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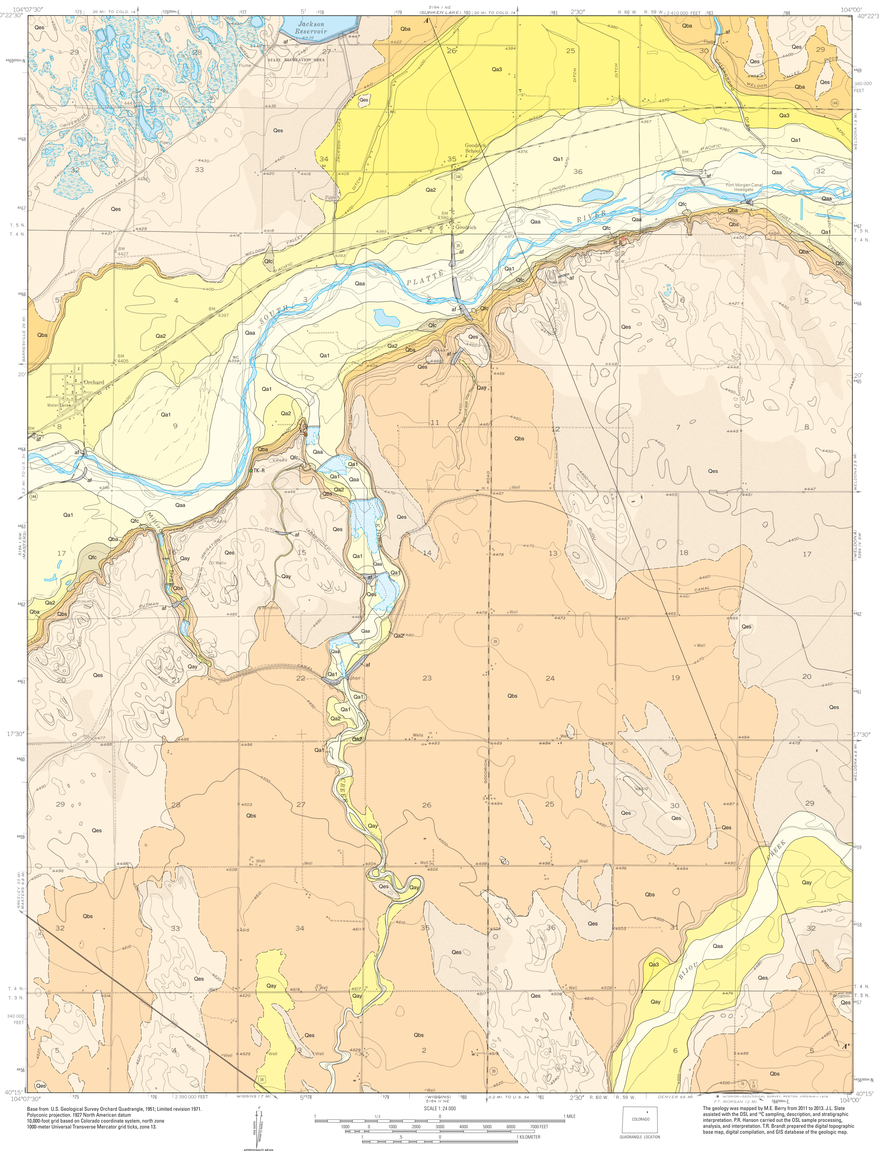

Base from U.S. Geological Survey Orchard Quadrangle, 1951; Limited revision 1971.
Polyconic projection, 1927 North American datum
10,000-foot grid based on Colorado coordinate system, north zone
1000-meter Universal Transverse Mercator grid ticks, zone 13.

SCALE 1:24 000

CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Geologic Map of the Orchard 7.5′ Quadrangle, Morgan County, Colorado

By

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2015

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CORRELATION OF MAP UNITS

SURFICIAL DEPOSITS

Artificial fill (af) | Alluvial deposits (Qaa, Qa3, Qa2, Qa1, Qay, Qfc, Qbs, Qbo, Qbm, Qbw, Qsw) | Alluvial and colluvial deposits (Qsa, Qsm, Qsb, Qsd, Qsc, Qsf, Qsl, Qsp, Qsr, Qsv, Qsx, Qsy, Qsz) | Eolian deposits (Qes)

Holocene

QUATERNARY

Pleistocene

BEDROCK UNIT

Kp — Upper Cretaceous

CRETACEOUS

DESCRIPTION OF MAP UNITS

[Calibrated radiocarbon ages are expressed as "cal ka B.P.," which stands for calibrated thousand years before present (0 B.P. = 1950 A.D.). Uncertainties are given at the 95 percent (2σ) confidence level. Calibrated ages are reported as the midpoint of the calibrated range. In cases where calibrated produced more than one age range with a probability of 5 percent or more, ages are based on the mean of the ranges weighted by their probabilities, and are presented without uncertainties.

The soil-horizon terminology used in this report is that of the Soil Survey Staff (1993), except for Bk horizon stages of carbonate morphology, which are described in Birkeland (1999). The term "consistence" is the resistance to crushing of soil or surficial material in the hand, as described by Soil Survey Staff (1993). Most colors are field dry colors that were described with the aid of Munsell soil color charts (Munsell Color, 1975)]

SURFICIAL DEPOSITS

Artificial fill

af **Artificial fill (latest Holocene)**—Includes abutments where roadways cross South Platte River, small dams across sidestreams and gullies, some artificial levees and banks, and fill associated with gravel pits. Fill consists of poorly to moderately sorted clay and silt along most canals and ditches but only mapped locally. Chiefly consists of gravel, sand, silt, and rock and concrete fragments.

Alluvial deposits

Qaa **Active channel and floodplain alluvium (late Holocene)**—Equivalent to part of post-Piney Creek alluvium of Scott (1963). Very pale brown, light brownish gray, light yellowish brown, or light pinkish brown (photo 1). Mostly fine to coarse sand, pebbly sand, silty sand, and sandy pebble gravel, interstratified with thin (<1–5 cm) layers or lenses of very pale brown silt and dark grayish brown, organic-rich clays of local origin. Poorly to moderately sorted. Sand beds moderately stratified. Sand beds commonly cross-stratified. Filled burrows common. Pebbles and minor small cobbles generally subrounded to rounded clasts of granite, gneiss, quartzite, feldspar, pegmatite, chert, and sandstone. Upper 0.5 m consists of soil with reddish yellow iron oxide and black manganese oxide. Some beds show signs of soft sediment deformation. Filled burrows common. Pebbles and minor small cobbles generally subrounded to rounded clasts of granite, gneiss, quartz, feldspar, pegmatite, chert, and sandstone. Uppermost sediment packet in alluvial sequence typically light grayish brown or pale brown, crudely stratified, poorly sorted sandy silt, silty sand, and granule to pebbly sand with lenses of silt and dark grayish brown clay. Mud ball rip-up clasts common locally. In tributaries, alluvium mostly fine grained, thinly stratified sand, sandy silt, and clayey silt. Unit contains lignite fragments thought to be eroded from Upper Cretaceous Laramie Formation. Surface soil typically weakly developed A/C or A/AC/C profile; B horizons developed locally. Estimated thickness 3–5 m

Qa3 **Young alluvium 3 (Holocene and latest Pleistocene?)**—Piney Creek Alluvium of Gardner (1967) and Scott (1978). Forms terrace 3–6 m above active floodplain. Gardner (1967) and McFaul and others (1994) considered this terrace correlative to Kuner terrace of Bryan and Ray (1940). Alluvium pale yellow, light yellowish brown, light olive brown, or grayish brown. Poorly to well-sorted, ranging from moderately stratified, fine sand, silt, clay to poorly stratified, coarse sand, pebbly gravel, and silt with coarse sand lenses and granule to fine pebble stringers. Soft to slightly hard in consistence. Pebbles mostly subrounded clasts of granite, gneiss, quartz, feldspar, pegmatite, chert, and sandstone. Locally, weakly developed buried soil separates deposits in white alluvial sequence. Soil horizon (USDA Natural Resources Conservation Service, 2009) shows surface soil as typically having thin (approximately 25–35 cm thick) argillic B horizon and weakly developed Bk horizon with stage I–II carbonate morphology.

Radiocarbon (°C) and optically stimulated luminescence (OSL) age estimates for a section exposed in a gravel pit at the northeast edge of the Orchard adjacent Weldona 7.5′ quadrangle (site AK, near section AK of Gardner, 1967; fig. 1) suggest that alluvium of Qa3 was deposited during the latest part of early Holocene (tables 1 and 2; Berry and others, 2013). Probable *Succinea* snail shells collected at depths of approximately 4.7 m and deeper yielded OSL age estimates of 9.1±0.9 ka (UNL–3502, 5 percent moisture, table 1), and 11.95±0.24 ka B.P. (Aeon–995, table 2), respectively. Sediment collected at a depth of approximately 3.5 m, from a location approximately 10 m upstream from where the snail shells were collected, yielded an OSL age estimate of 9.1±0.9 ka (UNL–3503, 5 percent moisture, table 1).

A latest Pleistocene to early Holocene age for basal alluvium is also supported by an age of 11.68±0.36 cal ka B.P. (uncalibrated age of 10.1±0.09 ^{14}C ka B.P., AA–110843) obtained by Paul Hanson (written commun., 2012) from shells in charcoal from Kuner terrace alluvium (of Bryan and Ray, 1940) upstream of Kersey, Colo. Timing of episodes of arroyo cutting and alluvial-aggradation interpreted is constrained by a date from McFaul and others (1994) of 5.84±0.18 cal ka B.P. (5.12±0.08 ^{14}C ka B.P., Beta–82364) for soil humates from the A horizon of a buried soil developed on Qa3 terrace alluvium at a site in the adjacent Masters 7.5′ quadrangle. Degree of development of the buried soil is such that the Qa3 surface may have been stabilized for a few thousand years prior to its burial at that site by eolian sediment around 5.8 cal ka B.P. (McFaul and others, 1994). Stabilization of the Qa3 surface by mid-Holocene time is supported by degree of development of soils mapped on the terrace (Soil Survey Staff, 1993; USDA Natural Resources Conservation Service (2009). Estimated thickness 2–5 m

Qbs **Sidestream deposits of Broadway Alluvium (late Pleistocene)**—Mapped as informal Bijou Flats member of Broadway Alluvium by Scott (1978), Overlies and presumably interfingers with mainstream deposits of Broadway Alluvium (Qbo) south of South Platte River. Consists mostly of sheetflood deposits thought to have been deposited primarily by ley ing Colorado floods ding Bijou and Kiowa Creeks (Gardner, 1967; Scott, 1978, 1982). Distribution of deposits suggests that inflow of large amounts of sidestream alluvium during flood events deflected the South Platte River to the north side of its valley and may have episodically dammed the river for short periods of time (Scott, 1982) (fig. 2). Accumulation of sidestream alluvium built up surface to a level that now stands 21–24 m above the active floodplain of South Platte River at Orchard. Soil profiles represent maximum height of approximately 27 m above active floodplain several kilometers downstream from Orchard (Bijou Creek at Kiowa, Colorado). Unit identified as far downstream as Atwood, Logan County, Colo. (Scott, 1978). Upstream extent is Empire Reservoir area, near Weld County–Morgan County line.

Alluvium light yellowish brown, light olive brown, pale yellow, or light gray, poorly to well-sorted, moderately stratified, fine to coarse sand and silty sand in beds approximately 20–60 cm thick. Sand beds commonly separated by thin (1–5 cm) layers of pale yellow and gray, evenly laminated, clay to silt (mm thick) of thinly laminated dark-grayish brown or black organic-rich clay interbedded with layers of pale yellow to light olive silt and fine sand. Contains abundant detrital lignite thought to be eroded from Upper Cretaceous Laramie Formation (see discussion of Qbo). Graded beds that range upward from poorly sorted coarse sand and granules to mostly fine sand are common. Also common are sand beds that are cross-stratified, faintly laminated, ripple cross-stratified, or massive. Sand grains mostly subangular; lesser amounts subrounded. Coarse sand grains and granules of quartz and feldspar dominant. Uncommon fine to pebbles of ash-flow tuff, shale, and granitic rock types. Soft to hard dry consistence. Iron oxide mottles common locally. Organic alluvium and peat layers particularly in sandy clay layers. Typically forms vertical exposures, especially along South Platte River and Bijou Creek where upstream alluvium typically is sharp, marked by difference in color and coherence. Soil profile characterized by approximately 30–35 cm thick argillic B horizon with moderate prismatic structure, and Bk horizon with stage II filamentous carbonate morphology. Soil profile buried by younger alluvial sands in many areas.

OSL and ^{14}C age estimates indicate a late Pleistocene age for Qbs. A dated section at the mouth of Kiowa Creek (site KC) yielded OSL age estimates (5 percent moisture) of 12.0±1.1 ka (UNL–3462) at approximately 1.7 m depth, 16.8±1.7 ka (UNL–3460) at approximately 2.6 m depth, and 15.2±1.5 ka (UNL–3463) at approximately 3.6 m depth (table 1). These age estimates are in good agreement with a ^{14}C age of 15.04–56 cal ka B.P. (Aeon–954, table 2) obtained from probable *Succinea* snail shells collected at a depth of approximately 3.7 m from a section (SC) exposed in Scott Gulch on the bluff about 4.8 km downstream of Kiowa Creek (site H–R, at section H of Gardner, 1967). The ages also are in good agreement with OSL age estimates (5 percent moisture) for a section approximately 1 m above active floodplain at a site just east of Orchard quadrangle (site BC, in Weldona 7.5′ quadrangle about 13.5 km upstream of the river confluence, fig. 1) of 12.4±1.1 ka (UNL–3459) sampled at approximately 1.1 m depth; and 14.6±1.2 ka (UNL–3498) sampled at approximately 1.9 m depth (table 1).

Organic material collected from a thin (2–5 mm) interbed of organic debris and clay at approximately 2.5 m depth, just above OSL sediment sample UNL–3466, yielded an infinite ^{14}C age estimate (Aeon–950, table 2; J.S. Pigati, USGS, oral commun., 2012). Gardner (1967) also dated organic material from Qbs that yielded an anomalously old date. Pollen analysis of his dated sample indicated a plant assemblage of Late Cretaceous age, leading Gardner (1967) to interpret the sample as fragile from the Laramie Formation, which crops out along Kiowa and Bijou Creeks south of the map area. We suspect our sample (Aeon–950) also contained lignite from the Laramie Formation. Probable lignite debris is common in other exposures of Qbs along Bijou Creek and the South Platte River bluff, as also noted by Scott (1978) for areas downstream. Unit about 6–10 m thick where exposed along river bluff, but could be as much as 18 m thick south of the river, around Bijou Creek (Gardner, 1967)

Qay **Young alluvium 1 and 2, undivided (late Holocene)**—Mapped in tributary drainages and small draws where deposits of young alluvium (Qa1, Qa2, and locally Qaa) are either too small to map separately or are difficult to distinguish. Parts of surface occasionally flooded. Includes flood deposits left during June 1965 flood, which resulted in approximately 1 m of sediment deposition on the preexisting Qay surface in Bijou Creek drainage near the border between Orchard and Weldona 7.5′ quadrangles (McKee and others, 1967), and sheetwash deposits associated with Kiowa Creek near the southern border of the quadrangle. Estimated thickness 1–5 m

Qa2 **Young alluvium 2 (Holocene and latest Pleistocene?)**—Piney Creek Alluvium of Gardner (1967) and Scott (1978). Forms terrace 2–3 m above active floodplain. Gardner (1967) and McFaul and others (1994) considered this terrace correlative to Kuner terrace of Bryan and Ray (1940). Alluvium pale yellow, light yellowish brown, light olive brown, or grayish brown. Poorly to well-sorted, ranging from moderately stratified, fine sand, silt, clay to poorly stratified, coarse sand, pebbly gravel, and silt with coarse sand lenses and granule to fine pebble stringers. Soft to slightly hard in consistence. Pebbles mostly subrounded clasts of granite, gneiss, quartz, feldspar, pegmatite, chert, and sandstone. Locally, weakly developed buried soil separates deposits in white alluvial sequence. Soil Survey (USDA Natural Resources Conservation Service, 2009) shows surface soil as typically having thin (approximately 25–35 cm thick) argillic B horizon and weakly developed Bk horizon with stage I–II carbonate morphology.

Radiocarbon (°C) and optically stimulated luminescence (OSL) age estimates for a section exposed in a gravel pit at the northeast edge of the Orchard adjacent Weldona 7.5′ quadrangle (site AK, near section AK of Gardner, 1967; fig. 1) suggest that alluvium of Qa2 was deposited during the latest part of early Holocene (tables 1 and 2; Berry and others, 2013). Probable *Succinea* snail shells collected at depths of approximately 4.7 m and deeper yielded OSL age estimates of 11.90±0.28 cal ka B.P. (Aeon–994, table 2) and 11.95±0.24 cal ka B.P. (Aeon–995, table 2), respectively. Sediment collected at a depth of approximately 3.5 m, from a location approximately 10 m upstream from where the snail shells were collected, yielded an OSL age estimate of 9.1±0.9 ka (UNL–3503, 5 percent moisture, table 1).

A latest Pleistocene to early Holocene age for basal alluvium is also supported by an age of 11.68±0.36 cal ka B.P. (uncalibrated age of 10.1±0.09 ^{14}C ka B.P., AA–110843) obtained by Paul Hanson (written commun., 2012) from shells in charcoal from Kuner terrace alluvium (of Bryan and Ray, 1940) upstream of Kersey, Colo. Timing of episodes of arroyo cutting and alluvial-aggradation is constrained by a date from McFaul and others (1994) of 5.84±0.18 cal ka B.P. (5.12±0.08 ^{14}C ka B.P., Beta–82364) for soil humates from the A horizon of a buried soil developed on Qa3 terrace alluvium at a site in the adjacent Masters 7.5′ quadrangle. Degree of development of the buried soil is such that the Qa3 surface may have been stabilized for a few thousand years prior to its burial at that site by eolian sediment around 5.8 cal ka B.P. (McFaul and others, 1994). Stabilization of the Qa3 surface by mid-Holocene time is supported by degree of development of soils mapped on the terrace (Soil Survey Staff, 1993; USDA Natural Resources Conservation Service (2009). Estimated thickness 2–5 m

Qa1 **Young alluvium 1 (late Holocene)**—Equivalent to part of post-Piney Creek alluvium of Scott (1963). Forms low terrace approximately 1.5 m above active floodplain, and low gradient fan at Kiowa Creek and Millfoot Draw. Part of surface occasionally flooded. Along South Platte River, alluvium very pale brown, light brownish gray, light yellowish brown, or light pinkish brown; fine to coarse sand, pebbly sand, and sandy pebble gravel. Interstratified with thin (<1–5 cm) layers or lenses of very pale brown silt and dark grayish brown, organic-rich clays. Poorly to well-sorted, weakly to moderately stratified. Sand beds commonly cross-stratified. Loose to slightly hard dry consistence. Locally, grains stained with reddish yellow iron oxide and black manganese oxide. Some beds show signs of soft sediment deformation. Filled burrows common. Pebbles and minor small cobbles generally subrounded to rounded clasts of granite, gneiss, quartz, feldspar, pegmatite, chert, and sandstone. Uppermost sediment packet in alluvial sequence typically light grayish brown or pale brown, crudely stratified, poorly sorted sandy silt, silty sand, and granule to pebbly sand with lenses of silt and dark grayish brown clay. Mud ball rip-up clasts common locally. In tributaries, alluvium mostly fine grained, thinly stratified sand, sandy silt, and clayey silt. Unit contains lignite fragments thought to be eroded from Upper Cretaceous Laramie Formation. Surface soil typically weakly developed A/C or A/AC/C profile; B horizons developed locally. Estimated thickness 3–5 m

Qay **Young alluvium 3 (Holocene and latest Pleistocene?)**—Piney Creek Alluvium of Gardner (1967) and Scott (1978). Forms terrace 3–6 m above active floodplain. Gardner (1967) and McFaul and others (1994) considered this terrace correlative to Kuner terrace of Bryan and Ray (1940). Alluvium pale yellow, light yellowish brown, light olive brown, or grayish brown. Poorly to well-sorted, ranging from moderately stratified, fine sand, silt, clay to poorly stratified, coarse sand, pebbly gravel, and silt with coarse sand lenses and granule to fine pebble stringers. Soft to slightly hard in consistence. Pebbles mostly subrounded clasts of granite, gneiss, quartz, feldspar, pegmatite, chert, and sandstone. Locally, weakly developed buried soil separates deposits in white alluvial sequence. Soil Survey (USDA Natural Resources Conservation Service, 2009) shows surface soil as typically having thin (approximately 25–35 cm thick) argillic B horizon and weakly developed Bk horizon with stage I–II carbonate morphology.

Radiocarbon (°C) and optically stimulated luminescence (OSL) age estimates for a section exposed in a gravel pit at the northeast edge of the Orchard adjacent Weldona 7.5′ quadrangle (site AK, near section AK of Gardner, 1967; fig. 1) suggest that alluvium of Qa3 was deposited during the latest part of early Holocene (tables 1 and 2; Berry and others, 2013). Probable *Succinea* snail shells collected at depths of approximately 4.7 m and deeper yielded OSL age estimates of 9.1±0.9 ka (UNL–3502, 5 percent moisture, table 1), and 11.95±0.24 cal ka B.P. (Aeon–995, table 2), respectively. Sediment collected at a depth of approximately 3.5 m, from a location approximately 10 m upstream from where the snail shells were collected, yielded an OSL age estimate of 9.1±0.9 ka (UNL–3503, 5 percent moisture, table 1).

A latest Pleistocene to early Holocene age for basal alluvium is also supported by an age of 11.68±0.36 cal ka B.P. (uncalibrated age of 10.1±0.09 ^{14}C ka B.P., AA–110843) obtained by Paul Hanson (written commun., 2012) from shells in charcoal from Kuner terrace alluvium (of Bryan and Ray, 1940) upstream of Kersey, Colo. Timing of episodes of arroyo cutting and alluvial-aggradation is constrained by a date from McFaul and others (1994) of 5.84±0.18 cal ka B.P. (5.12±0.08 ^{14}C ka B.P., Beta–82364) for soil humates from the A horizon of a buried soil developed on Qa3 terrace alluvium at a site in the adjacent Masters 7.5′ quadrangle. Degree of development of the buried soil is such that the Qa3 surface may have been stabilized for a few thousand years prior to its burial at that site by eolian sediment around 5.8 cal ka B.P. (McFaul and others, 1994). Stabilization of the Qa3 surface by mid-Holocene time is supported by degree of development of soils mapped on the terrace (Soil Survey Staff, 1993; USDA Natural Resources Conservation Service (2009). Estimated thickness 2–5 m

Qbs **Sidestream deposits of Broadway Alluvium (late Pleistocene)**—Mapped as informal Bijou Flats member of Broadway Alluvium by Scott (1978). Overlies and presumably interfingers with mainstream deposits of Broadway Alluvium (Qbo) south of South Platte River. Consists mostly of sheetflood deposits thought to have been deposited primarily by ley ing Colorado floods ding Bijou and Kiowa Creeks (Gardner, 1967; Scott, 1978, 1982). Distribution of deposits suggests that inflow of large amounts of sidestream alluvium during flood events deflected the South Platte River to the north side of its valley and may have episodically dammed the river for short periods of time (Scott, 1982) (fig. 2). Accumulation of sidestream alluvium built up surface to a level that now stands 21–24 m above the active floodplain of South Platte River at Orchard. Soil profiles represent maximum height of approximately 27 m above active floodplain several kilometers downstream from Orchard (Bijou Creek at Kiowa, Colorado). Unit identified as far downstream as Atwood, Logan County, Colo. (Scott, 1978). Upstream extent is Empire Reservoir area, near Weld County–Morgan County line.

Alluvium light yellowish brown, light olive brown, pale yellow, or light gray, poorly to well-sorted, moderately stratified, fine sand and silty sand in beds approximately 20–60 cm thick. Sand beds commonly separated by thin (1–5 cm) layers of pale yellow and gray, evenly laminated, clay to silt (mm thick) of thinly laminated dark-grayish brown or black organic-rich clay interbedded with layers of pale yellow to light olive silt and fine sand. Contains abundant detrital lignite thought to be eroded from Upper Cretaceous Laramie Formation (see discussion of Qbo). Graded beds that range upward from poorly sorted coarse sand and granules to mostly fine sand are common. Also common are sand beds that are cross-stratified, faintly laminated, ripple cross-stratified, or massive. Sand grains mostly subangular; lesser amounts subrounded. Coarse sand grains and granules of quartz and feldspar dominant. Uncommon fine to pebbles of ash-flow tuff, shale, and granitic rock types. Soft to hard dry consistence. Iron oxide mottles common locally. Organic alluvium and peat layers particularly in sandy clay layers. Typically forms vertical exposures, especially along South Platte River and Bijou Creek where upstream alluvium typically is sharp, marked by difference in color and coherence. Soil profile characterized by approximately 30–35 cm thick argillic B horizon with moderate prismatic structure, and Bk horizon with stage II filamentous carbonate morphology. Soil profile buried by younger alluvial sands in many areas.

OSL and ^{14}C age estimates indicate a late Pleistocene age for Qbs. A dated section at the mouth of Kiowa Creek (site KC) yielded OSL age estimates (5 percent moisture) of 12.0±1.1 ka (UNL–3462) at approximately 1.7 m depth, 16.8±1.7 ka (UNL–3460) at approximately 2.6 m depth, and 15.2±1.5 ka (UNL–3463) at approximately 3.6 m depth (table 1). These age estimates are in good agreement with a ^{14}C age of 15.04–56 cal ka B.P. (Aeon–954, table 2) obtained from probable *Succinea* snail shells collected at a depth of approximately 3.7 m from a section (SC) exposed in Scott Gulch on the bluff about 4.8 km downstream of Kiowa Creek (site H–R, at section H of Gardner, 1967). The ages also are in good agreement with OSL age estimates (5 percent moisture) for a section approximately 1 m above active floodplain at a site just east of Orchard quadrangle (site BC, in Weldona 7.5′ quadrangle about 13.5 km upstream of the river confluence, fig. 1) of 12.4±1.1 ka (UNL–3459) sampled at approximately 1.1 m depth; and 14.6±1.2 ka (UNL–3498) sampled at approximately 1.9 m depth (table 1).

Organic material collected from a thin (2–5 mm) interbed of organic debris and clay at approximately 2.5 m depth, just above OSL sediment sample UNL–3466, yielded an infinite ^{14}C age estimate (Aeon–950, table 2; J.S. Pigati, USGS, oral commun., 2012). Gardner (1967) also dated organic material from Qbs that yielded an anomalously old date. Pollen analysis of his dated sample indicated a plant assemblage of Late Cretaceous age, leading Gardner (1967) to interpret the sample as fragile from the Laramie Formation, which crops out along Kiowa and Bijou Creeks south of the map area. We suspect our sample (Aeon–950) also contained lignite from the Laramie Formation. Probable lignite debris is common in other exposures of Qbs along Bijou Creek and the South Platte River bluff, as also noted by Scott (1978) for areas downstream. Unit about 6–10 m thick where exposed along river bluff, but could be as much as 18 m thick south of the river, around Bijou Creek (Gardner, 1967)

Qbm **Mainstream deposits of Broadway Alluvium (late Pleistocene)**—Mapped as Broadway Alluvium by Gardner (1967) and lower member of Broadway Alluvium by Scott (1978). Underlies and interfingered to northwest with sidestream Broadway Alluvium (Qbs) from Kiowa and Bijou Creeks south of South Platte River. North of river, forms terrace approximately 12–15 m above active floodplain; terrace largely covered by eolian sand (Qes). Unit crops out poorly due to cohesionless nature of the sediment when dry. High potassium feldspar content gives unit a distinctive pinkish hue, particularly in exposures along South Platte River bluff (photo 2).

Alluvium pink, pinkish gray, or light reddish brown, moderately well- to poorly sorted, fine to coarse sand, pebbly sand, silty sand, and sandy granule to pebble gravel. Commonly cross-stratified. Locally has interbeds of pinkish gray to very pale brown silt and sandy silt, and grayish brown clay. Sand grains mostly subrounded. Gravel typically rounded to subrounded clasts of granite, gneiss, pegmatite, feldspar, quartz, chert, and sandstone. Largest clasts commonly 3–5 cm diameter, but cobbles and small boulders (up to approximately 32 cm in diameter) present locally. Accumulations of reddish-yellow to yellowish-red iron oxide and black manganese oxide as coats on grains and masses in matrix common, and in many places accentuate bedding. Surface soil profile typically has thin argillic B horizon with weak to moderate prismatic structure, and a thin Bk horizon with stage II carbonate morphology.

At a site about 10 km west of Orchard quadrangle (in adjacent Masters 7.5′ quadrangle), unit includes 70 cm thick section of crumbly clay, pinkish silt, platy silty fine sand, burrowed sandy silt with gray and yellowish green color banding, and one white silt with common small fragments and articulated bivalve shells. Hard dry consistence. Interpreted as quiet water deposits that may have been deposited at a time when the river was constantly ponded behind eolian flood deposits. Underlying sands brightly stained reddish yellow, yellowish red, or dark red due to iron oxide accumulation.

OSL age estimate (5 percent moisture) of 9.4±1.0 ka (UNL–3504, table 1) was obtained for mainstream Broadway Alluvium where it underlies Qbs at a locality about 0.8 km upstream of Kiowa Creek confluence (site TK–R). This age estimate is stratigraphically young and stratigraphically inconsistent with ages obtained for overlying Qbs (see discussion above), and therefore is not considered a realistic estimate for age of the sediment. Another OSL age estimate for mainstream Broadway Alluvium (Qbm) of 12.5±1.1 ka (UNL–3464, 5 percent moisture, table 1), collected downstream in the Weldona 7.5′ quadrangle (near section AK of Gardner, 1967) also is anomalously young and stratigraphically inconsistent with ages obtained for the overlying deposit (Qbs), and therefore also not considered a realistic estimate. Reasons for the anomalously young OSL age estimates are unknown but could be due to a number of factors associated with sampling and dating, or complications due to pedoturbation by burrowing animals. Results of a dose recovery test on UNL–3504 rule out most systematic problems with laboratory procedures and measurements.

Broadway Alluvium is considered coeval with the Pinedale glaciation (Bryan and Ray, 1940; Scott, 1954; Scott and Cobban, 1965; Madole, 1991), which spanned from ~31 ka to approximately 15–13 ka (Nelson and others, 1979; Madole, 1986; Schildgen and others, 2002; Benson and others, 2004, 2007; Licciardi and Pierce, 2008; Madole and others, 2010; Young and others, 2011). Fluvial sediment age estimates from Broadway Alluvium (Qbo) in Bijou Creek deglaciation (Church and Ryder, 1972; Madole, 1991; Schildgen and others, 2002; Lindsey and others, 2005), a presumed Bull Lake equivalent (Scott, 1978), Upstream extent is Empire Reservoir area, near Weld County–Morgan County line.

Alluvium light yellowish brown, light olive brown, pale yellow, or light gray, poorly to well-sorted, moderately stratified, fine sand and silty sand in beds approximately 20–60 cm thick. Sand beds commonly separated by thin (1–5 cm) layers of pale yellow and gray, evenly laminated, clay to silt (mm thick) of thinly laminated dark-grayish brown or black organic-rich clay interbedded with layers of pale yellow to light olive silt and fine sand. Contains abundant detrital lignite thought to be eroded from Upper Cretaceous Laramie Formation (see discussion of Qbo). Graded beds that range upward from poorly sorted coarse sand and granules to mostly fine sand are common. Also common are sand beds that are cross-stratified, faintly laminated, ripple cross-stratified, or massive. Sand grains mostly subangular; lesser amounts subrounded. Coarse sand grains and granules of quartz and feldspar dominant. Uncommon fine to pebbles of ash-flow tuff, shale, and granitic rock types. Soft to hard dry consistence. Iron oxide mottles common locally. Organic alluvium and peat layers particularly in sandy clay layers. Typically forms vertical exposures, especially along South Platte River and Bijou Creek where upstream alluvium typically is sharp, marked by difference in color and coherence. Soil profile characterized by approximately 30–35 cm thick argillic B horizon with moderate prismatic structure, and Bk horizon with stage II filamentous carbonate morphology. Soil profile buried by younger alluvial sands in many areas.

OSL and ^{14}C age estimates indicate a late Pleistocene age for Qbs. A dated section at the mouth of Kiowa Creek (site KC) yielded OSL age estimates (5 percent moisture) of 12.0±1.1 ka (UNL–3462) at approximately 1.7 m depth, 16.8±1.7 ka (UNL–3460) at approximately 2.6 m depth, and 15.2±1.5 ka (UNL–3463) at approximately 3.6 m depth (table 1). These age estimates are in good agreement with a ^{14}C age of 15.04–56 cal ka B.P. (Aeon–954, table 2) obtained from probable *Succinea* snail shells collected at a depth of approximately 3.7 m from a section (SC) exposed in Scott Gulch on the bluff about 4.8 km downstream of Kiowa Creek (site H–R, at section H of Gardner, 1967). The ages also are in good agreement with OSL age estimates (5 percent moisture) for a section approximately 1 m above active floodplain at a site just east of Orchard quadrangle (site BC, in Weldona 7.5′ quadrangle about 13.5 km upstream of the river confluence, fig. 1) of 12.4±1.1 ka (UNL–3459) sampled at approximately 1.1 m depth; and 14.6±1.2 ka (UNL–3498) sampled at approximately 1.9 m depth (table 1).

Organic material collected from a thin (2–5 mm) interbed of organic debris and clay at approximately 2.5 m depth, just above OSL sediment sample UNL–3466, yielded an infinite ^{14}C age estimate (Aeon–950, table 2; J.S. Pigati, USGS, oral commun., 2012). Gardner (1967) also dated organic material from Qbs that yielded an anomalously old date. Pollen analysis of his dated sample indicated a plant assemblage of Late Cretaceous age, leading Gardner (1967) to interpret the sample as fragile from the Laramie Formation, which crops out along Kiowa and Bijou Creeks south of the map area. We suspect our sample (Aeon–950) also contained lignite from the Laramie Formation. Probable lignite debris is common in other exposures of Qbs along Bijou Creek and the South Platte River bluff, as also noted by Scott (1978) for areas downstream. Unit about 6–10 m thick where exposed along river bluff, but could be as much as 18 m thick south of the river, around Bijou Creek (Gardner, 1967)

Qbw **Broadway Alluvium (late Pleistocene)**—Mapped as Broadway Alluvium by Gardner (1967) and lower member of Broadway Alluvium by Scott (1978). Underlies and interfingered to northwest with sidestream Broadway Alluvium (Qbs) from Kiowa and Bijou Creeks south of South Platte River. North of river, forms terrace approximately 12–15 m above active floodplain; terrace largely covered by eolian sand (Qes). Unit crops out poorly due to cohesionless nature of the sediment when dry. High potassium feldspar content gives unit a distinctive pinkish hue, particularly in exposures along South Platte River bluff (photo 2).

Alluvium pink, pinkish gray, or light reddish brown, moderately well- to poorly sorted, fine to coarse sand, pebbly sand, silty sand, and sandy granule to pebble gravel. Commonly cross-stratified. Locally has interbeds of pinkish gray to very pale brown silt and sandy silt, and grayish brown clay. Sand grains mostly subrounded. Gravel typically rounded to subrounded clasts of granite, gneiss, pegmatite, feldspar, quartz, chert, and sandstone. Largest clasts commonly 3–5 cm diameter, but cobbles and small boulders (up to approximately 32 cm in diameter) present locally. Accumulations of reddish-yellow to yellowish-red iron oxide and black manganese oxide as coats on grains and masses in matrix common, and in many places accentuate bedding. Surface soil profile typically has thin argillic B horizon with weak to moderate prismatic structure, and a thin Bk horizon with stage II carbonate morphology.

At a site about 10 km west of Orchard quadrangle (in adjacent Masters 7.5′ quadrangle), unit includes 70 cm thick section of crumbly clay, pinkish silt, platy silty fine sand, burrowed sandy silt with gray and yellowish green color banding, and one white silt with common small fragments and articulated bivalve shells. Hard dry consistence. Interpreted as quiet water deposits that may have been deposited at a time when the river was constantly ponded behind eolian flood deposits. Underlying sands brightly stained reddish yellow, yellowish red, or dark red due to iron oxide accumulation.

OSL age estimate (5 percent moisture) of 9.4±1.0 ka (UNL–3504, table 1) was obtained for mainstream Broadway Alluvium where it underlies Qbs at a locality about 0.8 km upstream of Kiowa Creek confluence (site TK–R). This age estimate is stratigraphically young and stratigraphically inconsistent with ages obtained for overlying Qbs (see discussion above), and therefore is not considered a realistic estimate for age of the sediment. Another OSL age estimate for mainstream Broadway Alluvium (Qbm) of 12.5±1.1 ka (UNL–3464, 5 percent moisture, table 1), collected downstream in the Weldona 7.5′ quadrangle (near section AK of Gardner, 1967) also is anomalously young and stratigraphically inconsistent with ages obtained for the overlying deposit (Qbs), and therefore also not considered a realistic estimate. Reasons for the anomalously young OSL age estimates are unknown but could be due to a number of factors associated with sampling and dating, or complications due to pedoturbation by burrowing animals. Results of a dose recovery test on UNL–3504 rule out most systematic problems with laboratory procedures and measurements.

Broadway Alluvium is considered coeval with the Pinedale glaciation (Bryan and Ray, 1940; Scott, 1954; Scott and Cobban, 1965; Madole, 1991), which spanned from ~31 ka to approximately 15–13 ka (Nelson and others, 1979; Madole, 1986; Schildgen and others, 2002; Benson and others, 2004, 2007; Licciardi and Pierce, 2008; Madole and others, 2010; Young and others, 2011). Fluvial sediment age estimates from Broadway Alluvium (Qbo) in Bijou Creek deglaciation (Church and Ryder, 1972; Madole, 1991; Schildgen and others, 2002; Lindsey and others, 2005), a presumed Bull Lake equivalent (Scott, 1978), and Piney Creek Alluvium of Gardner (1967) and Scott (1978). Some of the paleochannels, tens of meters deep, locally may contain glacial outwash (Scott, 1978). Surface soil developed on Broadway Alluvium (Qbs and Qbo). Terrace deposits on north side of South Platte River previously mapped as Louviers Alluvium by Gardner (1967) and mapped here as mainstream deposits of Broadway Alluvium (Qbs). Gardner (1967) similarly recognized Broadway Alluvium in Orchard quadrangle based on soil development and fossil evidence, but mapped them as Louviers Alluvium because he inferred the age of Louviers Alluvium to be only approximately 50–105 ka.

The Louviers Alluvium is considered coeval with the Bull Lake glaciation (Scott, 1975; Madole, 1991). However, if the Bull Lake glaciation is less well constrained than that of Pinedale, but ages that have been obtained for Bull Lake deposits suggest the glaciation spanned the interval approximately 190 to 130 ka (see discussions in Madole, 1991; Schildgen and others, 2002; Pierce, 2003; Sharp and others, 2003; Kelley and others, 2013; Licciardi and Pierce, 2008). Fluvial sediment load may have been greater during and shortly after deglaciation (Church and Ryder, 1972; Madole, 1991; Schildgen and others, 2002; Lindsey and others, 2005); therefore, some of the youngest alluvium may post-date the Bull Lake glaciation. Surface soil developed on Louviers Alluvium typically has a45 to 45 cm thick in paleochannels, but thickness is uncertain because unit is mostly buried by younger alluvium and eolian sand. Location and dimensions of ponds and river channels shown on this map are based on 2013 NAIP orthoimagery

Alluvium and colluvial deposits

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