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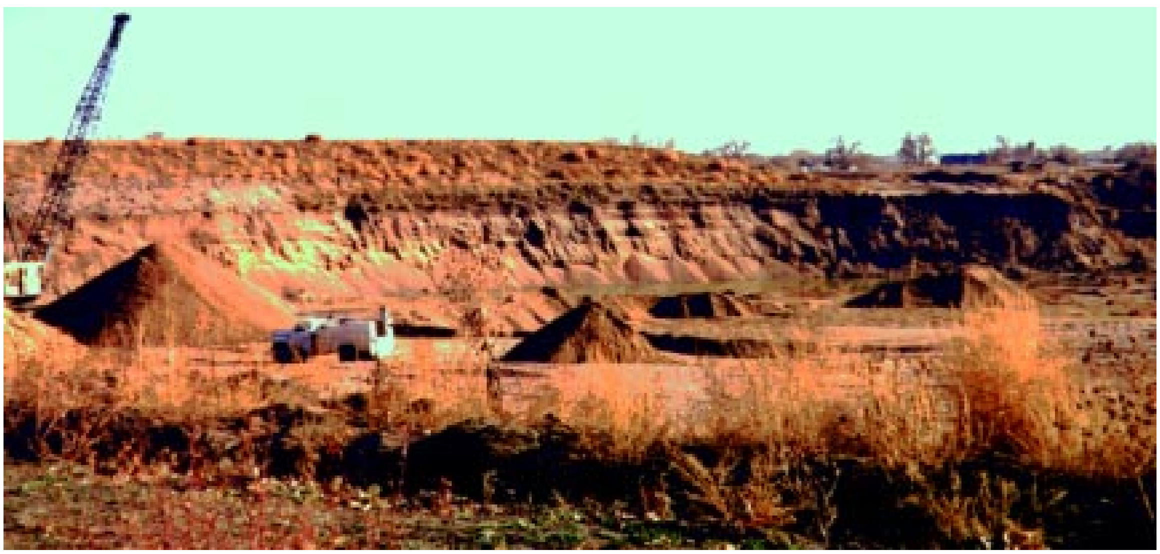
Gravel deposits of the South Platte River valley north of Denver, Colorado
Part A: Stratigraphy and sedimentary structures

by

David A. Lindsey[1], William H. Langer[1],
Linda Scott Cummings[2], and John F. Shary[1]

OPEN-FILE REPORT 98-148-A



Gravel stratigraphy exposed on the east face of the Mann Lake gravel pit, 126th Avenue

[1] U. S. Geological Survey, Denver, Colo.
[2] Paleo Research Laboratories, Golden, Colo.

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GRAVEL DEPOSITS OF THE SOUTH PLATTE RIVER VALLEY NORTH OF DENVER, COLORADO

PART A: STRATIGRAPHY AND SEDIMENTARY STRUCTURES

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SUMMARY

The stratigraphy and sedimentary features of gravel in the South Platte River valley north of Denver were studied to establish a geologic framework for assessment of gravel resources. Major gravel resources occur beneath the Broadway terrace north and south of Brighton, Colo., and beneath the floodplain and low terraces north of Denver.

The Broadway terrace is underlain by Pleistocene alluvium and, at some places, by fine-grained wind-blown deposits. The Piney Creek terrace, low terraces, and the floodplain are underlain by Holocene and Pleistocene alluvium. Gravel beneath the floodplain and low terraces of the South Platte River is divisible into three units that are persistent northward from Denver to Ft. Lupton, Colo. The upper gravel is Holocene in age, the middle gravel is probably Holocene, and the basal gravel is probably Pleistocene.

The upper gravel was deposited by a stream that was essentially identical to the braided-to-meandering modern South Platte River. Although the exact fluvial environment remains problematic, the middle gravel may have been deposited by a braided stream confined only by shallow gravel-bed channels. Compared to the stream that deposited the basal gravel, the streams that deposited the upper and middle gravels had a smaller discharge and were underfit in the valley of their predecessor. The coarse basal gravel was most likely deposited by a glacial meltwater river that had much greater discharge, a coarser bedload, and a larger valley than the modern South Platte.

SCOPE AND PURPOSE OF STUDY

Coarse gravel deposits form nearly continuous layers in the valley of the South Platte River from Denver, Colo., northward to the vicinity of Ft. Lupton, Colo. (Figures 1 and 2). Floodplain and low terrace gravels are near the surface and are the principal exploited source of aggregate. Extensive high terraces along the east side of the South Platte River valley also contain significant resources of coarse gravel aggregate, especially north and south of Brighton, Colo. Closer to Denver, however, thick wind-blown deposits of fine-grained sediment on the terraces may preclude extraction of gravel beneath much of the high terrace.

By 1980 gravel mining had exhausted the accessible major deposits in the Denver metropolitan area and urbanization had precluded extraction of most of the remaining gravel resource (Schwochow, 1980). The South Platte River valley north of Denver was considered the last major source of gravel aggregate in the metropolitan area. In 1995-96, the valley north of Denver was the site of 15 active permitted sand and gravel mines (Hemborg, 1996). By 1997, mining was proceeding at a rapid rate and had advanced downstream to the vicinity of Ft. Lupton, about 9 miles north of the downstream limit of mining in 1974 (shown on the map of the Brighton quadrangle by Schwochow and others, 1974).

The study reported here focuses on the physical stratigraphy of alluvial terraces, on sedimentary features of gravel beneath the floodplain and low terraces of the South Platte and, more specifically, on gravel located between major metropolitan development and the downstream limit of gravel mining in 1974. The area between the 1974 and 1997 limits of gravel mining was examined by reconnaissance, but time did not permit detailed study. Likewise, gravel deposits in paleovalleys peripheral to the South Platte River and in dissected high terraces of nearby upland areas are discussed only briefly. Probably, only minor resources of high-quality gravel aggregate occur in paleovalleys and beneath dissected high terraces.

The stratigraphy and sedimentary features of gravels in the South Platte River valley north of Denver were studied to establish a geologic framework for assessment of the quantity and quality of gravel resources. Although the regional distribution of gravel is well-established (Colton, 1978; Schwochow and others, 1974; Trimble and Machette, 1979), and detailed maps of gravel-bearing terraces have been published for the Ft. Lupton (Soister, 1965) and Commerce City (Lindvall, 1979) 7 1/2’ quadrangles, information on the stratigraphy of gravels in the valley of the South Platte River is scattered and incomplete. Subsurface information published to date includes generalized cross sections of the South Platte aquifer (Smith and others, 1964), a map showing total thickness of surficial deposits (Robson, 1996), postings of reconnaissance data on gravel thickness, particle size, and pebble composition (Colton and Fitch, 1974; Schwochow and others, 1974; Trimble and Fitch, 1974), and well logs of surficial deposits (Schneider, 1962). Previous to this study, the only stratigraphic framework was a regional one, based primarily on surface mapping of river terraces and examination of exposures located mostly outside the study area (Hunt, 1954; Scott, 1965; Wayne and others, 1991).

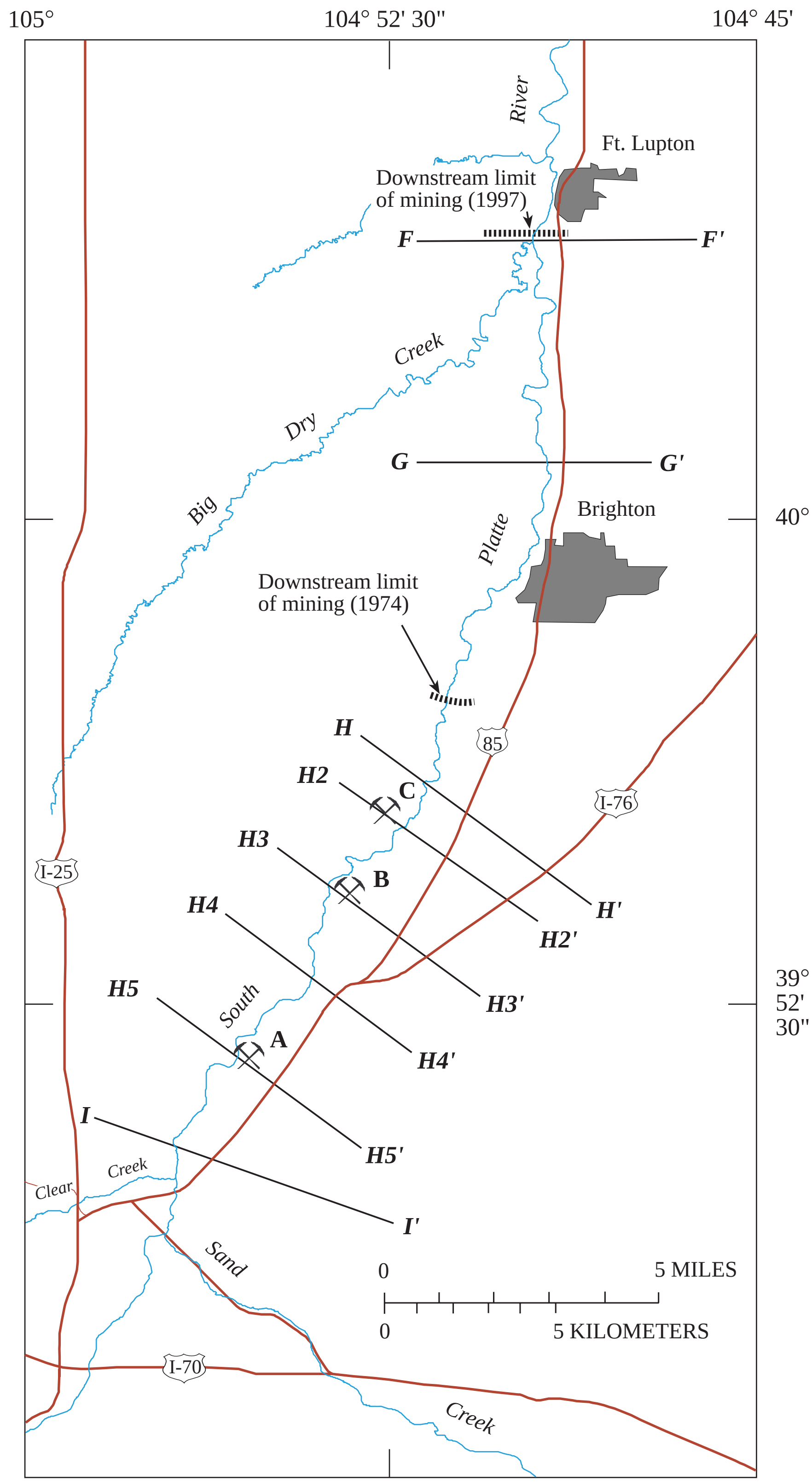

Figure 1.—Map showing general location of sample sites and valley cross sections in the South Platte River valley north of Denver, Colo. Locations of sample sites: A, Camas Cooley North Dahlia pit; B, Western Mobile Howe pit; and C, Western Mobile Mann Lake pit. Valley cross sections shown in figures 3 and 4.

METHODS AND ACKNOWLEDGEMENTS

New and existing data on the subsurface of the South Platte River valley were collected and synthesized to produce a new stratigraphic framework. Drillhole logs (Schneider, 1962) were compiled into new cross sections showing the stratigraphy of valley deposits. Stratigraphic relationships and sedimentary features of gravel beneath the floodplain and low terraces were mapped and described from three 1,000-foot exposures at the Camas Cooley North Dahlia pit, the Western Mobile Howe pit, and the Western Mobile Mann Lake pit (Figure 1; Table 1). Results of stratigraphic studies in the gravel pits were incorporated into cross sections. Published geologic maps (Colton, 1978; Lindvall, 1979; Trimble and Machette, 1979) and aerial photographs were examined to identify terrace levels on valley cross sections. In addition, stratigraphic interpretation was guided by carbon-14 and pollen determinations on material from two of the three gravel pits.

Samples of wood and clay were selected from two gravel pits for age and environmental interpretation. Pollen in clay from gravel was identified by L. Scott Cummings and T. E. Moutoux, Paleo Research Laboratories, Golden, Colo., and wood was identified by K. Puseman, Paleo Research Laboratories. Carbon-14 ages and isotopic analyses of wood were determined by Beta Analytic, Inc. (M. A. Tamers and D. G. Hood, Directors), Miami, Florida. In addition, samples of gravel were collected for studies of gravel quality (Part B of this report) and samples of clay were collected for mineralogical and chemical analyses to determine the origin of clay lenses in gravel (Part C of this report).

We thank employees of Western Mobile and Camas Cooley for granting access to company gravel pits and for sharing their knowedge of individual gravel deposits and mining operations.

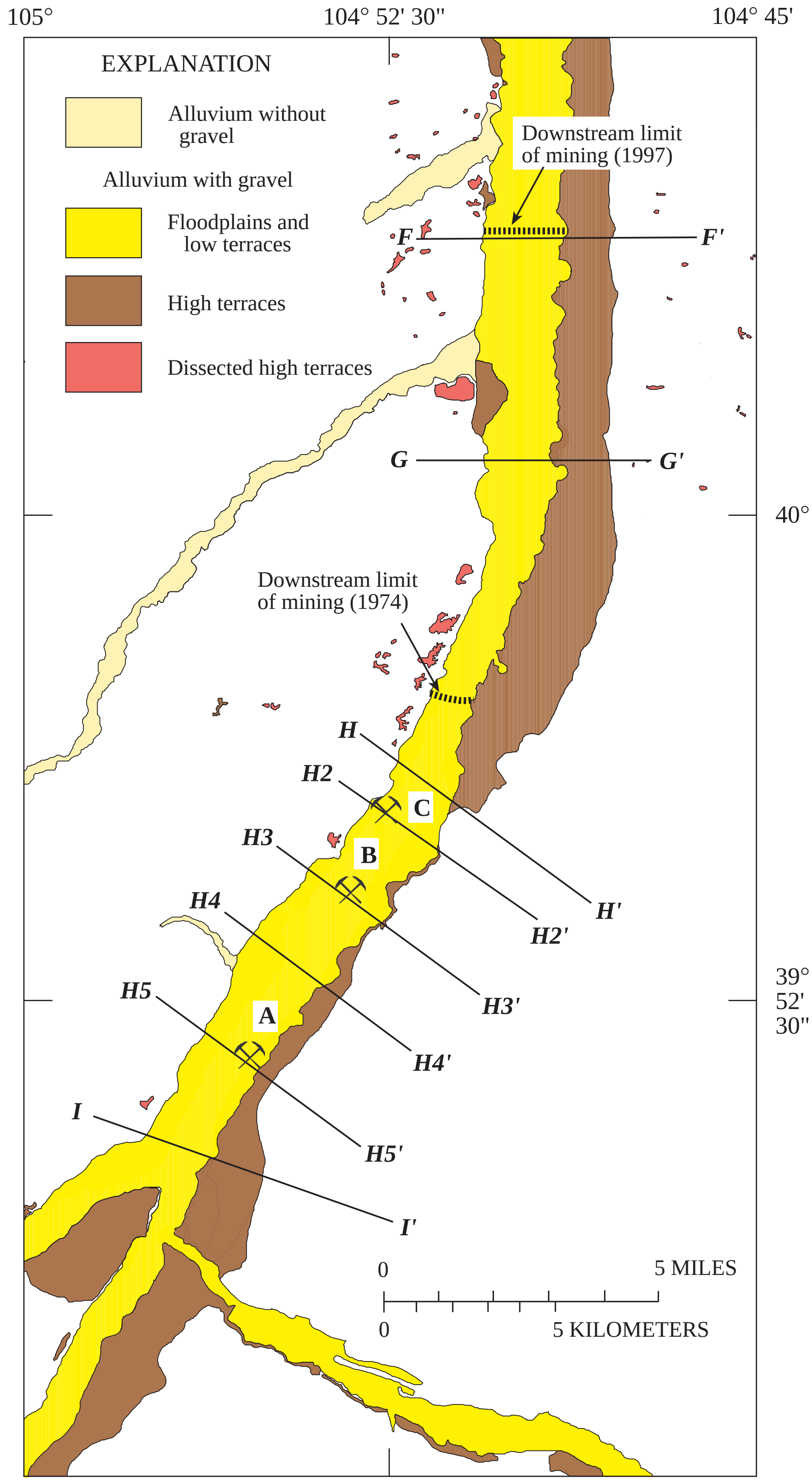

Figure 2.—Map showing alluvial deposits of the South Platte River valley north of Denver, Colo. Locations of sample sites: A, Camas Cooley North Dahlia pit; B, Western Mobile Howe pit; C, Western Mobile Mann Lake pit. Valley cross sections shown in figures 3 and 4. Contacts adapted from Schwochow and others (1974).

STRATIGRAPHY OF QUATERNARY ALLUVIUM

Alluvial landforms

Alluvial deposits of Quaternary age underlie three classes of landforms (Figure 2) that have been mapped regionally in the South Platte River valley (Colton, 1978; Trimble and Machette, 1979). From highest (oldest) to lowest (youngest), the major landforms are dissected high terraces (Rocky Flats, Verdos, and Slocum Alluvium of Pleistocene age), high terraces (Louviers and Broadway Alluvium of late Pleistocene age), and floodplain and low terraces (Piney Creek, post-Piney Creek, and floodplain alluvium of Holocene age) (Scott, 1965). Wind-formed dunes comprise a fourth landform of Quaternary age in the South Platte valley. The four landforms are the basis for corresponding aggregate deposit models (Lindsey, 1997). In the area studied, dissected high terraces are underlain by isolated erosional remnants of thin alluvial gravel deposits on hills overlooking the South Platte valley (Figure 2). Dissected terrace gravels along the South Platte are small in volume and are used only locally as sources of fill material. In contrast to dissected high terraces, the high terraces underlain by Louviers and Broadway Alluvium are large continuous surfaces intermediate in elevation between the older dissected high terraces and the low terraces. The high terraces are underlain by a variety of deposits, including coarse gravels that constitute a major aggregate resource. Most of the high terrace in the South Platte valley north of Denver is assigned to the Broadway Alluvium. The Broadway terrace extends northward along the east side of the South Platte and, north of the study area, forms a broad plain known as the “Kersey terrace.” In the region between sections H-H’ and H5-H5’ in the study area (Figure 2), the high terrace deposits and adjoining uplands are covered by varying thicknesses of eolian sand and loess (shown on valley cross sections of Figure 3 but not on Figure 2). The low terraces

Table 1.—Location data for sample sites and measured sections in three gravel pits on the floodplain and low terraces of the South Platte River valley north of Denver, Colo. Denver area street address given for westernmost section at each sample site; 1/4-1/4-1/4 section-township-range locations are within 600 ft; latitude and longitude locations are within 100 ft. Measured sections at each site are located approximately 500 ft apart. Gravel thickness is interval between overbank sediment and bedrock.

SITE-SAMPLE SECTION	PIT	DENVER AREA STREET ADDRESS	1/4-1/4-1/4 SECTION-TOWNSHIP-RANGE	LATITUDE	LONGITUDE	GRAVEL THICKNESS (FT)
A-1	Cooley North Dahlia	89th Avenue and Holly Street	NW-SW-SW 20-2S-67W	39° 51' 32" N.	104° 55' 13" W.	>23
A-2	-do-	-do-	SW-NW-SW 20-2S-67W	39° 51' 36" N.	104° 55' 13" W.	>13
A-3	-do-	-do-	SE-NE-SE 19-2S-67W	39° 51' 37" N.	104° 55' 18" W.	26
B-1	Western Mobile Howe	112th Avenue, 0.6 mile west of Brighton Road	NW-NW-NE 9-2S-67W	39° 54' 00" N.	104° 53' 31" W	19
B-2	-do-	-do-	NE-NE-NW 9-2S-67W	39° 54' 00" N.	104° 53' 36" W.	20
B-3	-do-	-do-	NE-NE-NW 9-2S-67W	39° 54' 00" N.	104° 53' 41" W.	23
C-1	Western Mobile Mann Lake	126th Avenue, 0.3 mile east of Riverdale Road	NW-SE-NW 19-1S-67W	39° 55' 30" N.	104° 52' 40" W.	21
C-2	-do-	-do-	NW-SE-NW 19-1S-67W	39° 55' 30" N.	104° 52' 35" W.	23
C-3	-do-	-do-	NE-SE-NW 19-1S-67W	39° 55' 30" N.	104° 52' 30" W.	22

and modern floodplain occupy a narrow valley, less than half the width of the valley defined by the high terraces. Commonly, the lowermost (post-Piney Creek) terraces lie at elevations only slightly higher than the floodplain, so that they can not be distinguished on most topographic maps. The floodplain and low terraces are underlain by coarse gravel, which currently is the most-exploited gravel resource in the South Platte valley. Overburden, consisting mostly of overbank alluvial deposits, is generally thin above floodplain gravels.

Valley cross sections

The alluvial stratigraphy of the South Platte River valley is delineated on a closely-spaced set of cross sections (Figure 3). For the most part, the cross sections show two ages of deposits: the older, Pleistocene alluvium underlying the Broadway terrace, and the younger, Holocene alluvium underlying the Piney Creek terrace, low terraces below the Piney Creek, and the floodplain. On the sections, alluvial deposits of Holocene age, situated beneath the floodplain and the Piney Creek terrace, are shown separately from deposits of Pleistocene age. The separating contact marks the base of the Holocene valley of the South Platte River. In most cases, alluvium of Holocene age does not extend to the bedrock of the Late Cretaceous and Paleocene Denver Formation, but is separated from bedrock by a layer of coarse gravel interpreted to be of Pleistocene age. Evidence for the Holocene age of alluvium above the coarse basal gravel is discussed in a later section of this report.

Much of the Broadway terrace between Denver and Brighton is covered by wind-blown sand, silt, and clay (Figure 3). At some places, the thickness of wind-blown deposits is as much as 50 feet (ft). The wind-blown deposits extend onto the uplands east of the river and also cover abandoned alluvial valleys of Cherry Creek (east half, section I-I') and the I-76 reach of the ancestral South Platte River (east side, section H-H') (see Lindvall, 1979, Smith and others, 1964, and Robson, 1996, for details of abandoned valleys).

Gravel deposits beneath the Broadway terrace are deeply buried in many parts of the study area, but they appear near the surface near Denver (section I-I') and near Brighton (sections H-H' and north). As much as 50 ft of coarse gravel lies beneath the surface on either side of U. S.

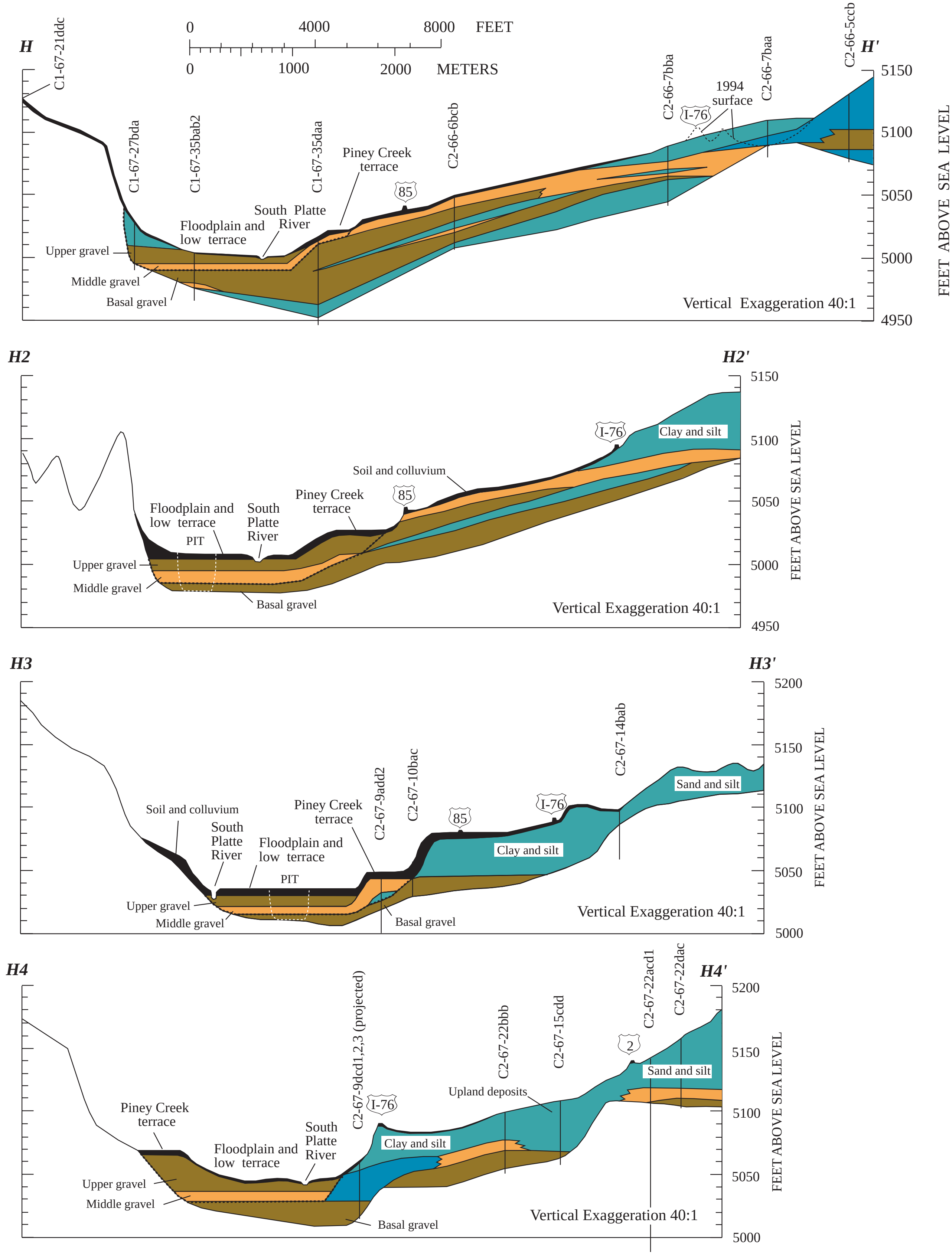

Figure 3.—Valley cross sections showing alluvial deposits of the South Platte River valley north of Denver, Colo., upstream from the limit of gravel mining in 1974. Section lines located in figures 1 and 2. Drillhole numbers keyed to logs tabulated by Schneider (1962).

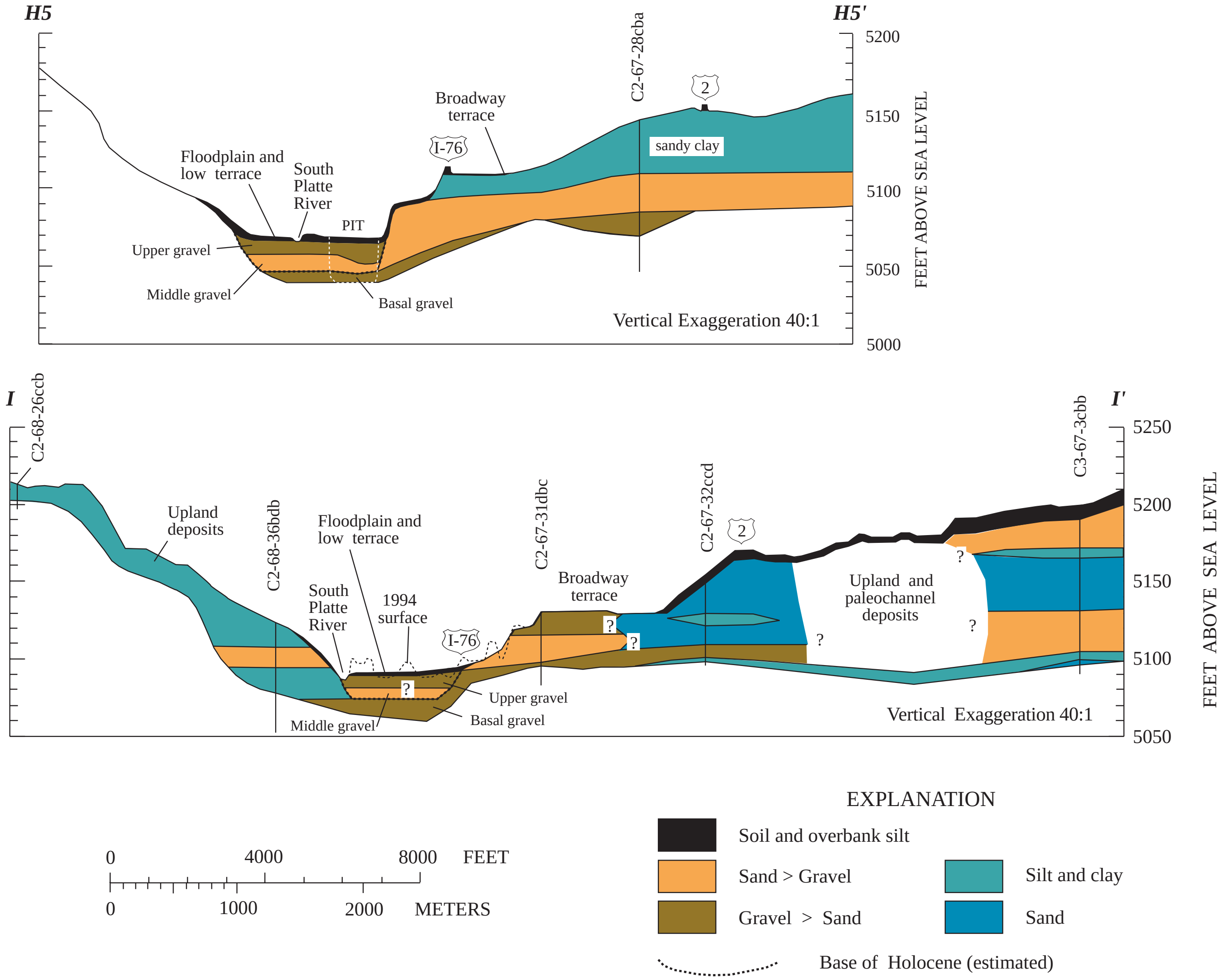

Figure 3 (Con't).—Valley cross sections showing alluvial deposits of the South Platte River valley north of Denver.

Highway 85 north and south of Brighton (Figure 4). East of the coarse gravel, the proportion of sand increases and alluvial gravel appears to intertongue with wind-blown sand, silt, and clay. To the west, the coarse gravel has been removed by the South Platte River where it cut a new valley during Holocene time.

The modern floodplain and the low terraces (including Piney Creek terrace and post-Piney Creek) are typically underlain by about 20 ft of alluvial gravel and sand. Soil and overbank deposits are typically only 3-6 ft thick. Where examined in gravel pits, gravel beneath the floodplain is readily divisible into three units: an upper gravel, a middle sandy gravel, and a coarse basal gravel. All three units are mined for gravel. The three-fold division of gravel beneath the floodplain can be traced in drillhole logs as far north as Ft. Lupton, where all three gravel units are sandy (Figure 4).

ALLUVIAL DEPOSITS BENEATH THE FLOODPLAIN AND LOW TERRACES

Description of units

From top to bottom, the floodplain and low terraces are underlain by four units of Quaternary age (Figures 5, 6 and 7): 1) soils and overbank deposits (commonly 3-5 ft thick), 2) an upper gravel (3-15 ft thick, average 8.7 ft at the three sites studied in detail), a middle sandy gravel (3-12 ft thick, average 7.6 ft), and a coarse basal gravel (4-8 ft thick, average 6.3 ft). The base of the soil and overbank unit is typically sharp, even erosional (Figure 8), and is marked by an abrupt change in grain size from clay, silt, and sand to gravel. The contact between the upper and middle gravel unit is also commonly sharp and erosional, but locally it may be gradational, with well-bedded pebbly gravel of the upper unit commonly discernible above the sandy gravel of the middle unit. At the Howe pit (Figure 6), the upper gravel contains abundant masses, measuring from a few inches to 40 ft across, of organic-rich clay and rootlets, which tend to be concentrated in channel scours at the base of the upper gravel. The clay

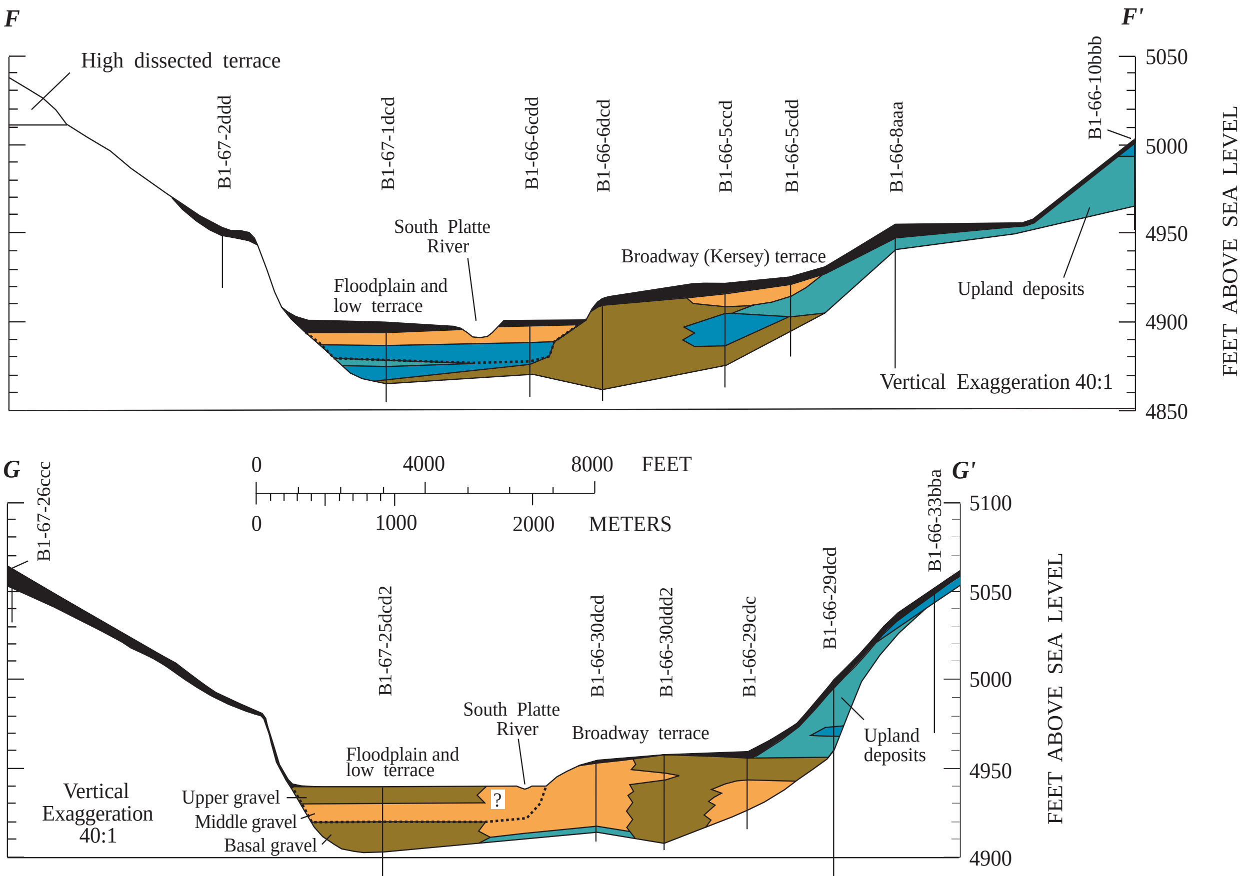

Figure 4.—Valley cross sections showing alluvial deposits of the South Platte River valley north of Denver, Colo., between the 1974 and 1994 downstream limits of gravel mining. Section lines located in figures 1 and 2. Drillhole numbers keyed to logs tabulated by Schneider (1962).

masses probably represent overbank deposits that were undercut and caved by flood waters. The contact between the upper and middle gravels is also marked by a color change, from grayish brown (5YR 6/4 , 5YR 7/2, and 10YR 6/2) to yellowish brown (10YR 5/4 and 10YR 6/2) in the middle and lower gravels. The contact between the middle and lower gravels varies from abrupt to gradational, with little or no color contrast, but a marked contrast in grain size. The middle gravel tends to be sandy, whereas the basal gravel consists mostly of coarse pebbles and cobbles. The coarse basal gravel rests directly on bentonitic mudstone of the Paleocene to Late Cretaceous Denver Formation. At some exposures, sand lenses were observed in the lowermost part of the basal gravel.

Soil and overbank deposits—Overbank deposits of the floodplain and low terraces are commonly recorded in drillhole logs as “soil” or “loam” (Schneider, 1962). Overbank deposits were examined in reconnaissance along the west side of the Howe pit, along the east side of the Mann Lake pit, and in riverbank exposures upstream from the North Dahlia pit and below Ft. Lupton. On the west face of the Howe pit, sections about 4 ft thick consist of the sequence soil (top 12 inches), sand and granule gravel (about 20 inches), and dark gray clay (12 inches) on the upper gravel unit (Figure 9). The bed of sand and gravel was traced for more than 1,000 ft parallel to the modern South Platte. The bed may be a natural levee deposit. It contains a distinctive sequence of structures (Figure 9) indicative of two periods of maximum current velocity. The bed is coarsest near the base, even containing a few small pebbles; the middle, sandy part of the bed contains ripple cross-lamination; the upper part is crossbedded and contains coarse sand and granules. Although the base of the bed is sharp, it is not erosional into underlying silt and clay. Upstream, south of the North Dahlia gravel pit, and downstream near Ft. Lupton, layers of fine sand up to 6 inches in thickness were observed in the riverbank. Thin beds of sand and fine gravel were probably deposited on natural levees during large floods. Given the young age of the floodplain at the Howe pit, some of the beds may have been deposited during the historic floods described by Mathai (1969).

Soil on the floodplain has well-developed organic and calcareous horizons even though development has obviously been interrupted by flooding and deposition of sand and gravel. At the Howe pit, caliche is well-developed in and below sand and fine gravel beds. The top of the underlying gravel is oxidized yellow-

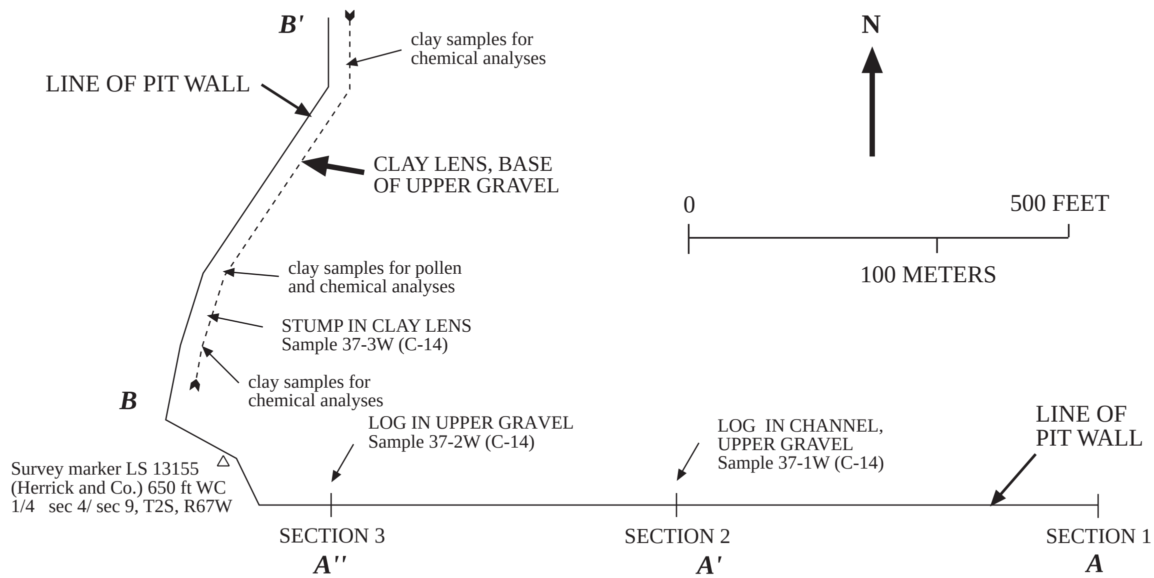

Figure 5.—Plan showing location of samples and sections sampled for gravel particle size at the Howe pit. The location of cross sections showing pit wall in figure 6 are also shown.

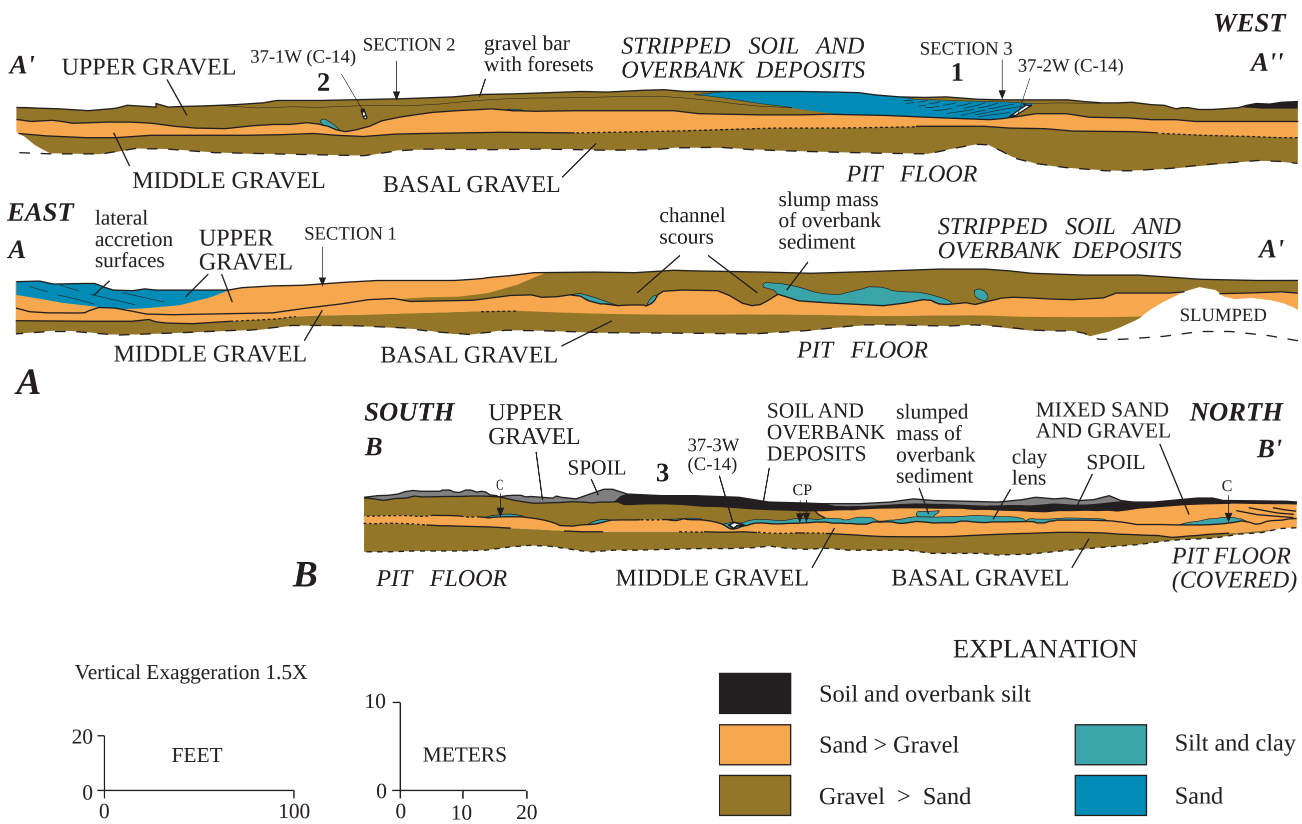

Figure 6.—Sections of pit walls showing details of alluvial deposits in part of the Howe pit. ***A***, view looking south at east-to-west pit wall at site B, showing sections sampled and locations of wood dated by C-14 method. ***B***, view looking west at south-to-north pit wall immediately west of site B, showing locations of wood dated by C-14 method, pollen samples from clay lens, and chemically analyzed clay samples. Locations of features including those shown in photographs, section A'-A": 1, figure 12, lateral accretion surfaces formed by migration of sand bar and inclined cottonwood log sampled for C-14 age; 2, figure 14, channel scour filled with slumped masses of overbank sediment and gravel of upper unit; section B-B': 3, figure 9, sequence of overbank sediment with layers of fine gravel. Sample locations shown by arrows: C, sample for chemical analysis of clay; P, sample for identification of pollen in clay.

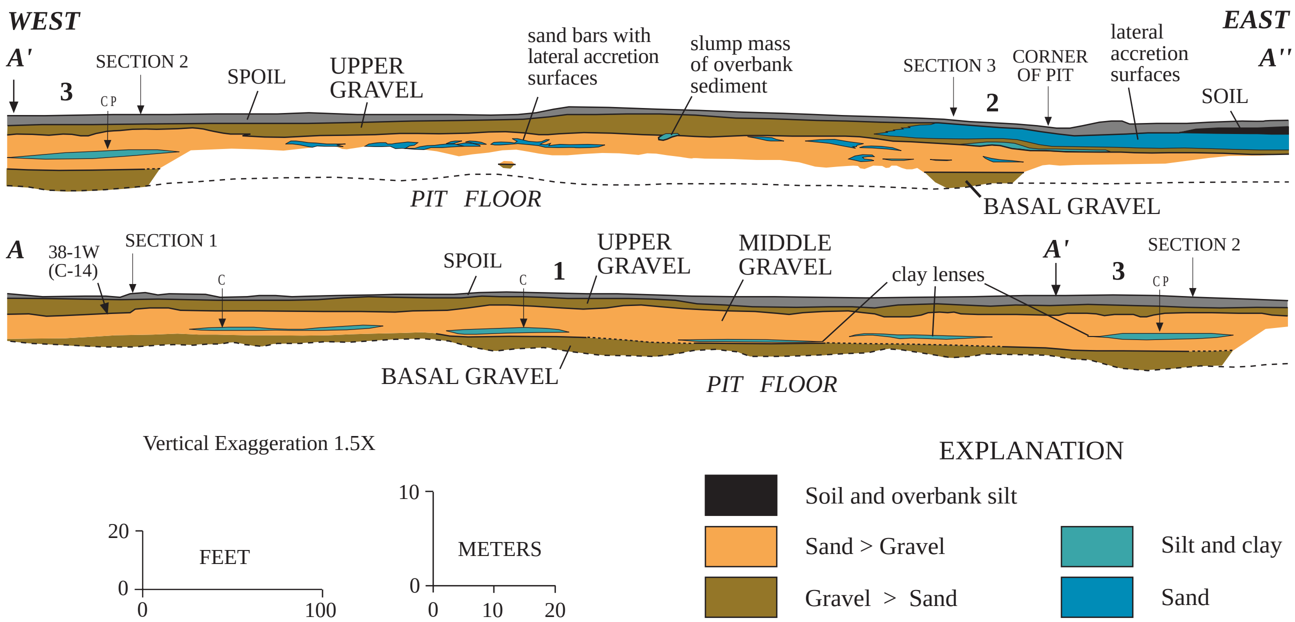

Figure 7.—Section of north pit wall showing details of alluvial deposits in the Mann Lake pit. Mapped pit wall is sample site C, adjacent to 126th Avenue, across from Adams County Regional Park. Locations of photographs as follows: 1, figure 10, showing typical structure and particle size of upper and middle gravel units, and of figure 16, showing cross-bedded structure formed by migrating megaripples, middle gravel unit; 2, figure 11, showing abrupt intertonguing of sand and gravel, upper gravel unit; and 3, area of clay lens sampled for pollen and chemical analysis, shown in figure 1 of Part C. Sample locations shown by arrows: C, sample for chemical analysis of clay; P, sample for identification of pollen in clay.

Figure 8.—Photograph showing soil and overbank sediment in erosional contact with upper gravel unit, east side Mann Lake pit. Gravel is a clast-supported pebble deposit, moderately well-sorted, with sand occupying interstices.

brown. As will be discussed in a following section, the soil here cannot be older than about 300 years.

Evidently, deposition of overbank deposits and soil formation followed abandonment of river channels. Overbank deposits typically overlie gravel along a sharp contact. The base of the floodplain overbank deposits at the Mann Lake pit is erosional (Figure 8), cutting across as much as 2 feet of underlying gravel.

Upper gravel unit—The upper gravel is the most heterogenous of the three gravel units beneath the floodplain (Figures 6 and 7). Clast-supported pebble gravel with sand in interstices (Figures 8 and 10) dominates the upper gravel, but sand is locally abundant (Figures 11 and 12). Study of faces in the Howe pit indicate that, for each 500-foot interval, about one sand body can be expected. Sand bodies are commonly 100 ft across and occupy the entire thickness of the upper gravel. Boundaries between sand and gravel range from abrupt (Figure 11) to interfingering but almost always follow gently inclined bedding interpreted as lateral accretion surfaces that form during development of a lateral or point bar. Lateral accretion surfaces occur within both predominantly gravel and sand bodies (Figure 12). Broad, sweeping surfaces are typically inclined at low angles to horizontal, are concave up and down, and contain erosion surfaces that separate sets of

Figure 9.—Photograph showing soil and overbank sediment with sand and gravel, west side Howe pit. Location of photograph shown in figure 6B. Overbank sand and gravel shows a fining-upward sequence beginning at position of thumb, with pebbly gravel at base, rippled sand above, and coarse sand with granules. Sequence probably represents a single flood with two crests. Pre-flood soil (below thumb) developed in overbank silt and clay in sharp contact with underlying upper gravel unit (rusty brown color).

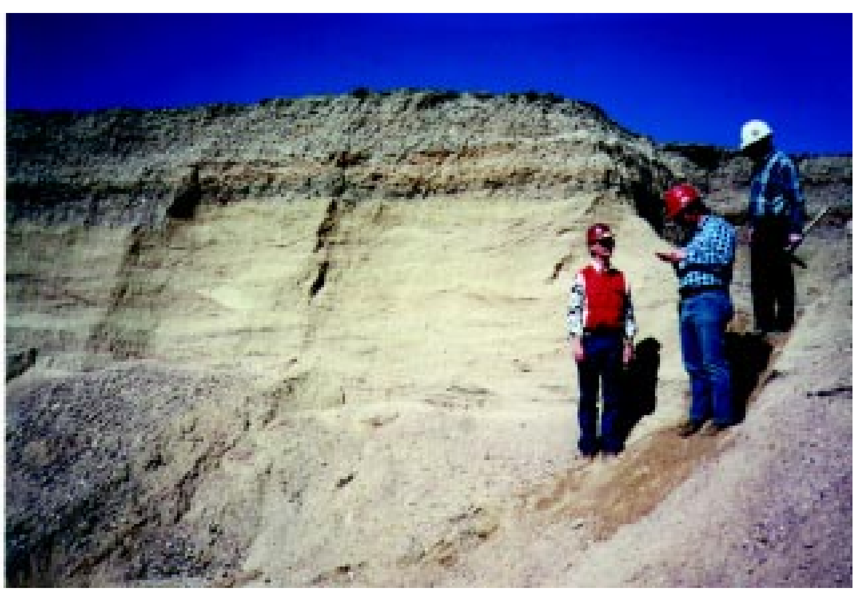

Figure 10.—Photograph showing upper and middle gravel units in sharp contact. The upper gravel typically consists of coarse pebble gravel and is gray in color; the middle gravel (left of men) is sandy and yellow-brown in color. Location shown in figure 7, Mann Lake pit.

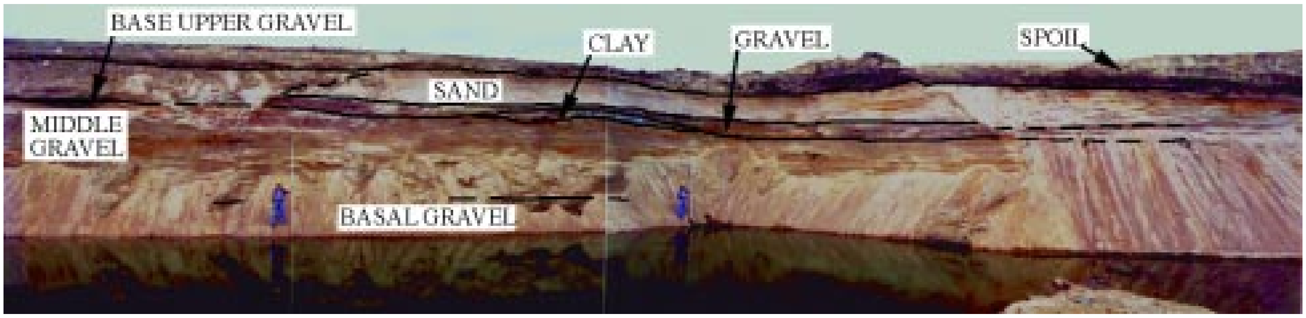

Figure 11.—Photograph showing sharp lateral change from pebble gravel to sand in the upper gravel unit. Gravel bed at base of the upper gravel unit fills channel scours cut into underlying clay lens and marks the lowest level of last reworking by the South Platte River. Both sand and gravel phases of upper gravel unit contain gently inclined lateral accretion surfaces, formed by migration of bars. Stadia rod is 10.5 ft high. Location shown in figure 7, Mann Lake pit.

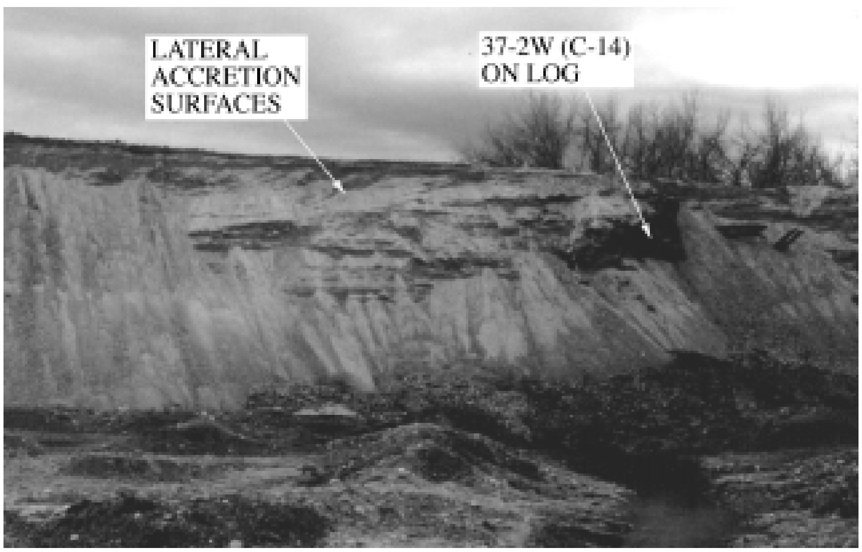

Figure 12.—Photograph showing lateral accretion surfaces in sand body of the upper gravel unit. Several sets of surfaces are visible, with gentle inclination and concave-up form. Sand has accumulated next to inclined cottonwood log (in shadow) sampled for C-14 age; position of log indicates rapid deposition of entire thickness of sand bar at this point. A second log protrudes from the pit face to the right of the sampled log. The sand body is overlain by a 2-foot layer of pebble gravel. Pit face is about 20 feet high. Location shown in figure 6A, Howe pit.

Figure 13.—Photograph showing planar crossbedding, formed at the slip face of a migrating gravel bar in the upper gravel unit, North Dahlia pit. Pit face is about 25 feet high.

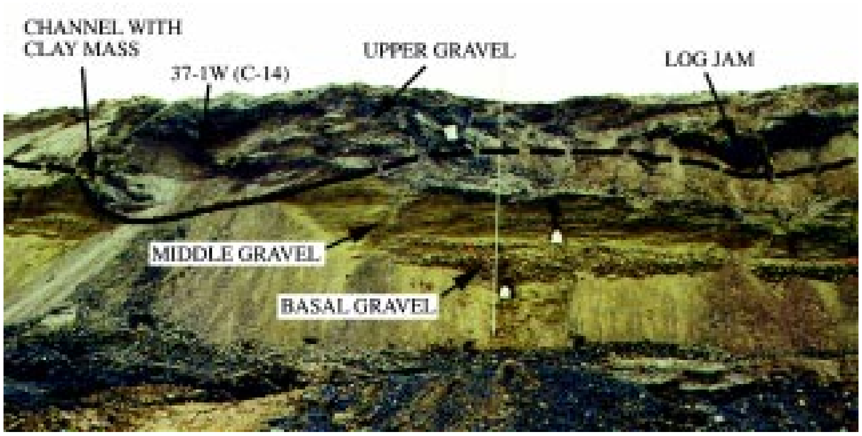

Figure 14.—Photograph showing gravel-filled channel scour and log jam in the upper gravel unit. Layer of pebble gravel (above log sampled for C-14 age) overlies channel fill. Left side of channel is steep and contains mass of organic-rich overbank clay. Pit face is about 20 feet high. Location shown in figure 6A, Howe pit.

Figure 15.—Photograph showing large channel filled with gravel of the upper gravel unit, east side of North Dahlia pit. Pit face is about 25 ft high.

surfaces of varying inclination and direction of dip (other examples described by Willis, 1993). Gravel beds also contain medium- and large-scale (>2 ft in height) planar crossbed sets (Figure 13), interpreted to have formed by downstream migration of bar slip faces (other examples described by Boothroyd and Ashley, 1975). Planar crossbedding forms laterally persistent sets in individual gravel beds. Individual foresets of pebble gravel and sand commonly alternate; they are uniformly inclined at angles of about 20-30°. Channel bars that might give rise to structures observed in the upper gravel are typical of gravel-bed rivers (Church and Jones, 1982). Both lateral accretion surfaces and bar foresets can be observed in present-day lateral bars of the South Platte north of Denver, a braided-to-meandering river (Lindsey and Shary, 1997).

The local abundance of slumped masses of overbank sediment and organic matter including cottonwood logs and log jams (Figures 12 and 14) in the upper gravel has already been noted. Although most conspicuous at the Howe pit, most of these features were observed in the upper gravel at the North Dahlia and the Mann Lake pits. Lenses of silty clay as much as 3 ft thick were found over a 500-foot interval at the base of the upper gravel unit in the Howe pit (Figure 6B). The upper gravel commonly fills small channel scours (Figure 14); at the North Dahlia pit, a 15-foot-deep channel filled with the upper gravel was observed (Figure 15).

Masses of organic-rich clay, commonly containing rootlets, are concentrated along the base but may occur at any horizon in the upper gravel. Masses of rootlet-rich clay also occur in log jams. The clay ranges from brownish gray (5Y 4/1) to dark gray (N2 to N5) in color. The clay masses are interpreted as blocks of overbank sediment that were undercut by the river channel, fell into the channel, and were subsequently inundated by gravel. Bank caving and burial of overbank deposits was probably most common during flooding. Overbank deposits that fall into a channel during low flow are more likely to be weathered and washed away before burial.

Lenses of dark gray silty clay lie at the base of the upper gravel for about 500 ft along the west face of the Howe pit (Figures 5 and 6B). The clay is mostly massive, with faint laminae detected near the base at one place where the clay fills a small erosional scour in underlying gravel. The clay lenses are considered to belong to the time of deposition of the upper gravel because they fill shallow depressions that were eroded into the underlying gravel and do not

Figure 16.—Photograph showing crossbedding formed by migration of megaripples on sandy gravel bar in the middle gravel unit. Planar crossbed set formed on bar slip face visible in lower left. Pit face oriented north-south, parallel to direction of streamflow. Scale bar is in inches and cm. Approximate location shown in figure 7, Mann Lake pit.

themselves appear to have been eroded. And, a stump buried in one lens yielded a carbon-14 age consistent with the age of the upper gravel.

The upper gravel is interpreted to represent the last period of reworking of alluvium by the South Platte. The gray color and abundance of organic matter including logs is dependent upon the degree of preservation, which, in turn, is probably dependent upon the time elapsed since reworking. Organic matter, including logs, are far less abundant in the upper gravel at the Mann Lake pit than at the Howe pit. As discussed in the following section, the upper gravel unit at the Mann Lake pit is older than the upper gravel of the Howe pit. The presence of cottonwood logs in part of the North Dahlia pit suggests that the upper gravel at this site is closer in age to that at the Howe pit than the Mann Lake pit.

Middle gravel unit—The middle gravel is crossbedded sandy gravel (Figures 10 and 16). Sand and gravel are interbedded at a small scale, so that individual bodies of sand and pebble gravel are far less common than in the upper gravel. Much of the middle gravel contains gently dipping lenses of sand and gravel interpreted as having formed by lateral accretion of small bars. Medium (<6 inch)-scale trough cross-bedding of the type formed by migrating megaripples (Figure 16) on bar surfaces is common, also. Migrating megaripples typically form on surfaces of gravel and sand bars of braided and meandering gravel-bed rivers (examples described by Boothroyd and Ashley, 1975). Planar crossbedding formed by migration of bar slip faces was also observed.

The middle gravel contains lenses of silty clay, discussed in detail in Part C of this report. Although present locally at the Howe and North Dahlia pits, they are best developed along the north face of the Mann Lake pit (Figure 7). Clay lenses occur at two or more levels in the lower part of the middle gravel along nearly 500 feet of the north face of the Mann Lake pit, perpendicular to the trend of the South Platte valley and the presumed direction of streamflow. In the eastern part of the pit, lenses of clay at the top of the middle gravel have been partially removed by channel scour subsequent to deposition of the upper gravel (Figure 11). As discussed in Part C, the clay deposits probably represent clay and silt deposited in back channels (chutes) of lateral bars.

Basal gravel unit—The basal gravel consists mainly of clast-supported pebble and cobble gravel. Sand and clay lenses are sparse. Sedimentary structures are not evident, probably in part because of the coarse particle size, but also because the basal gravel is commonly saturated where exposed. The wet condition of the gravel obscures sedimentary features. The base of the gravel is gently undulating, suggesting deposition in relatively unconfined channels. The clast size and overall coarseness of the basal gravel is consistent with deposition by a much larger stream than the present-day South Platte.

Age of gravel

The Piney Creek and lower terrace levels of the South Platte valley are generally considered to be of Holocene age, and the Broadway and Louviers terraces are considered to be of Pleistocene (Pinedale glaciation or older) age (Hunt, 1954; Scott, 1965; Wayne and others, 1991). Ages of terrace levels are based on fossils, soil profiles, and a few carbon-14 dates (e.g., Hunt, 1954; Machette, 1977). The age of the upper part of the alluvium on the floodplain and low terraces was considered to be Holocene. The age of most of the gravel beneath the floodplain and low terraces, however, has long been interpreted as

Table 2.—Carbon-14 age data for wood from the upper gravel unit, South Platte River valley north of Denver, Colo. Location data for sample sections and sites in table 1; area of site B, Howe pit, in figures 5 and 6; area of site C, Mann Lake pit, in figure 7. Measured carbon-14 (C-14) ages reported in radiocarbon years before present (present = 1950 AD). δ C13 (0/00), C13/C12 in parts per thousand relative to PDB-1 standard. +/-, one standard deviation (68 percent probability). Calendar (dendro-calibrated) age spans two standard-deviations (95 percent probability); calibration method of Vogel and others (1993); —, calibration not done. Analyses and calibration by Beta Analytic Inc., Miami, Florida.

FIELD NUMBER	LAB. NO.	SAMPLE LOCATION	MEASURED C-14 AGE (YEARS BP)	δ C13 (0/00)	CONVENTIONAL C-14 AGE (YEARS BP)	CALENDAR--CALIBRATED AGE
37-1W	Beta-105280	sample section 2, site B, Howe pit	150 +/-50	-31.2	50 +/-50	--
38-2W	Beta-105281	sample section 3, site B, Howe pit	180 +/- 50	-29.6	110 +/-50	AD 1670-1950
37-3W	Beta-105282	320 ft at 330° from sample section 3, site B, Howe pit	290 +/-60	-29.3	220 +/-60	--
39-1W	Beta-105283	sample section 1, site C, Mann Lake pit	860 +/-50	-28.5	800 +/-50	AD 1170-1290

Pleistocene (Wisconsin) (Hunt, 1954; Lindvall, 1979).

New information on the geologic age of gravel units from pits at the Howe and Mann Lake pits indicates that the upper gravel is definitely Holocene and that the middle gravel is probably Holocene, also. Only the coarse basal gravel is considered to be Pleistocene.

Upper gravel unit--Logs and branches of cottonwood and willow were observed in the upper gravel at the North Dahlia, Howe, and Mann Lake pits. Logs of cottonwood up to two ft in diameter and tens of feet in length are abundant in parts of the Howe pit. Samples from three different pieces of wood from the Howe pit (see figure 6 for stratigraphic positions) were dated at less than about 300 years BP (Present = AD 1950) by the carbon-14 method. The best calibrated age, of sample 37-2W from a large log at section 3 (Figure 12) in the Howe pit, gave a calendar-year age interval of AD 1670-1950 (Table 2). The log was deposited in a steeply inclined position, so that it extended through much of the interval of the upper gravel unit. The inclined position of the log indicates nearly instantaneous deposition of the entire thickness of upper gravel at the location of the log. Thus, the age of the log is a good indicator of the age of most of the gravel unit. Similarly, sample 37-3W (located in Figure 6B), of a large stump buried in a clay lens at the base of the upper gravel unit, yielded a conventional age of 220 +/60 BP, consistent with interpretation of the age of the entire upper unit as < 300 years BP.

In addition to carbon-14 dating of wood from the stump, the clay lens that hosted the stump was sampled for pollen. Samples were taken from the upper and lower 4 inches of the clay lens and 200 pollen grains identified from each sample (Scott Cummings and Moutoux, 1997). Pollen in the clay was identified to search for evidence of climatic conditions that might be linked to age, and to test the possibility that the overlying gravel might post-date European settlement. No pollen from non-native species (either crops or non-native weeds) was found, indicating that the clay lens, and the overlying gravel of the upper unit, predates European agriculture in the area.

The clay lens yielded an abundant pollen assemblage (Table 3); Cyperaceae (sedges), Poaceae (grasses), and Artemisia (sagebrush) are most abundant. Sedges appear to have been abundant in the riparian vegetation community along the South Platte River, and grasses also grew among the riparian vegetation. A moderately large quantity of Artemisia pollen indicates that sagebrush was the dominant plant outside the riparian zone along the South Platte River. Other plants represented include Picea, Pseudotsuga, Populus, Quercus, Salix, low-spine and high-spine Asteraceae, Liguliflorae, Brassicaceae, Caryophyllaceae, Euphorbia, Lamiaceae, Rosaceae, and Toxicodendron. Of these, Picea (spruce) and Pseudotsuga (Douglas fir) pollen were probably transported from distant montane vegetation communities. Populus (cottonwood), Quercus (oak) and Salix (willow) pollen probably represent trees growing in the riparian community along the South Platte River.

A single branch fragment identified by K. Puseman as probably willow was collected from the base of the upper gravel in the Mann Lake pit. It yielded a conventional carbon-14 age of 800 +/-50 BP (Table 2).

Table 3.—Summary of pollen types observed in four samples from clay lenses at the base of the upper gravel unit (Howe pit) and 4 ft above the base of the middle gravel unit (Mann Lake pit). Identifications based on 200 grains in each sample by L. Scott Cummings and T. E. Moutoux, Paleo Research Laboratories. Pollen samples from Howe pit located in figures 5 and 6; from Mann Lake pit, in figure 7.

SCIENTIFIC NAME	COMMON NAME
ARBOREAL POLLEN	
Juniperus	Juniper
Pinaceae:	Pine family
--Picea	Spruce
--Pinus	Pine
--Pseudotsuga	Douglas fir
Populus	Poplar
Quercus	Oak
Salix	Willow
NON-ARBOREAL POLLEN	
Asteraceae:	Sunflower family
Artemesia	Sagebrush
--Low-spine	Includes ragweed, cocklebur, etc.
--High-spine	Includes aster, rabbitbrush, snakeweed, sunflower, etc.
--Liguliflorae	Includes dandelion and chicory
Brassicaceae	Mustard family
Caryophyllaceae	Pink family
Cheno-am	Includes amaranth and pigweed family
Cyperaceae	Sedge family
Euphorbia	Spurge
Gentianaceae	Gentian family
Lamiaceae	Mint family
Petalostemum	Prairie clover
Poaceae	Grass family
Rosaceae	Rose family
Shepherdia	Buffaloberry
Toxicodendron	Poison ivy
Indeterminate	
SPORES	
Monolete	Fern
Trilete	Fern
Selaginella densa	Little club moss

Calibration gave a two standard-deviation calendar interval of AD 1215-1275. The upper gravel at the Mann Lake pit is clearly older than that at the Howe pit.

The young age, and the variation in age, of gravel in the upper unit is consistent with the continuing process of erosion and reworking of floodplain gravel by the South Platte River. The South Platte reworks gravel by undercutting its banks and depositing gravel bars (Lindsey and Shary, 1997). Lateral channel switching, evidence of which is visible on aerial photographs of the floodplain, has resulted in reworking of the entire floodplain during Holocene time. The age of the upper unit at any one site represents the last time the river occupied the site and reworked earlier gravels. Thus, the age of the upper gravel may be expected to range from a few years to perhaps thousands of years.

Middle gravel unit—The middle gravel could not be dated directly by carbon-14, but clay lenses found immediately above the middle gravel in the Howe pit and in the lower part of the middle gravel in the Mann Lake pit offer an indirect means of dating by environmental criteria. Specifically, large relative abundance of pollen from conifers would be consistent with a nearby glacial environment and a Pleistocene age; sparse pollen from conifers is consistent with a post-glacial (Holocene) environment. By comparing pollen from the clay lens immediately above the middle gravel in the Howe pit, known to be < 300 years BP by carbon-14 dating, with pollen from a clay lens in the lower part of the middle gravel in the Mann Lake pit, an assessment of the most likely climatic environment (and age) of the middle gravel was made.

A large clay lens occurs about 8 ft below the top of the middle gravel in the Mann Lake pit (Figure 7). The lens is about 4 ft above the base of the middle gravel and about 20 inches thick. Samples for pollen were taken from the top and bottom 4 inches of the lens and 200 pollen grains identified from each sample. Pollen from the upper part of the clay lens is dominantly Cyperaceae (sedges), Poaceae (grasses), and Artemisia (sagebrush) (Table 3). Pinus and Picea (spruce) pollen are present but minor. Pollen in the lower part of the clay lens is sparse and mostly redeposited; spores from ferns and clubmoss were identified.

Pollen counts for the clay lens at the base of the upper gravel (Howe pit) were compared with those in the clay lens in the middle gravel (Mann Lake pit) by removing the most abundant species (Cyperaceae) from each count (Scott Cummings and Moutoux, 1997). The resulting modified pollen diagrams are all consistent with a Holocene climate and age. In particular, the low content of spruce pollen is indicative of a Holocene age. Spruce pollen was observed to increase at the time of the Pinedale glacial advance and to decrease at about 7,600 years BP at Redrock Lake in Boulder County (Maher, 1972). The increase in spruce pollen during the Pinedale advance should be visible in other records along the Front Range and onto the plains, but no such increase was noted in pollen from the clay lens in the middle gravel.

Basal gravel unit—No new information is available on the age of the basal gravel. Based on previous evidence, the age is considered to be Pleistocene. The basal gravel is presumably the ultimate source of fossil mastodon and mammoth teeth and other remains of extinct Pleistocene mammals (Hunt, 1954) found in the gravel pits. In addition, the coarse size of the basal gravel indicates deposition by a stream having much greater discharge than the present-day South Platte, consistent with a glacial meltwater stream.

Origin of gravel

The gravels beneath the floodplain of the South Platte River are divisible into three layers that are persistent northward from the Denver metropolitan area to Ft. Lupton. The upper and middle gravels are evidently Holocene in age, whereas the basal gravel is probably Pleistocene in age. The Holocene gravels are finer-grained and contain different sedimentary features than the basal Pleistocene gravel. The small Holocene South Platte inherited a bed of coarse gravel in a broad valley formed during the last Pleistocene ice age, when the South Platte was swollen with glacial meltwater. The Holocene river reworked the uppermost part of the meltwater-deposited gravel and cut a new valley that is narrower than its ice-age predecessor. Before the construction of dams to control flooding, the South Platte reworked the upper part of the Holocene alluvial fill once more, by channel migration across the valley, and formed a floodplain by depositing mostly fine-grained sediment outside its banks. Although details differ, inheritance of valleys and bedload from predecessor ice-age streams has been described for other streams in glaciated regions (Brown, 1995).

The lateral variability of the upper gravel, the evidence for channel migration and reworking of older gravel, the presence of slumped masses of overbank sediment, and the young age of the upper gravel unit, indicates that it was deposited under flow conditions essentially identical to those of the modern South Platte. Both now and at the time of deposition of the upper gravel, the South Platte River north of Denver was a meandering-to-braided stream that deposited gravel in lateral and midstream bars and deposited fine sediment on the floodplain. (The spectrum of braided-to-meandering streams is discussed by Gilvear and Bravard, 1996). Streamflow was and is seasonally variable in the South Platte, with sustained high discharge during spring snowmelt in the mountains and short intervals of high discharge during intense rainfall on tributary drainage basins in spring and summer (Elliott and others, 1982). Most erosion and deposition, both in channels and on the floodplain, occurs during peak discharge.

The heterogenous particle size of the upper gravel, ranging from sand to coarse gravel over distances of a few hundred feet, is consistent with deposition by lateral migration of bars. Individual bars in braided rivers contain sediment having a wide variety of particle sizes (Bluck, 1982). The surfaces of lateral bars in the modern South Platte are covered with patches of gravel, sand, and silt and clay that, if preserved by burial, would probably be indistinguishable from deposits of the upper gravel. A map (Figure 17) of a complex lateral bar along the bank of the South Platte below its confluence with Clear Creek was prepared to illustrate the degree to which particle size can vary over short distances. Many lateral bars in the South Platte are simpler than the example shown in Figure 17, consisting of a gravel-covered bar and a chute (Lindsey and Shary, 1997), with only local accumulations of sand. The spectrum from simple to complex may reflect hydraulic conditions or maturity but, whatever their origin, the complex lateral bars reveal the explanation for heterogenous particle size in gravels.

Thin beds of sand and gravel on the floodplain are strong evidence that vertical accretion as well as lateral accretion and bar migration formed the floodplain of the South Platte River (see discussion of floodplain formation by Gilvear and Bravard, 1996). Lateral accretion and bar migration were responsible for forming a foundation of sand and gravel, and vertical accretion and pedogenesis formed the fine-grained overbank deposits.

The assemblage of sedimentary structures in the middle gravel unit is consistent with deposition by small bars that had an abundance of megaripples on the surface. The absence of caved masses of overbank sediment may indicate that the floodplain of the stream that deposited the middle gravel unit was composed of gravel, not overbank silt and clay. During periods of peak discharge, gravel would have been transported over the entire floodplain.

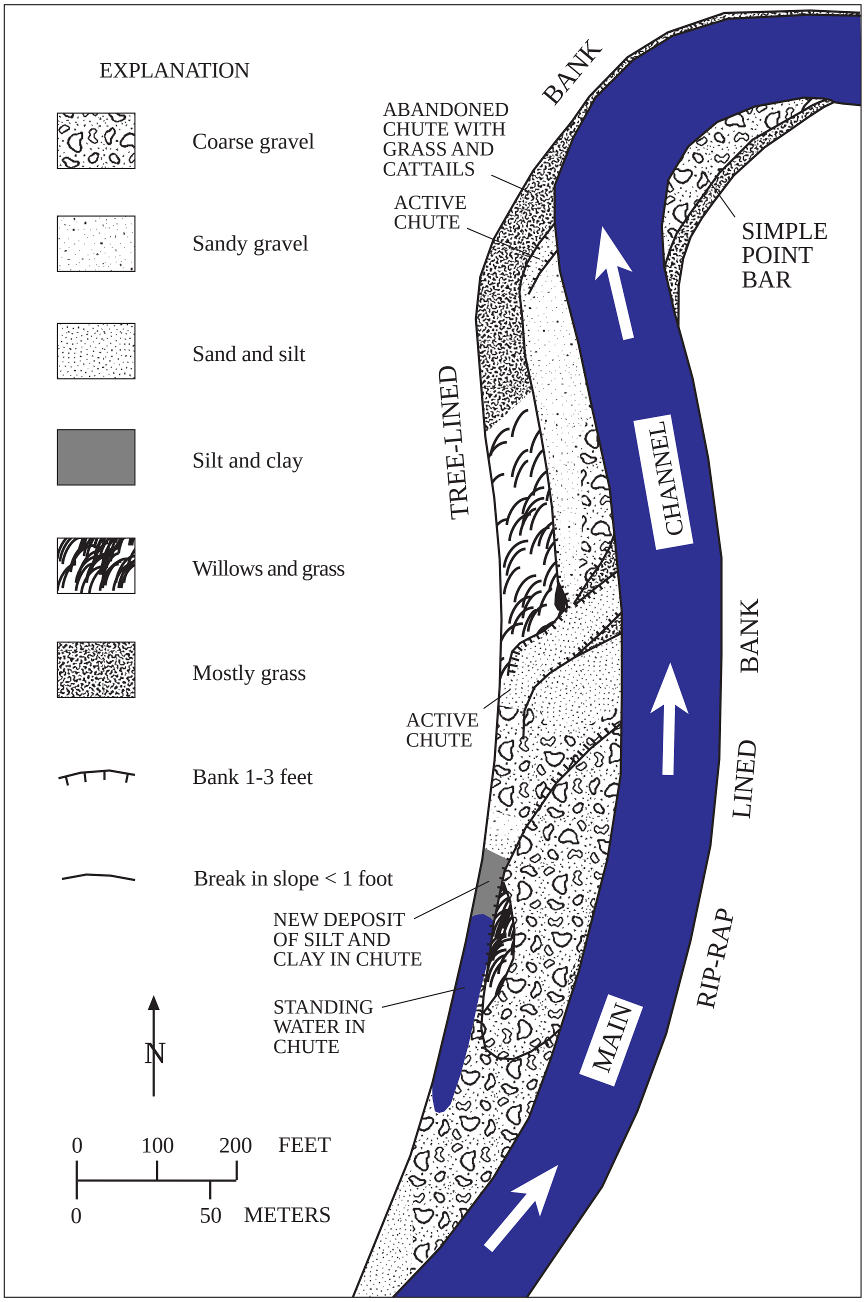

Figure 17.—Plan view of complex lateral bar 0.5 mi below the confluence of Clear Creek and the South Platte River, showing distribution of sediments and vegetation. Mapped by tape and compass in January, 1998, by D. A. Lindsey. All boundaries approximate; sediment particle size and vegetation generalized to show major features only.

A river that flowed in wide, shallow channels over coarse gravel would most likely have been braided rather than meandering. Alternatively, floodplain overbank deposits of silt and clay may have been destroyed by erosion prior to deposition of the upper gravel. Any reconstruction of the fluvial environment of the middle gravel must also account for local clay lenses. As proposed in Part C, these lenses are considered to have probably been deposited in the back channels (chutes) of lateral bars, which form in both braided and meandering rivers. Although the exact fluvial environment remains problematic, the middle gravel may have been deposited by a stream having more channel braiding and less development of floodplain overbank deposits than the modern South Platte. The South Platte of the middle gravel must have been an underfit, braided stream that flowed over a coarse bedload inherited from the previous large stream. Stream power was insufficient to rework all of the basal gravel.

The coarse basal gravel unit was most likely deposited by a river that had much greater discharge than the modern South Platte. The most likely source of the additional discharge would have been melting ice from glaciers in the valleys of upper Clear Creek and the upper South Platte River. The coarse particle size of the basal gravel is consistent with deposition by a large stream fed by glacial meltwater.

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U. S. English to metric conversion factors for distance measures:

1 inch (in) = 2.540 centimeters (cm)
1 foot (ft) = 0.3048 meters (m)
1 mile (mi) = 1.609 kilometers (km)