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Contours National Elevation Dataset, 2001
Imagery 2013
Roads U.S. Census Bureau, 2015-2016
Names National Hydrography Dataset, 2013
Hydrography National Hydrography Dataset, 2013
Boundaries National Hydrography Dataset, 2013
Public Land Survey System BLM, 2011
Wetlands FWS National Wetlands Inventory, 1977-2014

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GEOLOGIC MAP OF THE BERTHOUD QUADRANGLE, LARIMER, WELD, AND BOULDER COUNTIES, COLORADO

By Stephen M. Keller, Kassandra O. Lindsey, and Matthew L. Morgan
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DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

For surficial deposits, grain size is taken from *The Udden-Wentworth grain-size scale for clastic sediments (Nichols, 2009)* and color is taken from the *Munsell Soil Color Charts (Munsell Color, 1991)*.

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. Most of the artificial fill bodies in the Berthoud quad are along raised portions of Colorado Highway 287 and Larimer County Roads 15 and 17, and the material at these locations is presumed to be engineered fill. At the earthen dams at Berthoud, Hummel, and Ish Reservoirs it is not known if the earthen dams were engineered. Where fill is mapped as damming several small agricultural ponds in the southern part of the quadrangle, the material appears to have been excavated from the pond depressions and is presumed not to be engineered.

ALLUVIAL DEPOSITS

Qa₁

Alluvium one (upper Holocene) — This unit consists of fine to medium sand, subordinate amounts of medium to coarse sand, and pebble to cobble gravel, underlying a low terrace and adjacent channel deposits along the Little Thompson River, and its tributaries Dry Creek and Big Hollow. In the active channel of the Little Thompson River, some reaches contain or are covered with poorly sorted medium to very coarse sand and minor amounts of granitic granules and pebbles, and other reaches contain or are covered with clay, silt, and fine sand. In some reaches the sand is coarser and more angular and micaceous, and contains as much as 10% biotite and muscovite (<0.2 inches, < 4 mm). Channel bar deposits consist of medium to very coarse sand, and 10 to 20% gravel ranging from granules to cobbles (<6 inches, < 15 cm). The gravel is a mixture of mostly granitic and other crystalline rocks but also includes subordinate amounts of limestone and sandstone. The color of finer-grained deposits is dark-reddish-brown, and the coarse sand and gravel is pinkish-gray and pale red. Qa₁ terrace deposits consist chiefly of fine to medium sand but locally can include clayey silt to very fine sand. The sand fraction is moderately sorted, angular to subangular, and usually micaceous. Muscovite is the principal mica and constitutes up to 3% of the deposit, and flakes are as large as 1 mm. Granules and small pebbles (<0.2 inches, <5 mm) are present locally but constitute <5% of the deposit. The pebbles and granules consist mainly of angular to rounded granitic rocks and quartz, and subordinate angular Pierre Shale (Kp) mudstone fragments and rounded limestone and sandstone clasts. Overall, the colors of Qa₁ sediments include brown, dark brown, and dark reddish-brown, and less common olive and light olive-brown; sand and gravel bars in the stream beds are pinkish-gray. In the incised exposures secondary carbonate development is locally present. Exposed unit thickness was estimated from a 1-m resolution digital elevation model (DEM) and ranges from 9 to 15 ft (3 to 5 m). A radiocarbon analysis from Qa₁ alluvium (sample location Berthoud 3, 3 ft [1 m] below ground surface) (Table 1) indicates that the upper 3 ft (1 m) of Qa₁ was deposited after 1,530 ± 14C yr (late Holocene) (Beta Analytic sample #444186). In the Berthoud quadrangle the September 2013 flooding events caused the Little Thompson River to inundate the area mapped as Qa₁ and to damage property and infrastructure. The following estimates are based upon observed discharges at the Little Thompson River within the Berthoud quadrangle during the 2013 Front Range flood. At South County Line Road (Larimer County/Weld County line) the estimated recurrence interval for a 2013-magnitude flood is 1 to 100 years, and downstream at Interstate 25 the estimated recurrence interval is 100 years (Colorado Department of Transportation, 2015). In a 2010 map of flood zones in Colorado, the portion of the Little Thompson River flood plain (area mapped as Qa₁) within the Berthoud quadrangle and west of the Larimer/Weld County line is a 0.2% annual chance zone (500-year flood zone) and the portion east of the county line is a 1% annual chance zone (100-year flood zone) (Colorado Water Conservation Board, 2013). In the Big Thompson River, to which the Little Thompson River is a tributary, the 2013 event is considered a 100-year flood (Yochum, 2015). Bars in active channels of Qa₁ are small but are nonetheless potential sources of sand and gravel.

Qa₂

Alluvium two (middle to upper Holocene) — The deposit is a dark-yellowish-brown to dark-grayish-brown mixture of silt and sand and minor granules and pebbles. It underlies terraces 10-20 ft (3-6 m) above the modern streams and most of the valley floors of the Little Thompson River and its tributaries, and also the Big Thompson River at and beyond the north quadrangle boundary. The finer Qa₂ deposits are clayey silt or silty clay containing a trace of gravel to no gravel, and are locally micaceous (some flakes are 0.05 inches, <1 mm). Secondary calcium carbonate is present at most locations. The coarsest Qa₂ deposits range from silt to medium sand and have minor clay content. The sand is angular to subangular and locally very micaceous, and contains as much 10% mica (<0.1 inch, <2 mm). The deposit is usually moderately sorted but can have trace to minor, subrounded coarse sand and quartz granules. Secondary calcium carbonate is present at a few locations, and at one exposure the deposit contains abundant, white, granule-sized carbonate nodules. The coarsest Qa₂ deposits are found in the Little Thompson River upstream from the confluence with Dry Creek, and consist of fine to very coarse sand and minor gravel. Qa₂ correlates with the alluvium mapped as Qa1 (Holocene alluvium) in Dry Creek and the Little Thompson River, in the adjacent (to the west) Carter Lake Reservoir quadrangle (Braddock and others, 1988), and with unit Qa₁ (Alluvium two) of the adjacent (to the east) Johnston quadrangle (Palkovic and Morgan, 2017). Radiocarbon ages of Qa₂ (sample locations Berthoud 1 and Berthoud 2, 1.5 and 5 ft [0.4 and 1.5 m] below ground surface, respectively) are 910 ± 30 14C yr (late Holocene) (Beta Analytic sample #444184) and 2,930 ± 30 14C yr (late Holocene) (Beta Analytic sample #444185), respectively (Table 1). Qa₂ also may correlate with Qa₁ of the Longmont quadrangle (adjacent to the south), which has radiocarbon ages of 3835 ± 60 yr and 4420 ± 10 yr, and with Piney Creek Alluvium at a locality in the Commerce City quadrangle approximately 30 miles (50 km) to the south, where the Piney Creek Alluvium has an age of 1190 ± 28 14C yr (Madole and others, 2005). Qa₂ thickness was estimated from a 1-m LIDAR-derived DEM and ranges from 10 to 15 ft (3 to 5 m). This unit is likely not a source of sand and gravel.

Qa₃

Alluvium three (Upper Pleistocene to lower Holocene) — Generally, the deposit ranges from fine to coarse sand and minor silt and gravel, to fine sand to pebble gravel and minor silt and clay, to clast-supported subangular gravel up to 15 cm (6 inches) having a matrix of silt to granules. The unit is found in few small areas at higher elevations along Little Thompson River, at a tributary to Dry Creek, and at Big Hollow. The deposit is mostly 20 to 40 ft (6 to 12 m) above present-day stream level. Colors are dark-yellowish-brown, pinkish-gray, pale yellow, and light-brownish-gray. Local exposures vary in content from fine to medium sand and trace coarse sand and minor granules, to fine sand and pebble gravel, to fine to coarse sand and minor gravel, to very fine to very coarse sand and gravel, to clast-supported granule and pebble gravel. The sand is angular to subrounded, locally micaceous (some mica flakes are 0.05 inches, 1 mm), and locally poorly sorted. The gravel fraction consists of angular to subrounded quartz, granitic rocks, and sedimentary rocks; clasts are as large as 6 inches (15 cm) in diameter. Sedimentary clasts include flat, angular fragments of fine-grained sandstone, micritic limestone, and Kp siltstone; sedimentary clasts locally predominate over quartz and granitic clasts. At one location (Berthoud Gun Club) rinds of grayish-white secondary carbonate are abundant on pebbles and cobbles, although the sand and gravel matrix is poorly cemented. Exposed Qa₃ thickness can be up to 10 ft (3 m). The optically stimulated luminescence (OSL) age from Qa₃ (sample location Berthoud 4, 15 ft [4.6 m] below ground surface) is 10,940 ± 660 yr (S. Mahan, personal commun., 2017) (Table 1). At two locations Qa₃ is overlain by Qe. Qa₃ may correlate with Qa₁ of the Johnston quadrangle (Palkovic and Morgan, 2017). It may also correlate with Qa₁ location 1.8 miles (3 km) west of the Longmont quadrangle, where Qa₁ yielded radiocarbon ages of 10,600 ± 100 yr and 10,260 ± 70 yr (Madole, 2016). Small slope failures are possible where the Qa₃ has steep slopes, but landslides have not been mapped in the quadrangle and risk of slope failure for this unit is considered low. This unit is a potential

Qa₄

Gravel two (Middle (?) to Upper Pleistocene) — This poorly sorted sand and gravel was found at widely separated upland locations: Twin Mounds, the Town of Berthoud, and west of Ish Reservoir. The deposit is mostly 60 to 70 ft (18 to 21 m) above present-day stream level. The unit is a mixture of clayey silt to very fine sand and granule to cobble gravel. Gravel makes up ~25% of the deposit and includes clasts as large as 6 inches (15 cm) in diameter. The silt and sand fraction is micaceous and weakly to strongly calcareous; the sand is angular to subrounded. At Twin Mounds the soil profile includes a Bt horizon that has well-developed prismatic structures. At all the exposures, grayish-white carbonate rinds on clasts and well-developed Bk horizons are present. Carbonate development is at about Stage III+ as described by Machette (1985). Well developed Bt and Bk soil horizons indicate an older soil, about Middle Pleistocene in age. At Twin Mounds, where the exposure is ~6 ft (~2 m) thick, the orientation of carbonate rinds indicates rotation of clasts from original horizontal positions, suggesting reworking of the deposits. The Twin Mounds exposure includes a basal, clast-supported pebble and cobble gravel ~3 ft (~1 m) thick that overlies Kp. The clasts are light-grayish-brown sandstone, quartz, granitic rocks, and minor Kp mudstone. At the Town of Berthoud, the gravel fraction consists of reddish, fine-grained sandstone, light-gray micritic limestone, and minor olive-brown Kp mudstone. West of Ish Reservoir, the gravel fraction is quartz, gneiss, and dark-gray crystalline rock. Most of gravel at all localities is subangular to subrounded, containing some angular clasts. Qg₂ is overlain by Qe at all three localities. At the Town of Berthoud, where the exposed thickness is ~6 ft (~2m), the lower part of the unit is moderately bioturbated. Large, pale-brown, infilled burrows (bioturbation up to 3 ft [1 m] wide are found within the white deposit. The OSL age from sample SK4, collected from 5 ft (1.5 m) below ground surface at the Town of Berthoud, is 32,730 ± 2,340 yr. The OSL age of sample Berthoud 5, collected from 4 ft (1.2 m) below ground surface at Twin Mounds, is 35,950 ± 6,840 yr (S. Mahan, personal commun., 2017) (Table 1). Both ages are late Pleistocene. The strong Bt and Bk horizon development seen at these two locations, however, indicates a relative age of at least middle Pleistocene. The apparent discrepancies in the OSL age dates versus the soil profile development at the Town of Berthoud could be caused by sampling within a bioturbated zone, despite careful sampling efforts. The discrepancy at Twin Mounds could be caused by the reworking of the gravel deposit by debris flows or other gravitational and alluvial processes (causing rotation of carbonate-coated clasts), or by erosion. Unit Qg₂ is likely correlative with unit Qg₁ of the Johnston quadrangle (Palkovic and Morgan, 2017) and also may be correlative with unit Qa₀ and possibly Qa₃ of the Longmont quadrangle, adjacent to the south (Madole, 2016). The unit may be prone to slumping where underlain by shale bedrock, especially on the perimeter of the deposit. Qg₂ was mined for sand and gravel in the Johnston quadrangle, and may be a potential source of gravel in the Berthoud quadrangle.

Qf

Fan deposits (lower(?) to middle Holocene) — Alluvial fan-shaped bodies of dark-reddish-brown (Munsell 5YR) silt to very coarse subrounded sand, minor clay and trace mica, and a gravel fraction (~10% of the deposit) of angular to subangular granules. The material is weakly calcareous and weakly cohesive. It is present on slopes along the Little Thompson River and its tributaries, and along the Big Thompson River, and has an estimated thickness of 1 to 30 ft (0.3 to 9 m). Qf fans generally originate on slopes underlain by Kp and mantled by Qe. Relief is low on Qf areas and therefore the risk of slope failure is also low, though fans can be hydrocompactive and are susceptible to sheet-flood events. The unit is not a good source of sand and gravel.

EOLIAN DEPOSITS

Qe

Eolian sediment (Upper Pleistocene to middle (?) Holocene) — Generally, the unit is yellowish-brown (Munsell 10YR) and olive-brown (Munsell 2.5Y) clayey silt, silt to fine sand, and clayey silt to medium sand containing minor coarse sand. This material is described as less in the Longmont quadrangle adjacent to the south (Madole, 2016). Unit Qe locally might be slightly reworked and containing minor coarse sand to pebbles, and locally has high clay content due to derivation from areas of Kp upwind from the map area (Madole, 2016). The dominant Qe material is clayey silt, locally containing minor very fine sand and rarely containing medium to very coarse sand. It locally contains angular to subangular granitic and quartz granules and pebbles (<2.4 inches, <6 cm), rare angular Kp mudstone fragments (<0.4 inches, <1 cm), and rare micritic limestone pebbles. Secondary carbonate development is common and some localities have granule-sized carbonate nodules. Unit Qe is not associated with shallow topographic features and is present over a broad range of elevations (Madole, 2016). Natural exposures are rare, and thus the deposit is mapped from road cuts, building sites, geotechnical and water well logs, partial sampling (part of this mapping effort), county soils maps, and LIDAR imaging. Younger (Holocene) Qe deposits are dominant, but there are some older (late Pleistocene) exposures having soil profiles defined by well developed A, Bt, and Bk horizons. Carbonate development in Qe varies from secondary accumulation consisting of nodules, to Bk horizons developed to Stage III (Machette, 1985). Soil development in younger Qe (Holocene) deposits is usually weak or not discernable, but carbonate nodules are present locally. Qe is observed to overlie Qa₁, Qa₂, and Kp. Geotechnical logs indicate Qe thickness as generally from 7 to 16 ft (2 to 5 m). Qe can be prone to hydrocompaction. Sand content of the unit is low and it is not a potential source of industrial sand.

BEDROCK GEOLOGY

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 following descriptions of the Kp and other bedrock units are adapted from the descriptions of the adjacent (to the west) Carter Lake Reservoir quadrangle by Braddock and others (1988), and from a geologic and biostratigraphic map of the Kp by Scott and Cobban (1965). The latter map also was used to assist delineation of Kp members on the present map. The bentonite content of the Kpm and Kpl members makes these units prone to having expansive (swelling) soils, a well-known structural engineering problem along the Colorado River. Expansive soils may increase to 1.5 times their original volume when saturated (Colorado Geological Survey, 2017). The U.S. Geological Survey Mineral Resources On-Line Spatial Data system (USMIN) cites only one mineral resource in the quadrangle. It is in the Kp, is designated as "unknown, refractory clay" and the USMIN entry includes no other information. This location does not appear on the Coloration and Mine Safety (DRMS) map showing permitted, active, and inactive mines, nor are there any other DRMS locations mapped in the Berthoud quadrangle.

Uppermost transition member — This unit consists of friable gray and light-grayish-brown claystone, siltstone, and soft shaly sandstone containing thin beds of sand and calcareous concretions. It is exposed in dissected valley walls in the southeastern part of the quadrangle. Unit Kpt contains the index fossil ammonite *Sphenodiscus (Cochanites)* (Scott and Cobban, 1965). Thickness is approximately 2000 ft (610 m).

Upper shale member — This unit is a gray, friable, concretionary silty shale. It is exposed in dissected valley walls in southwest part of quadrangle. Kpu is mapped by Scott and Cobban (1965) over much of Berthoud quadrangle, but is mostly masked by Qe. The unit contains index fossil ammonites *Baculites clinochroa*, *Baculites grandis*, *Baculites bacula*, *Baculites elmsi*, and *Baculites jenseni* (Scott and Cobban, 1965). Thickness is approximately 2800 ft (853 m).

Unnamed sandstone in Kpu — This unit is a moderately indurated, subangular to subrounded, well-sorted, light-greenish-gray, fine- to medium-grained quartzose sandstone. Bedding varies in thickness between 1 and 3 inches (2.5 and 8 cm). Estimated thickness is 40 ft (12 m).

Larimer, Richard, 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. The units are exposed in a ridge that is trending northward from Welch Reservoir (northwestern part of the quadrangle), and the units also are present along Dry Creek and a tributary to Dry Creek (southwestern part of the quadrangle). The unit contains the index fossil ammonite *Baculites residae* (Scott and Cobban, 1965). Thickness is approximately 260 ft (79 m).

Middle shale member — This unit consists of highly friable, greenish-gray claystone, and sandy siltstone that contains thin bentonite beds. It is partially exposed between Welch and Ryan Gulch Reservoirs in the northwestern part of the quadrangle. The unit contains the index fossil ammonites *Baculites canebus*, *Baculites compressus*, *Dalymoceras cheyennense*, *Ecteloceras jenneyi*, *Dalymoceras stevensoni*, and *Dalymoceras nebrascense* (Scott and Cobban, 1965). Thickness is approximately 715 ft (218 m).

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 friable gray concretionary sandstone. The unit is exposed in a ridge that trends northward from Lonsere Reservoir. It contains the index fossil ammonites *Baculites scotti* and *Baculites gregoryensis* (Scott and Cobban, 1965). Thickness is approximately 760 ft (232 m).

In the northwest corner of the quadrangle, Kph is subdivided as follows per Scott and Cobban (1965):

Kph₁

Upper part — This unit consists of the upper and middle portions of Kph as described above.

Kph₂

Siltstone — This unit consists of sandy siltstone and layers of soft sandstone, equivalent to the lower portion of Kph.

The following units are shown only in cross sections (A-A' and B-B'). Descriptions are adapted from Braddock and others (1988).

Kp₁

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. It is exposed along the northern side of the Kp. Gulch Reservoir. The unit contains the index fossil ammonites *Baculites perplexus*, *Baculites asperifrons*, *Baculites mclernani*, and *Baculites obtusus* (Scott and Cobban, 1965). Thickness is approximately 1900 ft (579 m).

Kn

Niobrara Formation, undivided (Upper Cretaceous) — Very fissile, dark-gray shale that overlies and underlies thin (5 m, 15 ft) micritic limestone layers. Thickness is approximately 315 ft (96 m).

Kegg

Colorado Group - Carlile Shale, Greenhorn Limestone, Graneros Shale, and Mowry Shale (undivided) (Upper Cretaceous) — The 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 silty shale. Thickness is 410 to 500 ft (125 to 152 m).

Kd

Dakota Group: South Platte Formation and Layle Formation (undivided) (Lower Cretaceous) — This 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. Estimated thickness is 300 to 450 ft (91 to 137 m) based on oil and gas well logs within the Berthoud quadrangle.

JPm

Morrison (Upper Jurassic), Sundance (Middle Jurassic), Jelm (Upper Triassic), and Lykins (Lower Triassic and Upper Permian), undivided — This unit consists of green, red, yellow, and white claystone and siltstone, gray micritic limestone, and gray, fine- to medium-grained sandstone, fine-grained, gray to white sandstone and pink, orange-pink, and reddish-brown, fine- to medium-grained sandstone, and reddish-brown calcareous sandstone; and red and reddish-brown siltstone and fine-grained sandstone containing thin carbonate beds. Estimated thickness is approximately 900 ft (274 m), based on oil and gas well logs within the Berthoud quadrangle.

Ply

Lyons Sandstone (Permian) — Orange to pink to pinkish-gray, fine- to medium-grained, well-sorted quartzose sandstone. Thickness is approximately 50 ft (15 m).

Table 1. Age dates in the Berthoud quadrangle

Radiocarbon dating (by Beta Analytic, Inc., Miami, Florida, August 2016)				
Map unit	Map Location	Laboratory number	Material	Conventional 14C age (yr BP)
Qa ₂	Berthoud 1	Beta-444184	Silt and sand	910±30
Qa ₂	Berthoud 2	Beta-444185	Silt and sand	2,930±30
Qa ₃	Berthoud 3	Beta-444186	Silt and sand	1,530±30

Optically stimulated luminescence (OSL) dating (by U.S. Geological Survey, Lakewood, Colorado, February 2017)

Map unit	Map Location	Material	Age (yr BP)
Qg ₂	SK4	Fine to very coarse sand	32,730 ± 2,340
Qa ₃	Berthoud 4	Sand and gravel	10,940 ± 660
Qg ₂	Berthoud 5	Sand and gravel	35,950 ± 6,840

Note: Strong Bt and Bk horizon development observed in Qg₂ indicates an age of at least

Middle Pleistocene, which is at variance with the above OSL dates for Qg₂ samples.

MAP SYMBOLS

Contact — Approximately located

Oblique-slip fault — Dotted where concealed; U = upthrown side, D = downthrown side; arrows show relative motion

Thrust fault — Dotted where concealed; sawtooth on upper plate

Elevation of base of Niobrara Fm (feet above mean sea level) — This structure-contoured area presents a dome structure recognized when analyzing COGCC well data during map compilation. In the adjacent (to the west) Carter Lake Reservoir geologic map there is another dome, ~6 miles southwest of Berthoud quad dome and adjacent to the Berthoud quadrangle western boundary. The base of the Niobrara was structure-contoured for the Carter Lake Reservoir dome, and the same contact is contoured here for consistency between the two maps.

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

Dome

Sample locations for age dates

Carbon-14

Optically Stimulated Luminescence (OSL)

Oil and gas wells

Drilled and Abandoned

Plugged and Abandoned

Producing

Shut In

Alignment of cross section