INTRODUCTION

The Fort Morgan 7.5' quadrangle is located on the semiarid plains of northeastern Colorado,

along the South Platte River corridor where the river has incised into Upper Cretaceous Pierre

Shale. The Pierre Shale is largely covered by surficial deposits that formed from alluvial, eolian,

and hillslope processes operating in concert with environmental changes from the late Pliocene to

a major role in shaping surficial geology in the map area, which is several tens of kilometers

the present. The South Platte River, originating high in the Colorado Rocky Mountains, has played

downstream from where headwater tributaries join the river. Recurrent glaciation (and deglaciation)

of basin headwaters has affected river discharge and sediment supply far downstream, influencing

deposition of alluvium and river incision in the Fort Morgan quadrangle. Distribution and charac

teristics of the alluvial deposits indicate that during the Pleistocene the course of the river within

quadrangle (Bjorklund and Brown, 1957). The river shifted back to the north during the late

Pleistocene. Kiowa and Bijou Creeks (figs. 1 and 2) are unglaciated tributaries originating in the

geology of the map area. Periodically during the late Pleistocene, major flood events on these

tributaries deposited large volumes of sediment at and near their confluences, forming a broad,

Colorado Piedmont east of the Front Range that also have played a major role in shaping surficial

low-gradient fan composed of sidestream alluvium that could have occasionally dammed the river

for short periods of time (Scott, 1982). Wildcat Creek, also originating on the Colorado Piedmont,

and the small drainage of Cris Lee Draw dissect the map area north of the river (fig. 2). Eolian sand

deposits of the Sterling (north of river) and Fort Morgan (south of river) dune fields cover much of

the quadrangle and record past episodes of sand mobilization during times of prolonged drought

(fig. 2; Muhs and others, 1996). With the onset of irrigation and damming during historical times.

the South Platte River has changed from a broad, shallow, and sandy braided river with highly

variable seasonal discharge to a much narrower, deeper river with braided-meandering transition

morphology and more uniform discharge (Nadler and Schumm, 1981; Harvey and others, 1985).

METHODS

The geology of the Fort Morgan 7.5' quadrangle was previously mapped by M.E. Gardner

during the 1960s (Gardner, 1967). Gardner's map (1967) provided the foundation for the digital

methods, including field investigation, geochronologic research, and interpretation of the follow-

ing: National Agriculture Imagery Program (NAIP) orthoimagery (U.S. Department of Agriculture

[USDA] Farm Service Agency Aerial Photography Field Office, 2009, 2011, 2013, 2015); Quality-

level 2 lidar data (1-meter resolution) from the 2013 South Platte River Flood Area 1 lidar data set

satellite imagery viewed with Google Earth; Federal Emergency Management Agency (1989) flood

(NAPP) color-infrared (1988, 1:40,000 scale) and historical black and white (1948, 1:39,230 scale;

1949, 1:16,620 scale) aerial photographs; and subsurface lithologic data from test holes and water

wells (Bjorklund and Brown, 1957; Colorado Division of Water Resources, 2013). Field mapping

and research were carried out between 2011 and 2016. Digital mapping, completed in 2017 using

ArcMap software, was done on NAIP orthoimagery taken in 2015; location and dimensions of the

South Platte River and other water bodies shown on this map are based on the 2015 imagery. Much

of the area has been extensively farmed and cultivated for more than a century, and in many places

geomorphologic features are difficult to distinguish in orthoimagery or aerial photographs.

deposits, as well as sand dune crests and blowouts, and natural and artificial levees.

However, they are commonly evident in the lidar images even within areas traversed by central-

pivot irrigation equipment. The 1-meter resolution lidar data, available for roughly 75 percent of

the quadrangle, were used to enhance recognition and facilitate mapping of floodplain and terrace

and uranium-series (²³⁰Th/U) age determinations (tables 1–3, sheet 2; Berry and others, 2015a, b)

Sediment samples for OSL dating were processed and analyzed at the University of Nebraska-

Lincoln Luminescence Geochronology Laboratory using the single aliquot regenerative (SAR)

method (Murray and Wintle, 2000). Equivalent dose (D) was measured on a Risø DA-20 TL/OSL

reader and values were calculated using the central age model of Galbraith and others (1999). Dose

rates and age estimates were calculated using both field moisture of the sample and a fixed estimate

of 5 percent moisture (table 1, sheet 2; Berry and others, 2015a). Moisture content of some of the

samples collected in November, 2011 and April–May, 2012) may better represent moisture histor

of the samples for the purpose of calculating estimated ages from the dose rates. Radiocarbon ages,

including those obtained in this study (table 2, sheet 2, modified from Berry and others, 2015a) and

previously published ages cited from the literature, were calibrated using the IntCal13 dataset and

generated by other dating methods. Uranium-series age analyses were done at the U.S. Geological

Survey Denver radiogenic isotope laboratory (DRIL) using standard operating procedure "USGS-

DRIL-01, R0 Uranium-Thorium Disequilibrium Studies" summarized in Paces (2015). Details

about the samples analyzed and results obtained also are provided in Paces (2015). The ²³⁰Th/U

temporally to the minimum age of the depositional event.

may contain deposits of older alluvium.

35–45 m thick in the Fort Morgan quadrangle.

tions common along joints and as thin coats on clasts.

analyses provide constraints on the minimum ages of deposits from which samples were collected

(table 3, sheet 2; Berry and others, 2015b); the oldest ²³⁰Th/U ages are interpreted as being closest

SUBSURFACE ALLUVIAL DEPOSITS

LOUVIERS ALLUVIUM (Qlv)

map. It is composed of pebble-to-cobble gravel, sand, and finer grained alluvium filling paleovalle

located south of the modern South Platte River. Buried by younger alluvium (mostly Qba and

Qbs) but inferred from subsurface lithologic data from test holes and water wells in Fort Morgan

and adjacent quadrangles (Bjorklund and Brown, 1957; Colorado Division of Water Resources,

2013), and considered to be Louviers Alluvium by Gardner (1967) and Scott (1978). Locally, unit

The Louviers Alluvium is considered coeval with the Bull Lake glaciation (Scott, 1975;

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 from about 190 to ≤130 ka (see discussions in

Madole, 1991; see discussion of U-series ages for Louviers Alluvium in Szabo, 1980). Timing of

Madole, 1991; Schildgen and others, 2002; Pierce, 2003; Sharp and others, 2003; Kellogg and

others, 2008; Licciardi and Pierce, 2008; Schweinsberg and others, 2016). Fluvial sediment load

may have been greatest 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 by a few thousand years. Thickness is uncertain

because unit is mostly buried by younger deposits along the South Platte River corridor between

Greeley and the Colorado-Nebraska State Line (for example, see Colton, 1978; Scott, 1978), but

subsurface lithologic data from test holes and water wells (Bjorklund and Brown, 1957; Colorado

OLD ALLUVIUM (Qao)

This early Pleistocene unit also is within the subsurface of the study area and not shown on

map. Buried by eolian sand (Qes) but inferred from subsurface lithologic data from test holes and

water wells (Bjorklund and Brown, 1957; Colorado Division of Water Resources, 2013) that

indicate the presence of gravel deposits north of exposures of Verdos Alluvium and south of

exposures of Nussbaum Alluvium. Uppermost gravels estimated to be roughly 60–70 m above the

active floodplain, which supports a correlation with Rocky Flats Alluvium of Scott (1978, 1982).

Gardner (1967) also recognized the buried alluvium and considered it Rocky Flats Alluvium. In the

Masters 7.5' quadrangle (Berry and others, 2015b), old alluvium exposed in a quarry and interpret-

ed as Rocky Flats Alluvium (Gardner, 1967, p. 57) is light reddish or yellowish brown, moderately

to well cemented, poorly to moderately sorted, sandy pebble and cobble gravel, pebbly sand, sand,

and silty sand. Weakly to moderately stratified; sand beds commonly cross-stratified. Pebbles,

cobbles, and minor small boulders (up to 30 cm in diameter) generally rounded to well rounded.

Clasts mostly quartzite (including bluish-gray quartzite), gneiss, granite, pegmatite, and sandstone

Dense accumulations of red, yellowish-red, and reddish-yellow iron oxide and lesser amounts of

black manganese oxide prevalent in matrix, on grains, and along bedding planes. Secondary silica

may also be present based on the strength of cementation at that site. Calcium carbonate accumula-

Based on studies near the range front, Rocky Flats Alluvium has an estimated age of at least

1.6–1.4 million years (Ma) (Birkeland and others, 1996) or about 1.5 Ma (Dethier and others, 2001)

to about 2 Ma (Birkeland and others, 2003; Riihimaki and others, 2006; see discussion in Kellogs

and others, 2008), although cosmogenic radionuclide studies indicate a complicated history for

associated terrace surfaces, which may be much younger (Riihimaki and others, 2006; Dühnforth

and others, 2012; Foster and others, 2015, 2016). More locally, a fossil tooth (Stegomastodon

collected from a deposit approximately 60 m above the active floodplain and mapped as Rocky

Flats Alluvium by Scott (1978, 1982), was used by Scott (1982) to assign an early Pleistocene age

ACKNOWLEDGMENTS

elegans) from a site downstream from Fort Morgan (NW¼SW¼, sec. 7, T. 5 N., R. 55 W.),

to the deposit. Thickness is poorly constrained but locally could exceed 15–20 m.

Division of Water Resources, 2013) indicate that in buried paleochannels, unit could be up to

This middle Pleistocene unit is within the subsurface of the study area and not shown on this

CALIB 7.0 (Stuiver and Reimer, 1993; Reimer and others, 2013) for better comparison to ages

samples (collected in November, 2011) was very low and unlikely to approximate an average

condition; the fixed estimate of 5 percent (an intermediate value within the range of values for

Geologic mapping was aided by optically stimulated luminescence (OSL), radiocarbon (14C)

(U.S. Geological Survey, 2015); 7.5' topographic and 1/3 arc-second (10-meter resolution) digital

maps (1:19,200 approximate scale); stereoscopic pairs of National Aerial Photography Program

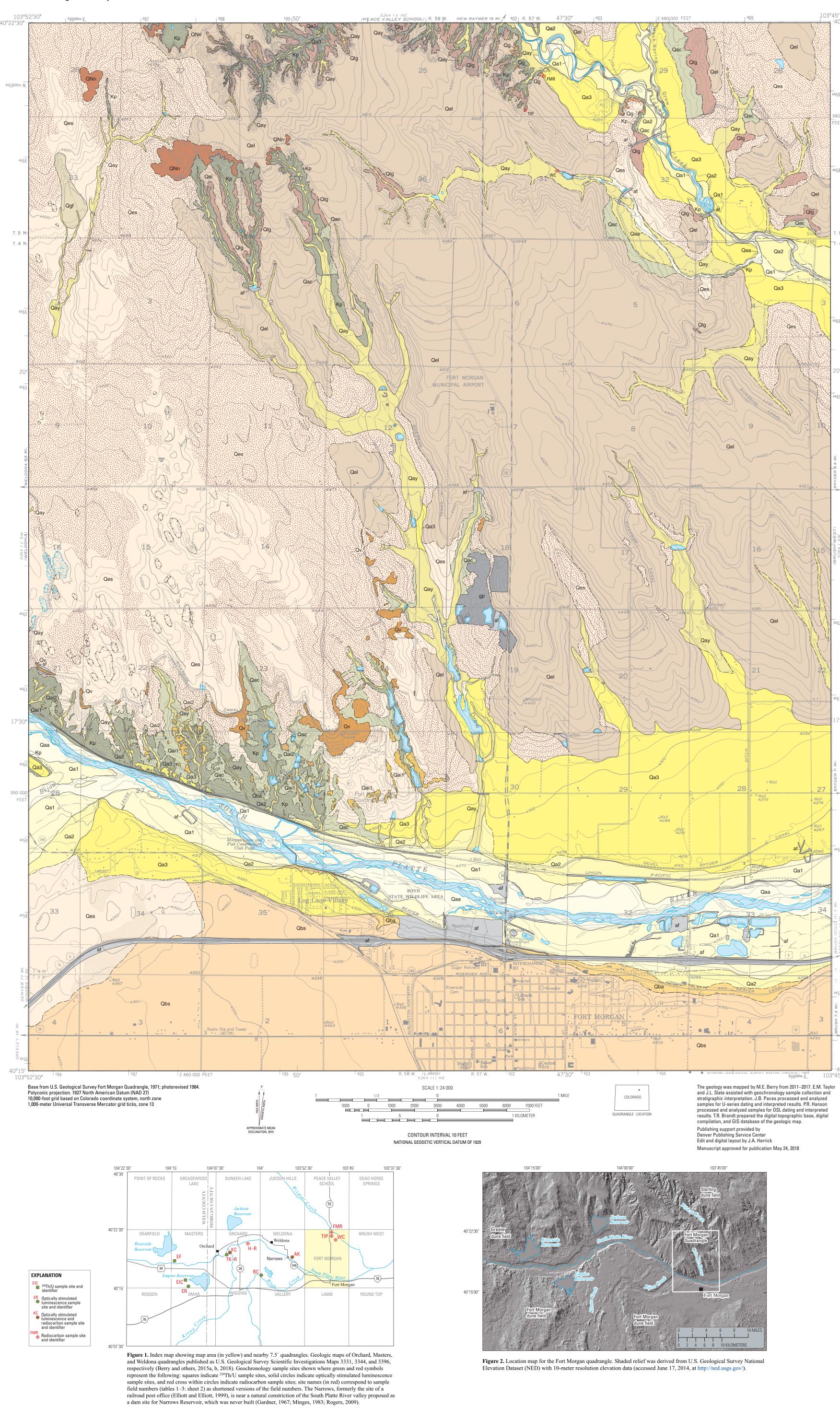
elevation data; digital soil survey data (USDA Natural Resources Conservation Service, 2009);

geologic map presented here. This new geologic map was completed using a combination of

the map area shifted progressively southward as it incised, and by late middle Pleistocene the river

was south of its present position, cutting and filling a deep paleochannel near the south edge of the





Geologic map of the Fort Morgan 7.5' quadrangle, Morgan County, Colorado

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CORRELATION OF MAP UNITS [The Louviers Alluvium (Qlv) and old alluvium (Qao) do not crop out in the study are but are present in the subsurface; for this reason, the units are blank but maintained for correlation purposes] SURFICIAL DEPOSITS Alluvial, colluvial. and grain-flow Eolian and alluvia Eolian deposits deposits BEDROCK UNIT

DESCRIPTION OF MAP UNITS

[Calibrated radiocarbon ages are expressed as "cal ka B.P.," which stands for calibrated thousand years before present (0 yr 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 calibration 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

Soil-horizon designations and other descriptive soil terminology used in this report follow criteria outlined in Soil Survey Division Staff (1993), Birkeland (1999), and Schoeneberger and others (2012). Most colors are field dry colors and based on Munsell soil color charts (Munsell Color, 1975). The term "consistence" is the resistance to crushing of soil or surficial material in the hand, as described by Soil Survey Division Staff (1993). Textures are field estimates. In descriptions of clast lithology, the term "granite" refers to phaneritic igneous or meta-igneous rock types that are felsic to intermediate in composition Geochronology sites are named by letters in their field numbers (tables 1–3, sheet 2), and correspond to letters shown in red on figure 1]

SURFICIAL DEPOSITS

ARTIFICIAL FILL Artificial fill and river control structures (latest Holocene)—Includes abutments where roadway crosses South Platte River, raised track of railroad, interstate roadbed, artificial levees and banks, metal river-control structures, small earther dams, and areas extensively modified by industrial activities. Artificial fill is present along most canals and ditches, but only mapped locally. Chiefly consists of gravel, sand, silt, rock and concrete fragments, and waste from sugar refinery ctive and reclaimed gravel pits (latest Holocene)—Chiefly consists of piles of gravel and sand in central part of map area. Pits reclaimed in places. Mapped as Verdos Alluvium by Gardner (1967), but alluvium so extensively mined since then that exposures of alluvium no longer exist and the landscape is almost entirely modified

ALLUVIAL DEPOSITS Qaa Active channel and floodplain alluvium (late Holocene)—Equivalent in part to post-Piney Creek alluvium of Scott (1963). Mapped along the South Platte River and its larger tributaries. In tributary drainages locally includes alluvium making up low terraces. South Platte River alluvium very pale brown, light brownish gray, light yellowish brown, or light pinkish brown. Mostly fine to coarse sand, pebbly sand, silty sand, and sandy pebble and minor small cobble gravel, interstratified with thin (<1–5 centimeters [cm]) layers or lenses of very pale brown silt and dark grayish brown, organic-rich clayey silt and clay. Poorly to well sorted, and weakly to moderately stratified. Sand beds commonly cross-stratified. Clasts mostly granite, gneiss, pegmatite, quartz, feldspar, and sandstone; most clasts subrounded to rounded. Locally, grains stained with reddish-yellow iron oxide and black manganese oxide at stream level. Uppermost 25–80 cm of sediment on floodplain typically light grayish brown, crudely stratified, poorly to moderately sorted sandy silt, silty clay, silty sand, and granule- to fine-pebbly sand. Less active parts of floodplain have weakly developed surface soil (A/C or A/AC/C profile). Krotovinas (filled animal burrows) are common locally. Unit contains minor amounts of detrital lignite eroded from bedrock (possibly Upper Cretaceous Laramie Formation; see Gardner, 1967) exposed along tributaries south and southwest of map area (Braddock and Cole, 1978; Sharps, 1980). Along Wildcat Creek, alluvium mostly light yellowish brown or pale yellow, moderately sorted sand, silt, and silty clay interstratified with minor beds or lenses of pinkish gray, poorly sorted pebbly sand; pebble rock types indicate many are reworked from South Platte River deposits. Estimated thickness 1–3 meters (m) along Wildcat Creek and 3–5 m along South Platte River

Young alluvium 1 (late Holocene)—Equivalent in part to post-Piney Creek alluvium of Scott (1963). Mapped along the South Platte River and its larger tributaries. Forms a low terrace that is occasionally flooded. Along South Platte River, terrace is generally 1.5 m above active floodplain. Parts of surface were within active floodplain in the 1960s (Gardner, 1967), but shifts in river course and addition of artificial levees have protected these areas from frequent flooding. Uppermost meter or more of sediment historical in age, at least locally, based on corroded metal debris embedded in stratified sands at one locale. Alluvium very pale brown, light brownish gray, light yellowish brown, or light pinkish brown, fine to coarse sand, pebbly sand, and sandy pebble and minor small-cobble gravel. Interstratified with thin (<1–5 cm) layers or lenses of very pale brown silt and dark grayish brown, organic-rich clavey silt and clav. Poorly to well sorted and 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 of the finer grained beds show evidence of soft sediment deformation. Clasts mostly granite, gneiss, quartz, feldspar, pegmatite, chert, and sandstone; most clasts subrounded to rounded. Uppermost sediment packet in alluvial sequence typically light grayish brown or pale brown, crudely stratified, poorly sorted sandy silt, silty sand, and granuleto fine-pebbly sand with lenses of silt and dark grayish brown clayey silt and clay. Unit contains minor amounts of lignite fragments. Surface soil typically poorly drained A/C or A/AC/C profile. Krotovinas are common locally. Along Wildcat Creek, alluvium mostly light yellowish brown or pale yellow, moderately sorted sand, silt, and silty clay interstratified with minor beds or lenses of pinkish gray, poorly sorted pebbly sand; pebble rock types indicate many are reworked from South Platte River deposits. Estimated thickness 1–3 m

along Wildcat Creek and 3–6 m along South Platte River Young sidestream alluvium, undivided (Holocene)—Mapped in tributary drainages and small draws north of the South Platte River; includes alluvium in channels. on floodplains, and forming low terraces 1–3 m above valley bottoms. Also includes reworked loess and eolian sand deposited by sheetwash processes to form flat-floored valleys between low-relief divides at the heads of small stream drainages; flat floor of valleys commonly incised up to 3–5 m by steep-walled gullies (arroyos). Unmapped Qay deposits also partly cover Qa3 terraces of Wildcat Creek but are not shown so that the underlying terrace is discernable. Alluvium commonly consists of pale yellow, pale brown, brown, light yellowish brown, or light brownish gray, sandy silt or silty sand with scattered granitic granules, pebbles, and lenses and stringers of poorly sorted pebbly silty sand. Pebble rock types indicate that most are reworked from South Platte River deposits. Weakly to moderately stratified. Loose to slightly hard dry consistence. Locally, alluvial sequence contains buried soils indicating episodic deposition. A radiocarbon (14C) age of 2.93±0.07 cal ka B.P. (Aeon-1580, table 2, sheet 2) for a buried A horizon at site WC provides a minimum-limiting age for alluvium in which the buried soil formed and a maximum-limiting age for the 80 cm of alluvium that overlies it; age indicates that deposition of Qay at site WC spanned at least the last 2.9 ka and probably longer. A bison tooth sampled at approximately 90 cm depth from a gully headwall at site TIP has a ¹⁴C age of about 0.13 cal ka B.P. (Aeon–1582, table 2, sheet 2), indicating that the upper meter of Qay filling the valley at this site could have been deposited since the early 1820s, and subsequently followed by as much as 5 m of gully incision. A very young age for uppermost meter of sediment at site TIP is supported by a lack of surface soil development at that site. Estimated thickness

Young alluvium 2 (late Holocene)—Equivalent in part to post-Piney Creek alluvium of Scott (1963). Mapped along the South Platte River and its larger tributaries. Forms a low terrace that is occasionally flooded in places and rarely flooded in others. Along the South Platte River, terrace is generally 3 m above active floodplain. Alluvium very pale brown, light brownish gray, light yellowish brown, or light pinkish brown, fine to coarse sand, pebbly sand, and sandy pebble and minor small cobble gravel. Interstratified with thin (<1–5 cm) layers or lenses of very pale brown silt and dark grayish brown, organic-rich clayey silt and clay. Poorly to well sorted and 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 evidence of soft sediment deformation. Clasts mostly granite, gneiss, quartz, feldspar, pegmatite, chert, and sandstone; most clasts subrounded to rounded. Uppermost sediment packet in alluvial sequence typically light grayish brown or pale brown, crudely stratified, poorly sorted sandy silt, silty sand, and granule- to fine-pebbly sand with lenses of silt and dark grayish brown clayey silt and clay. Surface soil variable, ranging from poorly drained A/C profiles to profiles with weakly developed textural B horizons (U.S. Department of Agriculture Natural Resources Conservation Service [USDA], 2009), Krotovinas are common locally. Unit contains minor amounts of lignite fragments. Along Wildcat Creek, alluvium mostly light yellowish brown or pale yellow, moderately sorted sand, silt, and silty clay interstratified with minor beds or lenses of pinkish gray, poorly sorted pebbly sand; pebble rock types indicate many are reworked from South Platte River deposits. Estimated thickness 1–3 m along Wildcat Creek and 3–6 m along South Platte River

Young alluvium 3 (Holocene and latest Pleistocene?)—Pinev Creek Alluvium of Gardner (1967) and Scott (1978). Forms terrace and low-gradient fans 8–12 m above active floodplain of South Platte River, and terrace 6–9 m above Wildcat Creek, Gardner (1967) and McFaul and others (1994) considered Qa3 terrace correlative to Kuner terrace of Bryan and Ray (1940), whose type locality is about 60 kilometers (km) west of Fort Morgan, Colorado, Includes sheetwash deposits and colluvium interbedded with terrace alluvium at valley sides. Locally, covered by unmapped deposits of Qay along Wildcat Creek. Alluvium pale vellow, light vellowish brown, light olive brown, or gravish brown. Poorly to well sorted, weakly to moderately stratified, fine sand, silt, clayey silt, pebbly sand, sandy pebble gravel, cobble gravel, and silt with coarse sand lenses and granule- to fine-pebble stringers; along Wildcat Creek alluvium mostly fined grained, thinly stratified sand, silt, and silty clay. Soft to slightly hard dry consistence. Clasts mostly granite, gneiss, pegmatite, quartzite, quartz, feldspar, chert, and sandstone; includes bluish-gray quartzite that probably originated from outcrops in Coal Creek Canyon (Lindsey and others, 2005), roughly 130 km southwest of map area. Most clasts subrounded to rounded. Locally, weakly developed buried soil separates deposits within alluvial sequence. Soil survey (USDA Natural Resources Conservation Service, 2009) shows surface soil as typically having thin argillic (Bt) horizon and weakly developed Bk horizon with stage I–II carbonate morphology. Radiocarbon (14C) and optically stimulated luminescence (OSL) age

tributary in adjacent Weldona quadrangle (site AK, near section AK of Gardner, 1967; fig. 1) indicate that basal alluvium was deposited in latest Pleistocene or early Holocene (tables 1 and 2, sheet 2; Berry and others, 2013; 2015a). Probable Succinea snail shells collected at depths of approximately 4.7 m and approximately 3.6 m yielded ¹⁴C ages of 11.90±0.28 cal ka B.P. (Aeon–994, table 2. sheet 2) and 11.95±0.24 cal ka B.P. (Aeon–995, table 2, sheet 2), respectively. Sediment collected at a depth of approximately 3.5 m, from a site about 10 m upstream from where the snail shells were collected, gave an OSL age estimate of 9.1±0.9 ka (UNL-3503, 5 percent moisture, table 1, sheet 2). 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 10.11±0.09 ¹⁴C ka B.P., AA-11084A) obtained by Haynes and others (1998) for humic acids in charcoal from Kuner terrace alluvium (of Bryan and Ray, 1940) at the Bernhardt site, roughly 80 km west of site AK. Timing of uppermost alluvium deposition and surface stabilization along the

South Platte River is constrained by a date from McFaul and others (1994) of 5.84±0.18 cal ka B.P. (5.12±0.08 ¹⁴C ka B.P., Beta–42564) for soil humate from a buried A horizon developed in Qa3 terrace alluvium at a site in the Masters 7.5' quadrangle. Degree of development of the buried soil indicates that the Qa3 surface may have been stabilized for a few thousand years prior to its burial at that site by eolian sediment about 5.8 cal ka (McFaul and others, 1994). Stabilization of the Qa3 surface by middle Holocene time is supported by degree of development of soils mapped on the South Platte Qa3 terrace surface by USDA Natural Resources Conservation Service (2009), and by a ¹⁴C age of 4.92±0.07 cal ka B.P. (Aeon–2101, table 2, sheet 2) for a buried A horizon developed in Qa3 terrace alluvium of Wildcat Creek (site FMR). Degree of development of the buried soil profile, which has a weakly developed Bt horizon roughly 35 cm thick and filamentous stage I carbonate accumulation, is consistent with several thousand years of soil development on the terrace surface prior to its burial at that site by episodic accumulation of sheetwash deposits (unmapped Qay) about 4.9 cal ka. Estimated thickness 2–6 m

informal Bijou Flats tongue of Broadway Alluvium by Gardner (1967) and upper

Sidestream deposits of Broadway Alluvium (late Pleistocene)—Mapped as

member of Broadway Alluvium by Scott (1978). Overlies and inferred to interfinger with mainstream deposits of Broadway Alluvium (Qba) south of South Platte River. Consists mainly of sheetflood deposits interpreted to have been deposited primarily by large-magnitude floods along Bijou and Kiowa Creeks (fig. 1; Gardner, 1967; Scott, 1978, 1982; Berry and others, 2015a, 2018). Deposits form a low-gradient fan that slopes roughly 3 m/km toward the South Platte River. Distribution of deposits suggests that influx 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). Accumulation of the sidestream alluvium built up the surface to a level that now stands approximately 21 m above the active floodplain in Masters 7.5' quadrangle (Berry and others, 2015b), 21–24 m above the active floodplain in Orchard 7.5' quadrangle (Berry and others, 2015a), and reaches a maximum height of approximately 27 m above the active floodplain in adjacent Weldona 7.5' quadrangle, near the Bijou Creek confluence (Berry and others, 2018). Here in Fort Morgan 7.5' quadrangle, height of surface decreases from approximately 22 m near Bijou Creek to 15 m at the east edge of the quadrangle. Deposits have been identified as far downstream as Prewitt Reservoir (roughly 35 km east) and Atwood, Colorado (roughly 50 km east) by Gardner (1967) and Scott (1978), respectively Alluvium light yellowish brown, light olive brown, pale yellow, or light

gray, poorly to well sorted, moderately stratified, coarse to very fine sand and

large effect. 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 lignite from the Laramie Formation, which crops out in Kiowa and

Bijou Creek drainage basins (Braddock and Cole, 1978; Sharps, 1980). The

dated sample (Aeon–950) also is suspected to contain lignite. Probable lignite

debris is common to abundant in other exposures of Qbs along Bijou Creek and

the South Platte River bluff, as also noted by Scott (1978). Estimated thickness

Alluvium by Scott (1978). Underlies and inferred to interfinger with sidestream

Broadway Alluvium (Qbs) from Kiowa and Bijou Creeks (fig. 1) south of South

Platte River. North of river, preserved only in a few isolated gravel lags roughly

15–18 m above active floodplain. Unit poorly exposed due to cohesionless

nature of the sediment when dry. High potassium feldspar content gives unit a

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 or laminations of dark grayish brown clay. Sand

grains mostly subrounded. Gravel typically rounded to subrounded clasts of

granite, gneiss, pegmatite, feldspar, quartz, chert, quartzite (including bluish-

of upper transition member Pierre Shale) present locally. Reddish-yellow to

yellowish-red iron oxide or black manganese oxide common as grain coatings

and a thin Bk horizon with stage II carbonate morphology.

vellowish red, or dark red due to iron oxide accumulation.

masses in matrix, and accumulations along bedding planes. Surface soil profile

typically has thin argillic (Bt) horizon with weak to moderate prismatic structure,

At a site in the Masters 7.5' quadrangle (Berry and others, 2015b), unit

includes an approximately 70-cm-thick section of (from top down) interbedded

crumbly clay, pinkish silt, platy silty fine sand, and burrowed sandy silt with

gray and yellowish green color banding and a few shell fragments, over thin

beds of white silt with small articulated clam shells, common shell fragments,

and a hard dry consistence. Interpreted as quiet-water deposits that may have

flood deposits (Qbs). Underlying sands brightly stained reddish yellow,

been deposited at a time when the river was temporarily dammed by sidestream

An OSL age estimate for mainstream Broadway Alluvium (8.0±0.7 ka,

UNL–3502, 5 percent moisture, table 1, sheet 2; Berry and others, 2015a) was

section AK of Gardner, 1967) at a depth of approximately 5.1 m, just below its

contact with young alluvium 3 (Qa3). This age estimate is anomalously younger

than and stratigraphically inconsistent with basal ages obtained for the overlying

Qa3 deposit (see previous discussion), and therefore not considered a realistic

(UNL-3504, 5 percent moisture, table 1, sheet 2; Berry and others, 2015a) was

obtained for mainstream Broadway Alluvium where it underlies approximately

7 m of Qbs at a locality about 0.8 km upstream from Kiowa Creek confluence

(site TK–R, fig. 1, Orchard 7.5' quadrangle). This age estimate is anomalously

younger than and stratigraphically inconsistent with ages obtained from samples

considered a realistic estimate for age of the sediment. Reasons for the anoma-

lously young OSL age estimates are unknown, but could be due to a number of

factors associated with sampling and dating, or exposure of sediment to sunlight

by burrowing animals. Results of a dose recovery test performed on UNL-3504,

Uranium-series age analysis of a bone fragment (possibly bison-horn core)

however, rule out most systematic problems with luminescence behavior of

analyzed for overlying Qbs (see discussion above), and therefore also not

estimate for age of the sediment. Another OSL age estimate of 9.4±1.0 ka

obtained for sediment collected at site AK (fig. 1, Weldona quadrangle; near

gray quartzite), and sandstone. Largest clasts commonly 3–5 cm in diameter, but

cobbles and rare small boulders (up to 32 cm in diameter for sandstone boulders

Alluvium is pink, pinkish gray, or light reddish brown, moderately well- to

Mainstream deposits of Broadway Alluvium (late Pleistocene)—Mapped as

Broadway Alluvium by Gardner (1967) and lower member of Broadway

18-20 m thinning to 6-9 m near east edge of quadrangle

distinctive pinkish hue

these dated sediments.

silty sand in beds generally 20–60 cm thick. Sand beds commonly separated by thin (1–5 millimeters [mm]) mats of organic debris and clay, or packets (5–10 cm thick) of thinly laminated dark-grayish brown or black organic-rich clay interbedded with layers of pale yellow or light gray silt and fine sand. Contains abundant detrital lignite that Gardner (1967) and Scott (1978) attribute to Upper also contain some pedogenic silica. Cretaceous Laramie Formation (see text below). Graded beds that fine upward from poorly sorted coarse sand and granules to mostly fine sand are common, as well as sand beds that are cross-stratified, finely laminated, crudely stratified, or massive. Sand grains and granules mostly subangular to subrounded, and are mostly composed of quartz and feldspar. Few scattered small pebbles of tuff, shale, and granitic rocks. Soft to hard dry consistence. Iron oxide nodules, masses, or pore linings present locally, particularly in sandy clay layers. Typically forms vertical exposures, especially along South Platte River bluff and quadrangle. Estimated thickness of alluvium 6–10 m Bijou Creek drainage (Berry and others, 2015a; 2018). Contact with mainstream Qao Old alluvium (early Pleistocene)—Subsurface unit not shown on map. See Subsuralluvium typically sharp, most notably marked by difference in color and dry face Alluvial Deposits section for description consistence attributable to differences in provenance. Soil profile characterized by thin argillic (Bt) horizon with moderate prismatic structure, and Bk horizon with stage II filamentous carbonate morphology. Soil profile buried by younger OSL and ¹⁴C age estimates indicate a late Pleistocene age for Qbs (Berry and others, 2015a). A dated section at the mouth of Kiowa Creek (site KC, in Orchard 7.5' quadrangle; fig. 1) 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-3466) at approximately 2.6 m depth, and 15.2±1.5 ka (UNL-3463) at approximately 3.6 m depth (table 1, sheet 2). These age estimates are in good agreement with a ¹⁴C age of 14.53±0.56 cal ka B.P. (Aeon–1064, table 2, sheet 2) obtained for probable Succinea snail shells collected at a depth of approximately 3.7 m from a section of Qbs exposed in the South Platte River bluff about 4.8 km downstream from Kiowa Creek (site H-R, in Orchard 7.5' quadrangle, at section H of Gardner, 1967; fig. 1). The ages also are in good agreement with OSL age estimates (5 percent moisture) for a section exposed in the north stage III+ carbonate horizon present locally. cutbank of Bijou Creek (site BC, in Weldona 7.5' quadrangle about 13.5 km upstream from the river confluence; fig. 1): 12.4±1.1 ka (UNL-3498) sampled at approximately 1.1 m depth; and 14.6±1.2 ka (UNL-3499) sampled at approximately 1.9 m depth (table 1, sheet 2). Organic material collected from a thin (2-5 mm) interbed of organic debris R. 56 W.). He used the fossil evidence and geomorphic position to correlate and clay at approximately 2.5 m depth, just above OSL sediment sample Nussbaum Alluvium with the Broadwater Formation of western Nebraska, and UNL-3466 (site KC), yielded a ¹⁴C age estimate of 43.90±5.69 cal ka B.P. fossil evidence to show equivalence between the Broadwater Formation and the (Aeon–950, table 2, sheet 2). This is likely an infinite age, meaning the sample is probably too old to date by the ¹⁴C method; the age is at the practical upper limit

> ALLUVIAL, COLUVIAL, AND GRAIN-FLOW DEPOSITS **Grain-flow deposits (late Holocene)**—Mapped in northwest corner of quadrangle. Mostly made up of eolian sand that has flowed downslope by mass wasting processes. Demarcated by arcuate headscarp and lobate toe. Vegetated by shortgrass prairie (Chapman and others, 2006). Pale brown, brown, or yellowish brown, moderately to well sorted, mostly very fine to medium sand. Estimated

thickness up to 3 m or more at toe

Alluvial and colluvial deposits (Holocene to middle? Pleistocene)—Mapped north of river mostly in areas where alluvial and colluvial deposits mantle hillslopes underlain by Pierre Shale (Kp). Largely deposited by overland flow and creep processes. Made up of reworked residuum from weathered bedrock mixed with sediments derived from river and eolian deposits higher on hillslopes. Locally includes areas where weathered residuum has not been reworked, and outcrops of Pierre Shale too small to map separately. Very pale brown, light yellowish brown, or light olive brown. Crudely stratified and poorly sorted. Mostly clayey silty sand or sandy clayey silt, with scattered, subrounded to rounded pebbles and cobbles of river alluvium and angular to subangular fragments of sandstone from

the Pierre Shale. Deposits typically calcareous. Estimated thickness up to 3 m

EOLIAN DEPOSITS Qes Eolian sand (Holocene and late Pleistocene)—Forms simple and compound parabolic dunes and low-relief sand sheets. Blowouts common within dune fields. Pale brown, brown, or yellowish brown, moderately to well sorted, mostly fine to medium sand. Locally contains minor amounts of coarse to very coarse sand and a few scattered, subangular to rounded granules and small pebbles composed mostly of granitic and gneissic rock types. Loose to slightly hard dry consistence. Sand deposits of more than one age commonly separated by one or more buried soils. Locally includes sheetwash deposits of reworked eolian sand, and marsh or pond deposits in interdune and other low-lying wetland areas. Deposits of Qes may be more extensive than mapped due to the difficulty in distinguishing thin eolian sand cover from sandy terrace alluvium in a region that has been farmed and cultivated for more than a century. Unstippled parts of **Qes** are shown in county soil survey as having mostly Valent, Valentine-Dwyer, and Dwyer soils, characterized by weakly developed A/C or A/AC/C soil profiles (USDA Natural Resources Conservation Service, 2009), typical of relatively young (late and middle Holocene) eolian sand deposits (Madole, 1995; Muhs and others, 1996; Madole and others, 2005). In the northern part of quadrangle, unstippled parts also include large areas of Vona-Dwyer soils that probably reflect both Holocene and late Pleistocene sand deposits in a distribution pattern too complex to map separately. Light stippled parts of Qes, located south of the South Platte River, are shown in county soil survey as having mostly Bijou and Truckton soils, characterized by argillic (Bt) horizon development in sandy, mostly alluvial soil parent material (USDA Natural Resources Conservation Service, 2009). Field investigation revealed argillic horizon to be part of a buried soil developed in the

underlying stream and sheetflood alluvium and later covered by a veneer of younger eolian sand. Therefore, as in unstippled areas, eolian sand deposits in light stippled areas probably are Holocene in age, but generally thin (<1 m), such that underlying buried soil controls soil classification and series designation. Dark stippled parts of Qes, located north of the South Platte River, are shown in county soil survey as having mostly Vona and Ascalon soils, characterized by A/Bt/Bk (stage I–II carbonate morphology) soil profiles developed in eolian sand (USDA Natural Resources Conservation Service, 2009). These soil profiles are typical of late Pleistocene eolian sand deposits (Madole, 1995; Muhs and others, 1996; Madole and others, 2005). Locally includes sand deposits of Holocene age that are too small to map separately Widespread deposition of eolian sand during the late Holocene is indicated

Berry and others, 2015b). The oldest ages are for two interior-most subsamples that produced apparent closed-system ²³⁰Th/U ages within analytical uncertainty of one another (Wp67–5 and Wp67–7, table 3, sheet 2; see fig. 1-1 in Paces, 2015). The error-weighted average value of these two oldest ages, 15.24±0.06 ka, may most closely estimate the minimum age of the deposit that contained the bone However, because data for the specimen indicate a complex history of uranium uptake and subsequent leaching (see discussion in Paces, 2015), data for additional specimens are needed to better constrain the minimum age of the deposit. Broadway Alluvium is considered coeval with the Pinedale glaciation (Bryan and Ray, 1940; Hunt, 1954; Scott, 1960, 1975; Madole, 1991), which spanned from >31 ka to about 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; Schweinsberg and others, 2016). Fluvial sediment load may have been greatest during and shortly after deglaciation (Church and Ryder, 1972; Madole, 1991; Schildgen and others, 2002; Lindsey and others, 2005), a process that started either about 17 ka (Licciardi and others, 2004; Benson and others, 2005; Schaefer and others, 2006) or about 16-15 ka (Young and others, 2011), and largely was completed between about 15 and 13 ka (Benson and others, 2007; Young and others, 2011; and references therein). Correspondingly, Clovis artifacts present in upper part of terrace alluvium near Kersey, Colo. (roughly 66 km west of Fort Morgan, Colo.), combined with other archaeological data, indicate that aggradation of Broadway Alluvium was still in progress between about 13.3 and 12.9 cal ka (11.5–11 ¹⁴C ka) but completed and the surface stabilized by about 11.5 cal ka (10 ¹⁴C ka) at the latest (Holliday, 1987). A ²³⁰Th/U age of 11.0±1.1 ka (Wp67–1, table 3, sheet 2; Berry and others, 2015b) for pedogenic carbonate coating the outer edge of bone fragment encased in uppermost Broadway Alluvium at site EF (fig. 1, Masters 7.5' quadrangle) further supports surface stabilization and the onset of soil formation sometime prior to 11 ka. Estimated thickness 12 m to as much as 30 m south of South Platte River; 1–1.5 m in gravel lags north of river

Louviers Alluvium (middle Pleistocene)—Subsurface unit not shown on map. See Subsurface Alluvial Deposits section for description Intermediate alluvium (middle Pleistocene)—Poorly preserved deposits of pebble and cobble gravel, pebbly sand, and silty sand in terrace remnants and gravel lags mapped along the north side of the South Platte River and in sidestreams west of Cris Lee Draw; either extensively eroded (westernmost part of quadrangle) or mostly buried by eolian deposits (near Cris Lee Draw). Mapped as Slocum Alluvium by Gardner (1967), but here recognized at two discrete levels and mapped as Qai1 and Qai2 (as in adjacent Weldona 7.5' quadrangle downstream from the Narrows; fig. 1; Berry and others, 2018). Alluvium very pale brown, light yellowish brown, or light reddish brown. Pebbles and cobbles mostly quartzite (including bluish-gray quartzite), gneiss, granite, pegmatite, vein quartz, sandstone, volcanic clasts, and chert; subrounded to well rounded; diameter of largest clasts commonly 13-16 cm but ranges up to 36 cm for sandstone boulders of upper transition member Pierre Shale (Kp). Some granitic clasts are weathered (partly disintegrated). Thin coats (rinds) of calcium carbonate on clasts common. Where soil profile partially preserved includes carbonate horizons with stage III morphology. Probably correlative at least in part to intermediate alluvium (Qai) in Masters 7.5' quadrangle, which has been dated using the uranium-series method (Paces, 2015). Uranium-series age analysis was done on innermost pedogenic

calcium carbonate rinds, subsampled from multiple clasts collected at approximately 100–120 cm depth from Qai alluvium exposed beneath eolian sand in a ditch at site EIC (fig. 1, Masters 7.5' quadrangle). The analysis produced reliable results and oldest ²³⁰Th/U ages that primarily cluster in two groups, one (Wp95–A1–2, Wp95–A2–1, Wp95–B1, and Wp95–B2, table 3, sheet 2) with an error-weighted-mean age of 334±9 ka and the other (Wp95–B3 and Wp95–E1, table 3, sheet 2) with an error-weighted-mean age of 382±16 ka (see fig. 1–7 in Paces, 2015). Age difference between clusters probably reflects difference in timing of calcium carbonate accumulation within the soil. Because method dates Loess (Holocene and late Pleistocene)—Mapped as Peorian and Bignell Loesses by a product of soil development, oldest ²³⁰Th/U ages are considered closest temporally to minimum age of deposit in which the soil formed. These data indicate with a high degree of confidence that the alluvial clasts at EIC were deposited prior to about 334 ka; based on the two oldest ages, the best estimate for the minimum age of the deposit is somewhat older than 382 ka. These results support correlating Qai at site EIC with older deposits of Slocum Alluvium of Kellogg and others (2008), who recognized two levels locally along the Front Range and proposed an age range of 390–320 ka for the higher (older) deposits based on correlation with marine oxygen isotope stages and nonlinear rates of incision. However, more data are needed to substantiate the age of Slocum Alluvium and to establish its relation to Qai deposits along this part of the South Platte River corridor. More data also are needed to determine how Qai deposits at site EIC correspond to Qai1 and Qai2 deposits in Fort Morgan and adjacent Weldona quadrangles. Alluvium at site EIC is inferred to be part of a terrace remnant roughly 24 m above the modern floodplain, but the terrace is everywhere buried or not preserved in Masters and Orchard quadrangles (fig. 1), so it cannot be traced downstream. A height of 24 m would suggest correspondence with Qai1 terrace deposits, but some data indicate that at times in the past the

others, 2018). Therefore, it is conceivable that alluvium at site EIC corresponds to Qai2 terrace deposits instead Intermediate alluvium 1 (middle Pleistocene)—Remnant gravel deposits roughly 21–25 m above South Platte River floodplain. More extensively preserved than Qai2 (in contrast to relation in adjacent Weldona 7.5' quadrangle; Berry and others, 2018). Includes sidestream terrace alluvium that grades to mainstream terrace alluvium; rock types in sidestream alluvium indicate clasts are mostly reworked from South Platte River deposits. Thickness commonly less than 1–1.5 m but could be as much as 4–12 m based on borehole data (Colorado Division of Water Resources, 2013)

gradient of the ancestral South Platte River was more gentle than that of the

modern river through the reach between Masters and Fort Morgan (Berry and

Intermediate alluvium 2 (middle Pleistocene)—Small, poorly preserved remnant gravel deposits roughly 32–40 m above South Platte River floodplain. Estimated thickness generally 1.5 m or less Verdos Alluvium (middle Pleistocene)—Also mapped as Verdos Alluvium by Gardner (1967) and Scott (1978). Forms terrace remnants roughly 49–55 m above the South Platte River floodplain. Extensively mined for gravel and sand; some areas previously mapped as Verdos Alluvium by Gardner (1967) and Scott (1978) are now reclaimed gravel pits (gp). Alluvium largely covered by eolian sand (Qes) but locally exposed along canals and well-exposed in gravel pit in adjacent Brush West 7.5' quadrangle (sec. 1, T. 4 N., R. 57 W.; photo 1, sheet 2). Alluvium very pale brown, yellowish brown, light reddish brown, or pinkish gray, poorly to moderately well sorted, pebble and cobble gravel, pebbly sand, sand, and silt. Sand and gravel commonly cross-bedded. Accumulations of yellowish-red and reddish-yellow iron oxide and black manganese oxide common in matrix, on grains, and along bedding planes. Pebbles and cobbles mostly quartzite (including bluish-gray quartzite), gneiss, granite, pegmatite, sandstone, chert, volcanic clasts, and petrified wood. Diameter of largest clasts commonly 14-20 cm. Most clasts subrounded to well rounded. Some clasts weathered (broken along foliation planes or beginning to disintegrate). Eroded soil profile includes 1-m-thick, variably cemented K horizon with stage III-IV carbonate morphology. Carbonate coats (rinds) on clasts up to 1 cm thick. May Age of Verdos Alluvium is constrained by its association with the Lava Creek B ash (Scott, 1960; Madole, 1991; Kellogg and others, 2008; and references therein), erupted from the Yellowstone Plateau volcanic field about 640 ka (Lanphere and others, 2002). Beds of Lava Creek B ash in Verdos Alluvium have been documented at several sites along the South Platte River corridor northeast of Fort Morgan 7.5' quadrangle (see Scott, 1978, 1982; Izett and Wilcox, 1982), although no ash deposits have been identified within the

Nussbaum Alluvium (early Pleistocene? and Pliocene)—Old alluvial deposits mapped as Nussbaum Alluvium by Gardner (1967) and Scott (1978, 1982). Preserved in remnants roughly 122–137 m above active floodplain. Light reddish or yellowish brown, light brown, or pinkish gray, variably cemented, poorly to that overlie it (Qel, Qes, or Qay). moderately sorted, pebble and cobble gravel, pebbly sand, sand, and sandy silt. Moderately to well stratified; sand and pebbly sand beds commonly crossstratified. Pebbles and cobbles mostly rounded to well rounded. Many cobbles 13–18 cm in diameter. Clasts mostly granite, pegmatite, and quartzite, with lesser amounts of gneiss, volcanic porphyry, chert, and petrified wood. High potassium feldspar content of sand and granules imparts pinkish hue to deposits. Beds weakly to moderately, and locally strongly, cemented by calcium carbonate (photo 2, sheet 2). Basal 1–3 m of alluvium commonly cemented into an colluvium. Estimated thickness at least 4 m indurated conglomerate or conglomeratic sandstone that unconformably overlies Pierre Shale. Secondary silica may also be present based on the strength of cementation. Truncated soil with 15–20 cm of reddish brown Bt horizon over Scott (1982) considered Nussbaum Alluvium to be about 3 Ma (Pliocene) based on its geomorphic position, fossils remains, and inferred ages of Stegomastodon fossils collected from the alluvium at sites northeast of Fort Morgan (NE¹/₄SE¹/₄, sec. 12, T. 7 N., R. 55 W. and NW¹/₄NE¹/₄, sec. 2, T. 5 N.,

Blanco Formation of Texas (Scott, 1982; Madole, 1991), which has an age of late many clasts have thin, patchy coats of calcium carbonate. Estimated thickness 1.5 m or less Bell and others, 2004). Scott's correlations, combined with the age range for Stegomastodon (Pliocene and early Pleistocene, see Bell and others, 2004), leave BEDROCK UNIT open the possibility that the age range of Nussbaum Alluvium likewise extends into the early Pleistocene. Thickness 7–12 m to as much as 21 m (Scott, 1982) Pierre Shale (Upper Cretaceous)—Upper transition member of Pierre Shale

mapped separately. Outcrops are light gray, fine-grained sandstone and shaly sandstone weathering to yellowish brown or light olive brown, and dark gray silty shale weathering to olive gray. Selenite (gypsum) crystals are common. Also contains concretionary limestone layers up to one meter thick. In northeastern Colorado, upper transition member of Pierre Shale is reported to contain diagnostic ammonites Sphenodiscus (Coahuilites) sp. and Baculites clinolobatus (Scott, 1978). Thickness of Pierre Shale about 1,800 m in map area (Gardner,

EXPLANATION OF MAP SYMBOLS

Contact—Dashed where approximately located

Blowout rim within dune field

Qes Light stipple—Areas where eolian sand (Qes) is likely Holocene in age (as in unstippled areas) but where sand deposits could be thin Qes Dark stipple—Areas where eolian sand (Qes) may be late Pleistocene in age

Intermittent wetlands and ponds—Low-lying areas prone to wetness and ponding within eolian sand deposits (Qes) Water—Includes water in natural and artificial ponds, and river and stream channels wide enough to be mapped at 1:24,000 scale

Radiocarbon (14C) sample location—With site name that links to sample field number (table 2, sheet 2)

DIVISION OF QUATERNARY TIME USED IN THIS REPORT¹

	Period	Epoch	Age	
Q		Holocene ²	late	0–4.2 ka
			middle	4.2–8.2 ka
	Quaternary		early	8.2 ka–11.7 ka
		Pleistocene	late	11.7–126 ka
			middle	126–781 ka
			early ³	781 ka–2.58 M
	¹ Ages for time divisions a Cohen and others (2013; ² Subdivisions of Holocen ³ Calabrian and Gelasian A	updated). Ma, million ye e are informal divisions a	ears; ka, thousand years	

(2005) for buried soils that provide maximum-limiting ages for uppermost sand deposits in adjacent or nearby quadrangles: 0.64±0.11 cal ka B.P. (0.68±0.08 ¹⁴C ka B.P., Beta-70542) near Bijou No. 2 Reservoir in Weldona 7.5' quadrangle; 1.14±0.16 cal ka B.P. (1.23±0.08 ¹⁴C ka B.P., Beta-70543) at Milliron Draw in Orchard 7.5' quadrangle; 0.88±0.21 cal ka B.P. (0.96±0.11 ¹⁴C ka B.P., Beta-84821) at south edge of Orchard 7.5' quadrangle near Bijou Creek; and 0.82±0.16 cal ka B.P. (0.89±0.10 ¹⁴C ka B.P., Beta–62192) in Greasewood Lake 7.5' quadrangle. Radiocarbon ages for soil carbonate rhizoliths collected from a quarry exposure north of Orchard, Colo., are in good agreement, indicating a maximum-limiting age for uppermost eolian sand of about 1.44±0.13 cal ka B.P. (1.56±0.07 ¹⁴C ka B.P., CAMS–8234, Muhs and others, 1996). Ages from elsewhere in the region also support widespread deposition of eolian sand during the late Holocene (Clarke and Rendell, 2003, and references cited therein). Eolian sand deposits of probable middle Holocene age are locally exposed, mostly underlying late Holocene sand deposits. At a site near Empire Reservoir (site ER, Masters 7.5' quadrangle, fig. 1), approximately 1 m below the surface, a middle Holocene sand deposit covered by a thin veneer of late Holocene sand has an OSL age estimate of 7.7±0.8 ka (UNL-3468, 5 percent moisture, table 1, sheet 2; Berry and others, 2015a, b). At Milliron Draw, Orchard 7.5' quadrangle, the age of a buried sand deposit is constrained by ages on buried soils that provide a maximum-limiting age of approximately 6.33±0.16 cal ka B.P. (5.51±0.09 ¹⁴C ka B.P., Beta–72203) and a minimum-limiting age of approximately 1.14±0.16 cal ka B.P. (1.23±0.08 ¹⁴C ka B.P., Beta-70543) for the deposit (Madole, 1995; Madole and others, 2005). Radiocarbon ages for soil carbonate rhizoliths collected from a quarry exposure north of Orchard, Colo., suggest a minimum-limiting age for buried eolian sand of approximately 3.90±0.20 cal ka B.P. (3.60±0.07 ¹⁴C ka B.P., CAMS–6378, Muhs and others, 1996) at that site. Episodes of eolian sand deposition during the middle Holocene are also documented at other sites within the region (Clarke and Rendell, 2003, and

references cited therein). Sand deposits of probable late Pleistocene age (marked by dark stipple) are extensive north of the South Platte River in the Fort Morgan 7.5' quadrangle, as well as regionally (Muhs and others, 1996; Madole and others, 2005). At site ER (fig. 1, Masters 7.5' quadrangle), a deposit of late Pleistocene sand has an OSL age estimate of 26.4±2.5 ka at 0.7 m depth (UNL-3467, 5 percent moisture, table 1, sheet 2; Berry and others, 2015a, b). This age is in good agreement with radiocarbon ages Muhs and others (1996) obtained for soil carbonate nodules from an underlying buried soil at a site about 2 km north of site ER that provide maximum-limiting ages for the overlying sand of 31.21±0.23 cal ka B.P. (27.30±0.17 ¹⁴C ka B.P., CAMS–11339), 31.36±0.48 cal ka B.P. (27.42±0.30 ¹⁴C ka B.P., CAMS-16612), and 30.58±0.51 cal ka B.P. (26.41±0.24 ¹⁴C ka B.P., CAMS-16604). Eolian sand deposition during the late Pleistocene likely was intermittent, and may have resulted in late Pleistocene deposits of various ages in the region; some may be as young as 12 or 13 ka (Madole and others, 2005). Eolian sands south of the South Platte River are part of a series of dune fields that make up the Fort Morgan dune field (fig. 2). Main sources of sand in the Fort Morgan dune field could include South Platte River sediments (Muhs and others, 1996; Aleinikoff and Muhs, 2010; Muhs, 2017) and the Tertiary Ogallala Formation (Muhs, 2017). North of the river, eolian sands are considered part of the Sterling dune field (Muhs and others, 1996). Sand source for the Sterling dune field has not been studied but could be similar to that for the adjacent Greeley dune field (fig. 2); likely sand sources for the latter are the Laramie Formation (Muhs and others, 1996; Aleinikoff and Muhs, 2010; Muhs, 2017) and the Ogallala Formation (Muhs, 2017). Dune orientation in Fort Morgan quadrangle is generally consistent with regional trends reported by Muhs (1985) and Muhs and others (1996), and indicates sand-transporting winds primarily from the northwest (Muhs and others, 1996; Madole and others, 2005).

reworked by sheetwash and creep processes. Very pale brown, pale brown, or light vellowish brown, moderately to well sorted, with a soft to slightly hard dry consistence. Deposits are mostly massive but locally contain stringers and thin lenses of medium and coarse sand. Surface soil variable; ranges from weakly developed A/C or A/Bk/C profile to A/Bt/Bk/C profile with stage I or II carbonate morphology (USDA Natural Resources Conservation Service, 2009). Aleinikoff and others (1999) and Muhs and others (1999a) identify sources for loess in northeastern Colorado as glaciogenic silt produced by valley glaciation in the mountains and dryland dust eroded from bedrock (primarily from Eocene-Oligocene White River Group with lesser amounts from Upper Cretaceous Pierre Shale). In the Fort Morgan 7.5' quadrangle, Qel covers much of the uplands north of the South Platte River from Cris Lee Draw east, but in regional perspective these deposits constitute an isolated area of loess aligned in a NW-SE distribution pattern generally centered around a similarly oriented Wildcat Creek drainage (Scott, 1978). This distribution pattern lends support to dryland dust sources northwest of the quadrangle being particularly important here (for example, see Mason, 2001); the White River Group crops out in a broad band north of Fort Morgan quadrangle (see fig. 2 in Muhs and others, 1999a, and

references therein), and the upper transition member of Pierre Shale crops out

Currently, dunes are mostly stabilized by short grass prairie vegetation (Chapman

and others, 2006). Thickness up to 10 m; thins to less than half a meter locally

Gardner (1967) and Peoria Loess by Scott (1978). Mostly wind-blown calcare-

ous, very fine sandy coarse silt, coarse silty very fine sand, and silt. Locally

extensively within Wildcat Creek drainage upstream (NW) from the loess deposits (Scott, 1978). Age estimates obtained for loess elsewhere in northeastern Colorado (Forman and others, 1995; Muhs and others, 1999a; Mahan and others, 2009; Pigati and others, 2013) support a correlation to late Pleistocene Peoria Loess. deposited at a time corresponding to Pinedale glaciation in the headwaters and deposition of Broadway Alluvium downstream in the South Platte River valley (see description for Qba). Locally, uppermost parts of Qel probably are Holocene in age (Madole, 1991), and therefore probably correlative to Bignell Loess, which has been noted in adjacent Peace Valley School 7.5' quadrangle (Gardner, 1967) and elsewhere in northeastern Colorado and Nebraska, where it is separated from Peoria Loess by the Brady Soil (see discussions in Muhs and others, 1999b; 2008; Bettis and others, 2003; Pigati and others, 2013). Deposition of Bignell Loess is thought to have started about 10.5–9 cal ka and continued episodically throughout the Holocene (Mason and others, 2003, 2008; Miao and others, 2007). No buried soils were observed within exposed sections of Qel in the Fort Morgan quadrangle that would allow differentiation of late Pleistocene and Holocene loess units, however, exposures are few, distribution of Bignell Loess is known to be patchy (Muhs and others, 1999b; Bettis and others, 2003), and locally its accumulation may have been small enough and slow meter locally

enough to be incorporated into the surface soil rather than form a discrete deposit (see Mason, 2001). Thickness for Qel up to 6–9 m, but thins to less than half a EOLIAN AND ALLUVIAL DEPOSITS Qlg Eolian and alluvial deposits, undivided (middle Pleistocene)—Loess and eolian sand partly reworked by sheetwash processes, grading downward into gravelly alluvial deposits that are probably correlative in part to Qg. Corresponds to map unit Gardner (1967) described similarly but interpreted as Loveland Loess grading downward into gravelly deposits he equated to Slocum Alluvium. Only tentatively correlated to Loveland Loess by Scott (1978). Mapped in Wildcat Creek drainage and in the headwaters of Cris Lee Draw. Fills paleovalleys now cut by modern arroyos in northernmost part of quadrangle. Brown, light yellowish brown, or brownish yellow. Typically consists of an upper section of weakly stratified sandy silt with lenses, stringers or scattered grains of sand and small pebbles, massive beds of silty very fine sand, or massive beds of sandy silt; and a lower section of interstratified sand, pebbly sand, silt, and poorly sorted sandy pebble or cobble gravel with cobbles 10–20 cm in diameter common (photo 3, sheet 2). Clasts mostly quartzite, gneiss, granite, sandstone, volcanic clasts and chert; rock types indicate that many clasts are reworked from older South Platte River deposits (probably Nussbaum Alluvium). Sands rich in potassium feldspar. Massive beds have slightly hard to hard dry consistence. Eroded pedogenic carbonate horizon with stage III carbonate morphology developed in Qlg marks contact between it and the younger deposits Timing of paleovalley cutting and filling is uncertain, but could have corresponded to when deep incision, followed by aggradation of Louviers Alluvium (coeval with Bull Lake glaciation in the mountains), occurred in the South Platte River valley; this sequence of events would likely have caused a similar response within tributary drainages. The gradational contact between **Gravel deposits (middle Pleistocene)**—Pebble and cobble gravel in eroded and

loess and eolian sand and alluvial deposits in the unit further supports correlating the gravelly alluvial deposits in Qlg to Louviers Alluvium rather than Slocum This work was part of the Greater Platte River Basins and Northern Plains Geologic Frame-Alluvium. Locally could contain older deposits of sheetwash, alluvium, and work Studies project of the U.S. Geological Survey's National Cooperative Geologic Mapping Program. The National Association of Geoscience Teachers (NAGT)—U.S. Geological Survey Cooperative Summer Field Training Program also provided support through a student summer partially buried remnant terrace deposits and thin gravel lags along Wildcat intern. We thank the many landowners who graciously granted access to their property. We also Creek. Probably correlative in part with gravelly alluvial section of Qlg based on thank the many other individuals who contributed to the project: Sarah R. Survis (NAGT Intern) valley position, clast lithology, and weathering characteristics. Overlies Pierre assisted with field work; Shannon A. Mahan (USGS) provided a portable gamma spectrometer to Shale and largely covered by late Pleistocene and Holocene eolian deposits (Qel measure OSL dose rates in the field; Jeffrey S. Pigati (USGS) provided helpful discussions and Qes). Previously mapped as Slocum Alluvium by Gardner (1967) but here regarding radiocarbon dating methods, samples, and interpretation, identified probable Succinea considered more likely correlative to Louviers Alluvium (see discussion of Qlg). snail shells, and submitted our radiocarbon samples for analysis; and Ralph R. Shroba (USGS) and Clasts mostly quartzite, gneiss, granite, sandstone, volcanic, and chert reworked David J. Lidke (USGS) provided thorough reviews that greatly improved this Scientific from older South Platte River deposits (probably Nussbaum Alluvium). Cobbles 10–20 cm in diameter common; locally includes a few boulders (up to 30 cm in diameter) of conglomerate probably derived from Nussbaum Alluvium. Locally,

composed chiefly of marine calcareous silty shale or claystone, shaly sandstone and sandy shale (Gardner, 1967; Scott, 1978). Mostly covered by unmapped weathered residuum; locally includes colluvium and other surficial deposits not

CONVERSION FACTORS Multiply To obtain millimeter (mm) 0.03937 inch (in.) centimeter (cm) 0.3937 inch (in.) 3.281 foot (ft) meter (m) 0.6214 mile (mi) kilometer (km)

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ISSN 2329-132X (online

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> ScienceBase citation: Berry, M.E., Taylor, E.M., Slate, J.L., Paces, J.B. Hanson, P.R., and Brandt, T.R., 2018, Data release for the geologic map of the Fort Morgan 7.5' quadrangle, Morgan County, Colorado: U.S. Geological Survey data release, https://doi.org/10.5066/F7QC02F ScienceBase citation for geochronology of the river corridor: Berry, M.E., Hanson, P.R., Paces, J.B., Taylor, E.M., and Slate, J.L., 2018, Data release of OSL, 14C, and U-series age data supporting geologic U.S. Geological Survey data release, https://doi.org/10.5066/F7QN65N Suggested citation: Berry, M.E., Taylor, E.M., Slate, J.L., Paces, J.B., Hanson, P.R., and Brandt, T.R., 2018, Geologic map of the Fort Morga 7.5' quadrangle, Morgan County, Colorado: U.S. Geological Survey Scientific Investigations Map 3408, 2 sheets, scale 1:24,000,

https://doi.org/10.3133/sim3408.

encased in fine-grained sediment from the uppermost meter of mainstream Broadway Alluvium at site EF (fig. 1, Masters 7.5' quadrangle) indicates that by radiocarbon ages reported by Madole (1994, 1995) and Madole and others burial of the bone occurred sometime between 15 and 11 ka (table 3, sheet 2; estimates from a section exposed in a stream cut along a small unnamed