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Gravel deposits of the South Platte River valley north of Denver, Colorado
Part C: Description, composition, and origin of clay lenses in gravel

by

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Clay and silt in bar chute, South Platte River—proposed origin of clay lenses in gravel

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GRAVEL DEPOSITS OF THE SOUTH PLATTE RIVER VALLEY NORTH OF DENVER, COLORADO
PART C: DESCRIPTION, COMPOSITION, AND ORIGIN OF CLAY LENSES IN GRAVEL

by David A. Lindsey, Joseph E. Taggart, Jr., and Gregory P. Meeker

SUMMARY

Clay lenses in the Western Mobile Howe and Mann Lake gravel pits were investigated to determine their distribution, form, composition, and depositional environment, with the ultimate goal of predicting their distribution beneath the surface. Clay lenses fill shallow local depressions in the underlying gravel; the depressions are comparable in size to back channels (chutes) of gravel bars, where clay is accumulating in the present-day South Platte River.

The lenses contain abundant silt deposited from turbid suspension. In addition to clay, other detrital minerals were observed with the scanning electron microscope. Field examination and chemical analyses reveal that the uppermost few inches of most clay lenses contain abundant dispersed organic carbon but no other visible development of soil horizons or concentrations of caliche (calcium carbonate). All of these features are consistent with deposition and soil development in poorly drained environments, including abandoned chutes of gravel bars.

The proposed origin of clay lenses as deposits of abandoned chutes on gravel bars yields a prediction that typical lens size will not exceed several hundred feet in length and several feet in thickness. Chutes are oriented subparallel to streamflow and to one another. Groups of clay lenses in the subsurface might be expected to occupy elongate areas parallel to former stream channels.

SCOPE AND PURPOSE OF STUDY

Clay lenses are locally common within alluvial gravels of the South Platte River valley north of Denver (see Figures 6B and 7 of Part A). In a gravel pit, clay is waste material. Where clay lenses are encountered, they add to the time and cost of mining. Before gravel beneath a clay lens can be mined, the clay must be removed and placed outside the area to be mined.

The clay lenses in the Western Mobile Howe and Mann Lake pits (location shown in Figure 1 of Part A) were investigated to determine their distribution, form, composition, and depositional environment. Understanding the depositional environment of the clay lenses is required to predict where they might occur in the subsurface of a floodplain or river terrace.

Alternatives for the origin of the clay lenses include deposition by water or wind, deposition in a river channel or on a floodplain adjacent to the river, and subsequent modification by soil formation under well-drained (above water table) or poorly drained (at or below water table) conditions. Various combinations of these alternatives were considered in drawing inferences about the most likely depositional environment of the clay lenses.

A brief reconnaissance was conducted to search for modern environments in the South Platte River where possible analogs to the clay lenses might be forming today. Such modern environments suggest ways to predict the occurrence and distribution of buried clay in gravel.

METHODS AND ACKNOWLEDGEMENTS

The origin of clay lenses in gravel was investigated by field examination and by mineral and chemical analysis. Mineral identifications were made on two bulk samples by X-ray diffraction and scanning electron microscopy (SEM), with energy dispersive X-ray analysis (EDS), by G. P. Meeker and D. A. Lindsey of the U. S. Geological Survey, Denver, Colo. J. R. Hassemer, U. S. Geological Survey, Denver, Colo., made X-ray diffraction records. The SEM method provides detailed images of individual grains and EDS provides detection of major and minor elements at points on grain surfaces, allowing highly reliable identification from crystal form and composition, as well as direct observation of particle packing and size. Vertical profiles of clay lenses were sampled in the field for pollen (reported in Part A) and for quantitative chemical analysis, to assess vertical migration of chemical components that might reflect soil formation. If present, the type of soil is indicative of environment after deposition. Major oxides in clay were analyzed by J. E. Taggart by X-ray fluorescence spectrometry (method described by Taggart and others, 1987, and Mee and others, 1996) in laboratories of the U. S. Geological Survey. Organic carbon and carbonate carbon in clay were analyzed by XRAL Laboratories, Toronto, Ontario (methods described by Jackson and others, 1987).

We thank the staff of Western Mobile for access to the Howe and Mann Lake pits. They first brought the existence of the clay lenses to our attention, and they explained the difficulty that the lenses present when mining gravel.

FIELD RELATIONS AND DESCRIPTION

Clay lenses in gravel locally exceed 0.76 meters (m) (30 inches) in thickness and extend continuously for distances as great as 30 m (100 feet) (ft) or more along the faces of gravel pits (Figure 1). The lenses fill shallow depressions in the underlying gravel; the tops of lenses are horizontal except where they have been eroded prior to deposition of the upper gravel (Figures 6B and 7 of

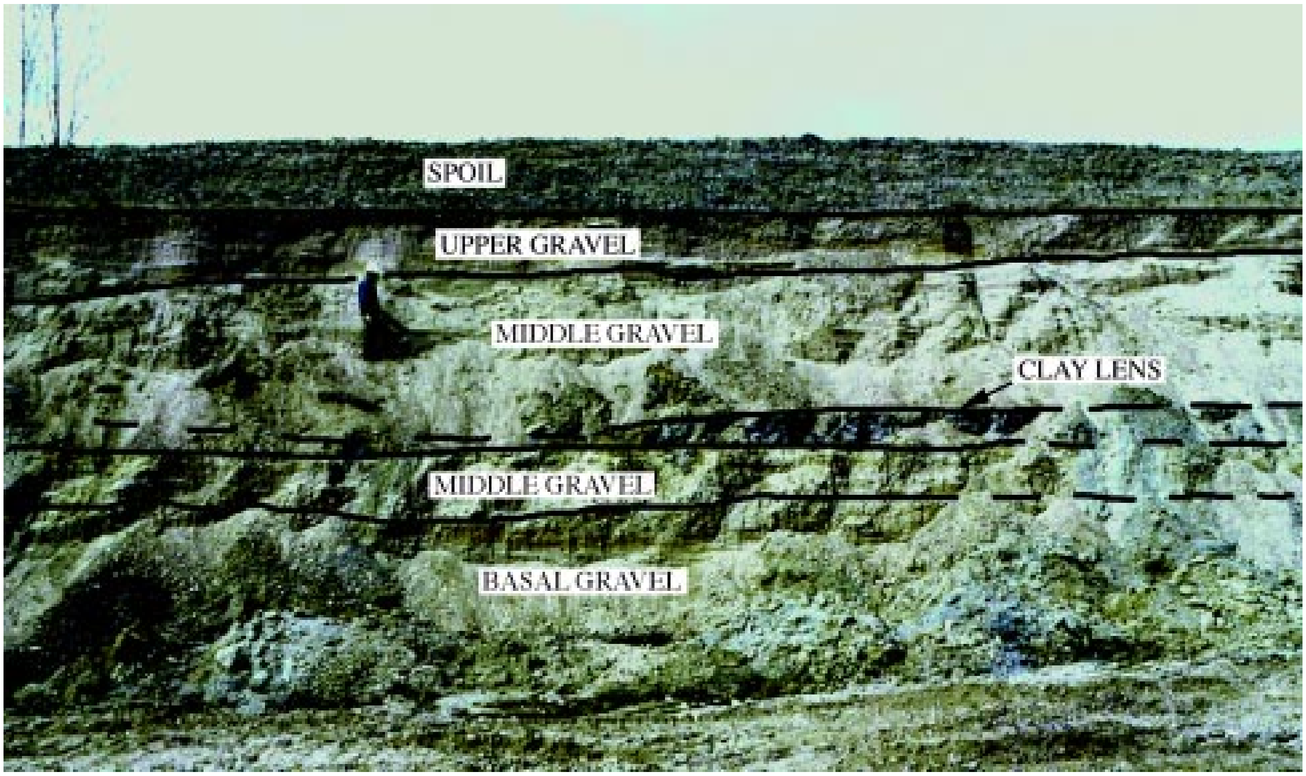

Figure 1.—Photograph showing clay lens in lower part of middle gravel unit, sampled for pollen and chemical analysis, Mann Lake pit. Location shown in Figure 7 of Part A.

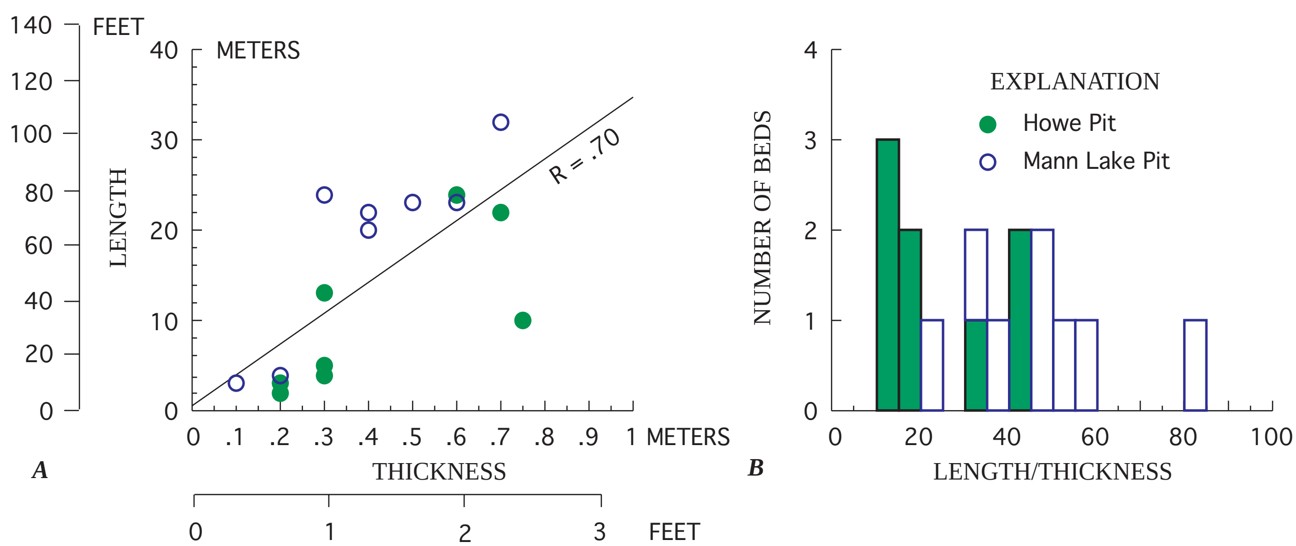

Figure 2.—Dimensions of clay lenses in the Howe and Mann Lake gravel pits: A) lens length (apparent, measured on pit face) versus maximum thickness; B) frequency distribution of lens length/thickness ratios of clay lenses.

Part A). The clay is silty, mostly gray to dark gray in color, and massive. No stratification or current structures were observed in most of the lenses. An exception to the absence of stratification was found in a thin lens on the west side of the Howe pit, where laminae less than one inch thick are draped over an irregular erosional scour in gravel below, suggesting deposition from suspension.

The dimensions of sixteen separate lenses (Figure 2) were determined from measurements and photographs of pit faces (shown in Figures 6B and 7 of Part A). Exposed lens lengths range from 2 to 32 m (6-105 ft). Maximum thickness of individual lenses ranges from about 0.1 to 0.76 m (4-30 inches). Ratios of exposed length to thickness range from 10:1 to 80:1 (Figure 2B). The exposed lengths and thicknesses of

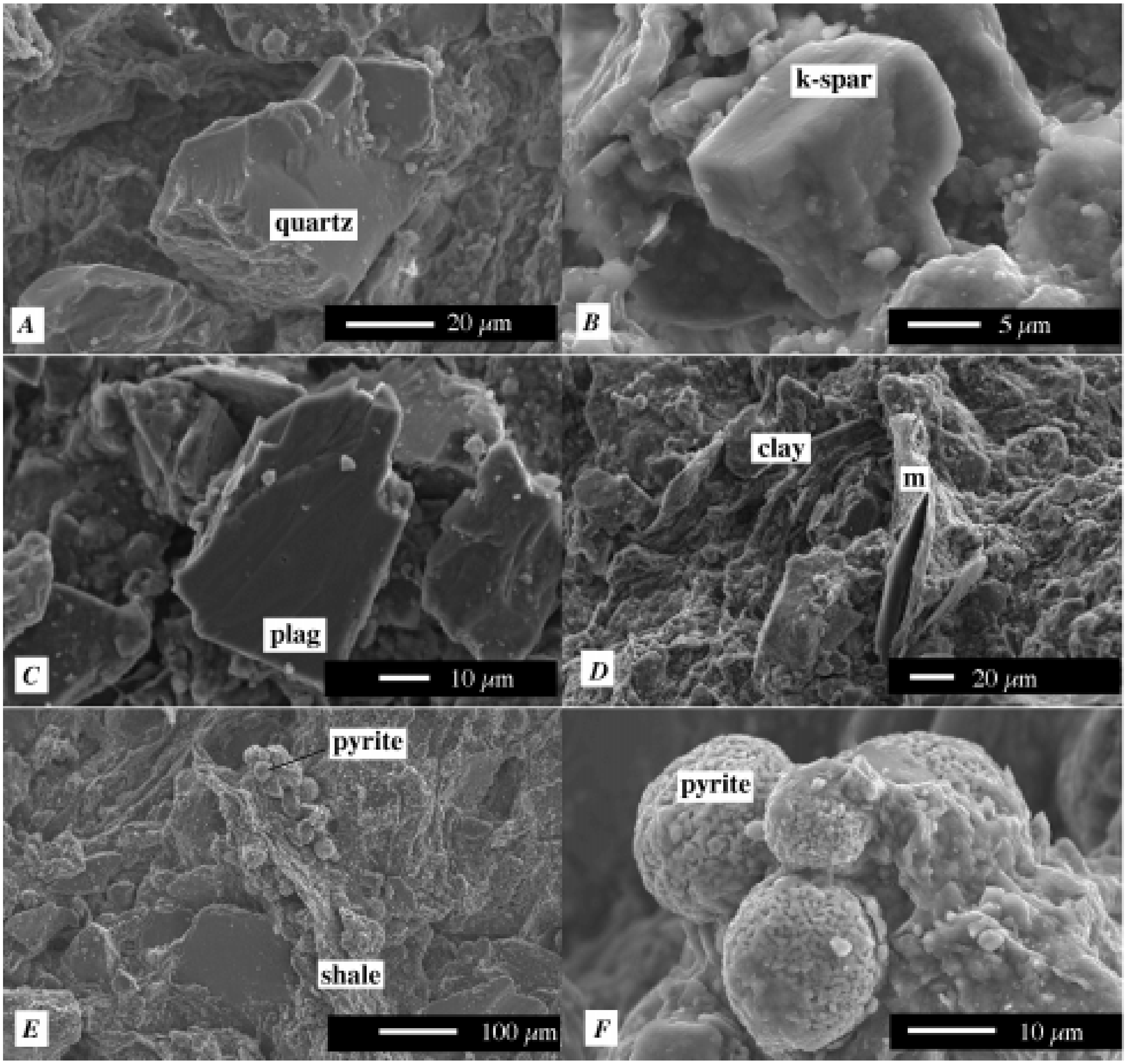

Figure 3.—Scanning electron microscope (SEM) photographs of individual mineral grains in clay lens, Howe pit. Most grains are silt size. A, quartz; B, potassium feldspar (k-spar); C, plagioclase (plag); D, probable illite (clay) and mica (m); E, shale fragment with small spheres of framboidal pyrite, probably derived from Cretaceous shale; and F, detail of framboidal pyrite in E. Scale bar in micrometers (μm); one μm = 10^{-6} meter.

lenses indicate deposition in local depressions on a surface of small relief.

GRAIN SIZE AND MINERALOGY

The lenses have a clay-like consistency when wet and, thus, are called “clay lenses,” but examination using a SEM reveals that much of the material in the lenses is 40-100 micrometers (μm) in average dimension, which is in the range of very fine to fine silt (Figure 3). X-ray diffraction of two samples showed a mixture of clay (kaolinite and well-crystallized illite or mica), quartz, potassium feldspar, and plagioclase; angular silt-size grains of all of these minerals except kaolinite were readily located and identified by SEM-EDS (Figure 3). The diverse orientations of these silt-size grains and the absence of crystal overgrowths are consistent with deposition of silt from turbid suspension. Rare grains of pyritic shale (Figure 3E, F) and zircon, identified by EDS, are additional evidence for a detrital origin for the clay lenses.

CHEMICAL COMPOSITION AND ZONING

The chemical composition of South Platte clay lenses is comparable to a variety of possibly related natural materials in the watershed of the

Table 1.—Summary of chemical composition of clay lenses in gravel and overbank sediment, floodplain and low terraces of the South Platte River valley north of Denver, Colo., compared to weighted average of Precambrian source rocks, Denver loess, and Front Range Urban Corridor soil. All values are arithmetic means except for Front Range Urban Corridor soil, which is the geometric mean; all values in pct (percent). —, not analyzed or not applicable.

OXIDE OR ELEMENT	AVERAGE CLAY LENS IN GRAVEL (20 SAMPLES)	AVERAGE OVERBANK SEDIMENT (4 SAMPLES)	AVERAGE PRECAMBRIAN SOURCE ROCK[1]	AVERAGE DENVER LOESS[2]	AVERAGE URBAN CORRIDOR SOIL[3]
SiO_2	66.5	64.3	67.2	65.1	67.6
TiO_2	0.63	0.63	0.56	--	0.35
Al_20_3	14.1	13.6	15.0	14.6	10.7
Fe_T0_3	3.50	4.35	4.73	5.17	3.09
MnO	0.03	0.08	0.08	--	0.04
MgO	1.04	1.12	1.72	1.35	0.68
CaO	1.09	1.88	2.19	2.53	1.16
Na_20	1.28	1.55	2.67	1.34	1.17
K_20	3.34	3.42	4.37	2.71	3.06
LOI[4]	7.72	7.73	1.154	7.014	--
P_20_5	0.14	0.18	0.14	0.32	0.09
C_T[5]	1.356	1.198	--	--	1.42
C_{Org}[5]	1.345	1.082	--	--	1.26
C_{Carb}[5]	0.011	0.116	--	--	0.018
Total[6]	99.37	98.84	99.81	100.13	--

1 Average of Precambrian source rock in the South Platte River watershed, weighted according to approximate percent of total Precambrian: 38 pct Early Proterozoic metamorphic rocks (90 analyses), 38 pct Middle Proterozoic Pikes Peak Granite (26 analyses), 6.5 pct Early Proterozoic Boulder Creek Granodiorite (79 analyses), and 6.5 pct Middle Proterozoic Silver Plume Quartz Monzonite (32 analyses); data from unpublished analyses in U.S. Geological Survey files.

2 Average of two loess samples from the Denver area (Hill and others, 1967, tab. 2).

3 Average soil, Front Range Urban Corridor, based on surface soils at 760 sites from Colorado Springs to Ft. Collins, Colo. (Severson and Tourtelot, 1994, tab. 3).

4 LOI, loss on ignition at 925°C; for average Precambrian source rocks and loess, LOI 925°C = $H_2O + CO_2$.

5 C_T, total carbon; C_{Org}, organic carbon; C_{Carb}, carbonate carbon.

6 Total calculated from oxides plus LOI 925°C; all forms of carbon omitted from total because they are included in LOI 925°C.

South Platte River (Table 1). On average, the clay lenses are remarkably similar in composition, including amount of organic carbon, to the average composition of overbank sediment including soil. Both clay and overbank sediment are close to the weighted mean silica and alumina composition of Precambrian source rocks in the South Platte River watershed of the Front Range; both show some depletion of iron, alkaline earth, and alkali oxides from weathering and transport from the mountains to the plains. Except for higher alumina and slightly lower silica, iron oxide, and MgO, the clay and overbank sediment are comparable to modern soils of the Front Range Urban Corridor (Severson and Tourtelot, 1994). The average composition of clay and overbank sediment also compares closely with the composition of loess in the Denver area (Hill and others, 1967), having only slightly less iron oxide and slightly more K_2O; however, they contain as little as half the CaO in loess. The overall similarity of clay to other weathered materials in the South Platte River valley indicates that the bulk of the minerals in the clay lenses are the product of weathering before final deposition.

The only visual evidence of soil horizons in clay lenses is a slightly darker, grayish-black color in the top 2-4 inches (5-10 cm) of clay. The dark upper parts of clay lenses contain as much as 4.66 pct organic carbon (Figure 4). Below the organic-rich zone, organic carbon declines to as little as 0.1 pct.

Vertical profiles of major-element oxides in the clay lenses suggest weak leaching and concentration consistent with soil formation under poorly-drained conditions (Figure 4). Conceivably, vertical variation in major-element oxides in buried clay lenses may also be the product of ground water alteration after burial. The concentrations of silica, Na_2O, K_2O, and possibly P_2O_5 (recalculated to volatile-free weight percent) tend

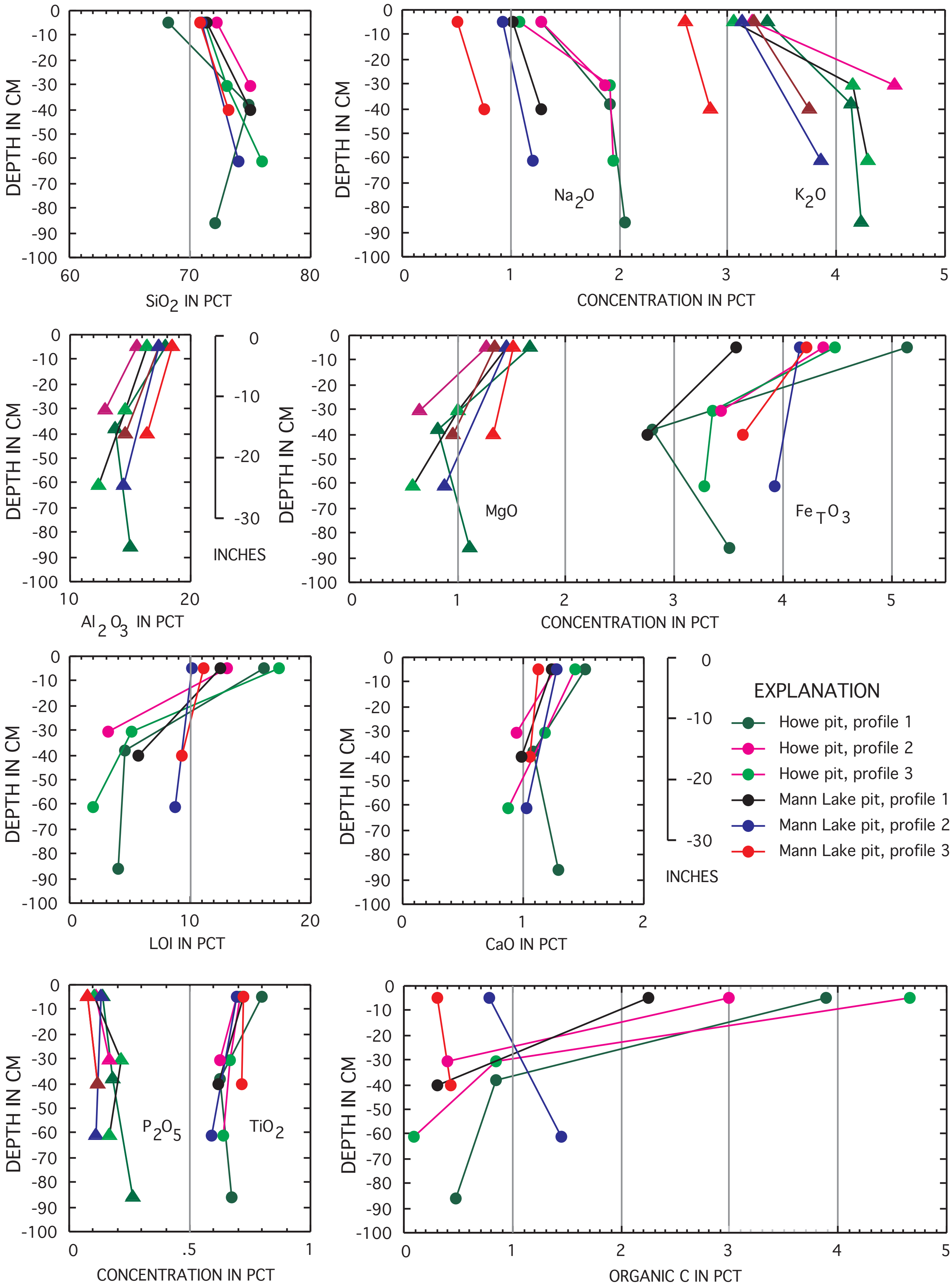

Figure 4.—Vertical profiles of major-element oxides, loss on ignition at 925°C, and organic carbon in six clay lenses from the Howe and Mann Lake pits. All major oxide values recalculated to volatile-free basis.

to be lowest in the organic-rich upper zone, whereas concentrations of alumina, MgO, iron oxide, and CaO tend to be slightly higher in the organic-rich zone. Titania and MnO (not shown) do not show vertical variation. A decrease in loss on ignition (LOI) with depth is only partly due to a corresponding decrease in organic carbon. Most of the decrease in LOI can be attributed to less water in the lower parts of clay lenses. Carbonate carbon was determed to be nil in all of the clay sampled. The absence of carbonate carbon confirms the visual appearance of the clay lenses as lacking a calcareous B soil horizon. Calcareous B soil horizons are common in well-drained soils of the arid plains of eastern Colorado, including the floodplain of the South Platte River and its tributaries (e.g., Hunt, 1954; Machette, 1977).

If the strong concentration of organic carbon in the upper parts of clay lenses and the weakly developed chemical zonation are products of soil formation, then the soil was developed in a poorly drained environment. In river valleys, poorly drained soils are found in floodplain backswamps and infilled channels (Gerrard, 1981).

ORIGIN OF CLAY LENSES IN GRAVEL: POSSIBILITIES AND IMPLICATIONS

Silty clay is deposited in as many as four environments in the present-day South Platte River: 1) on the floodplain, 2) on gravel bars, 3) in the back channel (chute) of gravel bars, and 4) in areas of slack water in the channel. A sixth environment of clay deposition, abandoned channel meanders cut off when the river switches to a new channel, was not examined but probably should have been. Of these environments, the first (floodplain) and last (channel) are considered least likely to have been the site of deposition of the clay lenses found in the gravel. Floodplain clays are continuous for much greater distances than the clay lenses, contain evidence of soil formation including calcareous deposits, and are commonly strongly layered and laminated below the A (humic) soil horizon. Thus, floodplain clays do not match closely the physical dimensions or characteristics of clay lenses. Thin (<1 inch) coatings and layers of clay can be observed in slack water in the shallow parts of channels. Channels are commonly shallowest on the convex sides of point bars. However, such channel clays are probably transitory, being exposed to scour during periods of maximum flow. In contrast, clay deposits occur locally on gravel bars (environments 2 and 3) and may be preserved beneath gravel during bar migration.

Gravel bars in the present South Platte are lateral (or, where the channel turns sharply, point bars) and medial varieties; most lateral bars are separated from the river bank by a back channel or chute, which commonly lies empty during low flow (Lindsey and Shary, 1997) (Figure 5; Figure 18 of Part A). Bar chutes are active during high flow, when the river flows directly over gravel bars. The river transports and deposits gravel on the bars during high flow, but when high flow recedes, sand, silt and clay are deposited on the surface of the bar. Fine-grained sediment is deposited first where stream velocity drops as it encounters the gravel bar. Small lenses of sand, silt, and clay are deposited at the upper ends of bars and along bar tops adjacent to the channel. When water depth recedes below the top of the bar, fine-grained sediment is deposited in the chute. During low flow, plants including cattails, grasses and willows become established on the silt and clay deposited on the bar and in the chute. Once vegetation becomes established on a bar, high flow is further impeded and the potential for deposition of fine-grained sediment is increased. Soils developed on the gravel bar are well-drained, but those in the chute are poorly-drained and commonly covered by standing water. Lamination in silt and clay would likely be destroyed by plant roots. The lower ends of bar chutes were observed in various stages of abandonment and filling with fine-grained sediment; examples range from chutes containing thin deposits of clay on gravel to chutes that are full of sediment and overgrown with vegetation (Figure 18 of Part A). Empty chutes are mostly barren of plants (Figure 5), but those that have

Figure 5.—Photograph of complex gravel bar in South Platte River, showing chute filling of sand, silt, clay and standing water. View downstream; downstream portion of bar contains infilled, vegetated chute.

been abandoned and filled with sediment are choked with vegetation.

Abandoned channel meanders are known as sites of clay accumulation (Gilvear and Bravard, 1996). Clay accumulates in an abandoned channel after it is temporarily occupied by flood water. Such clay deposits would be expected to differ from clay deposits in abandoned bar chutes primarily by their larger size. Typically, channel width and depth in the modern South Platte exceeds that of bar chutes by an order of magnitude. However, abandoned channels cannot be excluded completely as a possible environment for deposition of clay lenses without further study.

Abandoned bar chutes filled with fine-grained sediment are considered to be the most likely environment for the silty clay lenses seen in gravel deposits. If an abandoned chute filled with fine-grained sediment is buried by sand and gravel, it typically would form a lens oriented subparallel to streamflow and measuring as much as several hundred feet in length and 50 feet in width, consistent with the areal dimensions of clay lenses observed in the gravel pits. Typically, empty chutes along the South Platte are about two feet deep, approximately the thickness of clay lenses observed in the gravel pits. The general lack of structure in clay lenses, and the concentration of organic matter in the upper part, are both consistent with vegetation growing on a clay-filled chute. Finally, evidence for weak chemical leaching of the clay lenses is consistent with weak soil development in saturated sediment. All lines of evidence favor the chute over the bar top as the site of clay lens deposition.

If the bar chute environment represents the site of deposition for the clay lenses, then the plan view of size, shape and orientation of clay lenses in gravel can be predicted once the lenses have been detected in drillholes or exposed in pit faces. Size of clay lenses should be less than 50 by roughly 200 feet, the approximate maximum size of bar chutes in the present river, and orientation of the long dimension should be approximately parallel to the valley. Also, orientation of the long dimension of lenses should be predicted accurately from the orientation of small-scale crossbedding in subjacent gravel. According to the abandoned bar chute model, groups of clay lenses in the subsurface might be expected to occupy elongate areas parallel to former stream channels.

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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)