Surficial Geology of the Louisville Quadrangle Colorado

GEOLOGICAL SURVEY BULLETIN 996-E

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By HAROLD E. MALDE

A CONTRIBUTION TO GENERAL GEOLOGY

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By Harold E. Malde

ABSTRACT

Surficial deposits in the Louisville quadrangle, Colo., are divisible into three main groups—pre-Wisconsin, Wisconsin, and Recent. They indicate early Pleistocene valley incision below pediments and late Pleistocene valley filling and upland eolian deposition. Events recorded by Recent deposits have little modified the land, but they indicate minor climatic fluctuations.

The pre-Wisconsin deposits include material of probable Pliocene and early Pleistocene age, the former on pediment remnants along the Front Range foothills, the latter on a lower pediment and within valleys. Valley deposits include alluvial, colluvial, and eolian materials; deposits older than those in valleys are fluvial gravels. Pedogenic processes operated on these materials more than once during pre-Wisconsin time and developed thick layers thoroughly impregnated with calcium carbonate, overlain by oxidized layers characteristically rich in illite-type clay. At the close of soil-forming intervals the climate may have been relatively dry. Local development of relatively noncalcareous pre-Wisconsin soil on western parts of the pediment gravels may have been caused by forest cover. The physical geology and buried soils suggest that valleys were incised to near-present depth during the early Pleistocene.

Wisconsin fluvial and eolian deposits overlap erosional unconformities carved into pre-Wisconsin deposits. Gravel fill in major valleys and alluvial fill in tributary valleys were probable sources for an eolian mantle on the upland. Although Wisconsin and pre-Wisconsin soils are somewhat similar, Wisconsin soils contain much less carbonate in the subsoil and have a calcic montmorillonite-type clay in a thin, weakly oxidized horizon at the top. The soil may have developed chiefly during the mid-Wisconsin soil-forming interval recognized in Nebraska and Kansas.

Recent deposits overlap those of Wisconsin and pre-Wisconsin age but are of much smaller extent. They are mostly alluvial, but small areas are thinly covered by colluvium that may include reworked eolian sand. Alluvial deposition in arroyos on the upland and subsequent erosion (since A. D. 1000) suggest a dry-wet-dry climatic sequence. Modern alluviation along major streams consists of intermittent reworking of tops of older materials and deposition of small quantities of new alluvium. Recent soils have shallow and incompletely developed profiles.

INTRODUCTION

LOCATION, ACCESSIBILITY, AND GEOGRAPHY

The Louisville quadrangle, Colo., is adjacent to the eastern foothills of the Front Range and includes dissected uplands which are the highest areas between the foothills and the South Platte River Valley

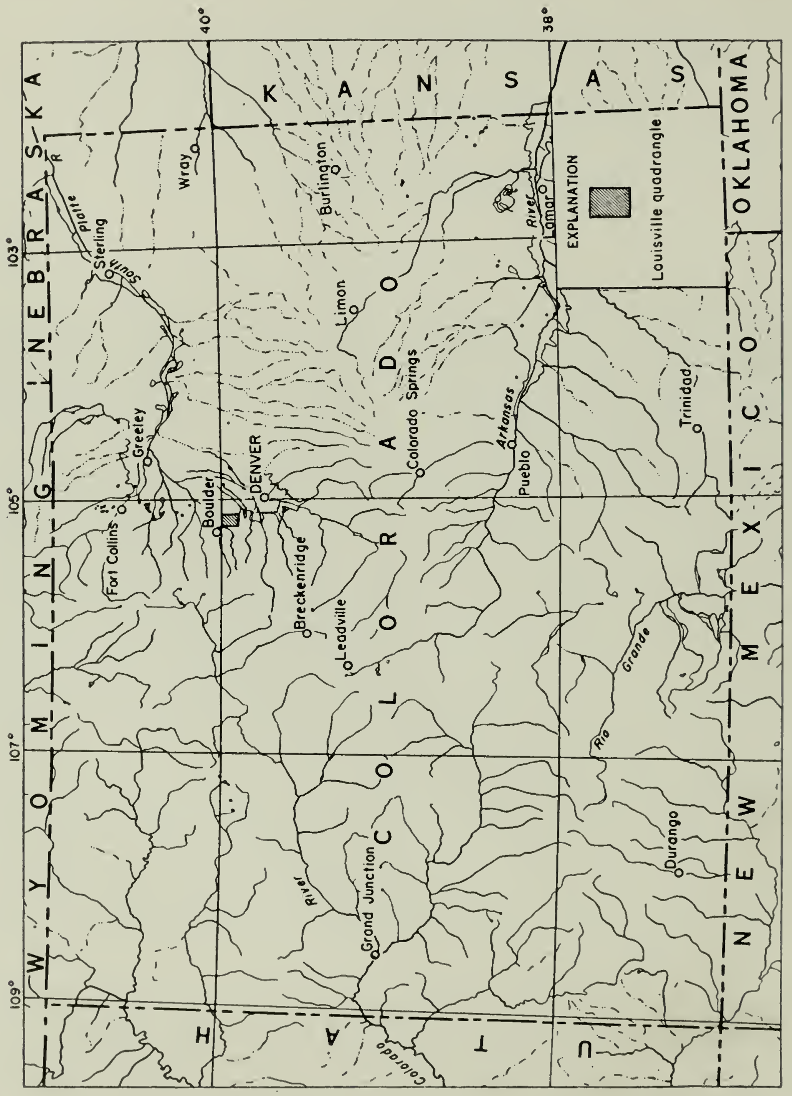

FIGURE 49.—Index map of the Louisville quadrangle and the Denver area.

(fig. 49). Two major tributaries of the South Platte River—South Boulder and Coal Creeks—emerge from the mountains near the western border of the quadrangle and pass through the area. The southern half of the quadrangle is drained by tributaries of Clear Creek. Altitudes range from 6,320 feet in the southwest corner to 5,270 feet near Base Line Reservoir.

The Louisville quadrangle is a part of the Colorado Piedmont, an area lying between the High Plains and the Front Range from which the Tertiary cover has been excavated by the Arkansas and South Platte Rivers (Fenneman, 1930, p. 30). Gilbert (1896, p. 578) estimated that these two rivers have deepened their valleys from 400 to 800 feet since the Tertiary mantle was deposited. The quadrangle lies about midway between the South Platte-Arkansas River divide and the High Plains escarpment to the north. Most of the relief in the quadrangle was carved during the Pleistocene. Although a Pliocene age is suggested for some deposits resting on high-level erosion surfaces near the foothills, the relation of these deposits to the Tertiary mantle to the north, east, and south is not known.

A network of graded rural roads connects farm properties with the towns of Louisville, Superior, and Marshall, and surfaced roads connect these towns with the main highways. The quadrangle is bounded on the north by Base Line road, a two-lane asphalt highway. This connects U. S. Highway 87, which parallels the quadrangle 2 miles to the east, and Boulder. State Highway 93, a gravel road, connects Marshall and Golden. The Denver-Boulder toll road, a four-lane highway not indicated on the topographic map base, enters the quadrangle near the southwest corner of sec. 28, T. 1 S., R. 69 W., passes the northeast corner of Superior, and continues to the northwest corner of the quadrangle. This road has no points of entry within the quadrangle, but it can be entered at Boulder and at Broomfield.

About one-third of the quadrangle is under irrigation; the rest is about equally divided between dry farming and grazing. Irrigation is necessary for sugar beets, alfalfa, truck crops, and fruits; dry farming suffices for raising corn, pinto beans, and grains. Grazing is chiefly restricted to the rocky uplands and dissected slopes. Boggy lowlands and gravelly areas in modern flood plains are used for dairy farming. Initially, irrigation was restricted to lowlands that were supplied with water by small private ditches from river channels nearby, but since about 1870 a system of large canals, dams, and headgates, later linked with large storage reservoirs, has supplied water independent of direct flow from streams.

Short grasses are the chief natural vegetation. Buffalo and gramma grasses predominate on well-drained upland soils of medium to heavy texture; bunch grass and sand sage are common on upland soils of sandy texture. In small, poorly drained valleys wheat grass is found, and in seep areas salt-grass, sedges, and squirrel-tail are indicators of the concentration of salts. On light- or medium-textured soils prickly pear and soapweed predominate. A stand of stunted ponderosa pine grows on the western part of high pediment remnants, and before 1900 this stand extended farther east. Cottonwood grows along modern stream courses.

Part of the coal-producing area of the Denver basin is included in the Louisville quadrangle. Mines at Marshall, which have produced coal since 1863, were among the earliest to be opened in Colorado, and the towns of Louisville and Superior owe their existence to mines nearby. A map made by Eldridge (Emmons, Cross, and Eldridge, 1896, pl. 3) shows about 20 square miles in the Louisville quadrangle underlain by coal within 400 feet of the surface. This area extends to the northeast from Marshall through Louisville and beyond in a belt from 2 to 3 miles broad. A restricted area of steeply dipping coal beds trends nearly due south from Marshall and continues beyond the quadrangle limits. Active coal mines and the larger abandoned mines are shown on the topographic base of the accompanying map. Because the coal usually slakes if stored in stockpiles, mining is done during the winter months when the demand is greatest. Miners who work the coal only during the winter commonly have small tracts of land that they farm in the summer.

PREVIOUS WORK

Before the present study, stratigraphic mapping of Pleistocene deposits of the Front Range foothills was limited to the Denver area (Hunt, 1954). Several interpretations of Tertiary and Pleistocene history of the Front Range, based upon reconnaissance surveys, have been proposed. Most of these proposals divide the Pleistocene into two stages. The last stage (Wisconsin) has been divided into substages in various ways. Physiographic evidence alone is insufficient to support a definite correlation between glacial deposits in the mountains and nonglacial deposits east of the mountains because of barren intervening canyons. However, Bryan and Ray (1940) studied glacial deposits in the Cache la Poudre drainage area and suggested a correlation with cycles of erosion and deposition in the Colorado Piedmont.

METHODS OF STUDY AND ACKNOWLEDGMENTS

This study was begun in October 1949 and continued intermittently until December 1951. Most of the field work was done in the summer of 1950. Previous to this work several areas in the northern Colorado Piedmont and in the mountains were visited and examined, partly with Herbert W. Dick, archaeologist of the University of Colorado Museum.

The Louisville quadrangle was selected as an area for detailed study because: It is near the Denver area (fig. 49) where surficial deposits were being studied by Charles B. Hunt. It is an upland area farther from the South Platte River than any part of the Denver area, and it might, therefore, include stratigraphy not represented on terrain contiguous to the South Platte River. It is adjacent to the foothills and includes steeper topography which, it was thought, would control facies changes in deposits present in the lower area of Denver.

Field mapping was done directly on the printed topographic sheet at a scale of 1:31,680. In most places contacts were drawn on the basis of assumed thickness and depth to a particular unit. An attempt was made to establish a datum plane 2 feet below the surface. Actual contacts between deposits can be seen only in ditches or similar exposures. Lines drawn on the map connect such exposures: contacts that are believed to be accurate within 100 feet are shown as solid lines on the geologic map (pl. 7); and those believed to be accurate within 300 feet are shown as dashed lines; inadequately exposed contacts are shown as dotted lines.

Free use was made of soil surveys (Harper, Acott, and Frahm, 1932; Sweet and Dodson, 1930) where it was known that a soil type or types corresponded to a surficial unit. Soil profiles were tested for the pH of their various parts. A soil hydrometer kit was used in the field to determine the combined silt and clay content, and the simplified Bureau of Reclamation soil hydrometer method was used in the laboratory to determine sorting of silt-size material and weight percent of silt and clay. Clay-size material was removed from suspension in a sedimentation cylinder, dried, and analyzed by the differential thermal method. The instrument used was a portable model calibrated to an accuracy of $\pm 10°$ C.

The work was done under the general direction of Charles B. Hunt whose findings in the Denver area have been a framework to which the stratigraphic record in the Louisville quadrangle has been referred. The laboratory investigation was aided by David J. Varnes of the U. S. Geological Survey and Myrle E. King of the U. S. Bureau of Reclamation. During the early part of the work the department of geology of the University of Colorado and Hugo G. Rodeck, director of the university museum, supplied office and laboratory space.

STRATIGRAPHY

UPPER CRETACEOUS AND PALEOCENE

Bedrock geology was not mapped during this study and the information given here is a brief summary from published sources. The only map that includes the entire area (Emmons, Cross, and Eldridge, 1896, pl. 2) is old, on a small scale, and in need of revision.

The quadrangle is underlain by shale and sandstone of Late Cretaceous age and by conglomerate, shale, and sandstone of Paleocene age. The beds are nearly horizontal in broad, open, northeast-trending folds throughout most of the quadrangle, but they are abruptly tilted to high angles near the western border along the foot of the Front Range uplift. In the northeast part of the quadrangle high-angle faults of small throw parallel gentle folds and break the limbs of these folds (Emmons, Cross, and Eldridge, 1896, pl. 4, section 2).

The oldest bedrock in the area is the Pierre shale which is on the west side of the quadrangle and crops out in fault blocks between Marshall and Louisville. The Pierre is dominantly a dark-gray clay shale that becomes sandier and lighter colored toward the top. Thin bentonite beds occur throughout all but the upper sandy part, and concretions of limestone and ironstone are common in the middle part. The Pierre is transitional to the Apishapa shale below and the Fox Hills sandstone above. Fenneman (1905, p. 72–76) has described in some detail the use of Pierre shale in local brick manufacture.

The Fox Hills sandstone consists of gray to grayish-yellow sandy shale that grades upward into poorly consolidated fine-grained yellow sandstone. The sandstone is slightly calcareous and includes iron-stained limy sand concretions. Locally, impure limestone layers and small calcareous and ferruginous concretions occur in the basal shales. A mineralogic distinction of the Fox Hills from the overlying Laramie formation has been proposed by Gude (1950, p. 1702–1705, fig. 1) who found that the clay fraction of the Fox Hills is a mixture of kaolinite and montmorillonite, whereas the clay fraction of the Laramie is a mixture of kaolinite and illite.

The Laramie formation is the most common bedrock unit in the Louisville quadrangle, underlying about 56 square miles. From this formation has been obtained all of the coal mined in the area. The lower 200 feet is dominantly a coarse gray quartz sandstone separated by thin beds of shale, clay, and coal. This zone contains by far the greatest number of workable coal beds, although coal seams are found above it. The overlying 350 feet or more of the formation is made up of irregular beds of drab shale and clay with numerous ironstone concretions. Carbonized plant remains, which are found throughout, and ripple marks and mud cracks further attest to a fresh and brackish water site of deposition for the formation.

Overlying the Laramie is the Arapahoe conglomerate. Paleontologically, the Arapahoe and the lower part of the Denver formation, which lies above, do not differ from the Laramie. Brown (1943) has suggested that the Laramie should include the Arapahoe conglomerate and the Cretaceous part of the Denver formation as members. The Arapahoe is a conspicuous conglomerate averaging 100 feet in thickness and containing fragments derived from local sedimentary rocks of older age and from the crystalline complex farther west. It has been mapped in the Louisville quadrangle only in an area half a square mile in size due south from the town of Louisville at the boundary of Boulder and Jefferson Counties.

LATE PLIOCENE OR EARLY PLEISTOCENE

Deposits interpreted as late Pliocene or early Pleistocene include old gravel capping a small knoll in the southwest corner of the quadrangle, and pediment gravel on Rocky Flats.

OLD GRAVEL

The oldest surficial deposit in the quadrangle is a coarse gravel, no thicker than 10 feet, which caps a small bedrock knoll in the SE¼ sec. 8, T. 2 S., R. 70 W. The base of the deposit is at an altitude of 6,310 feet, about 40 feet above Rocky Flats. Little can be ascertained about the original characteristics of the gravel because it occupies so small an area. The surface is strewn with a cobble and boulder concentrate that is almost exclusively quartzite. Large surface boulders are commonly 2 feet in diameter, and the average size of the cobbles is about 8 inches. Because the gravel is now isolated from other deposits of comparable topographic position, its correlatives, if any, are not known.

GRAVEL ON ROCKY FLATS

The dissected erosion surface known as Rocky Flats occupies much of the southwest part of the quadrangle, where it transects the Pierre shale, Fox Hills sandstone, and Laramie formation. At the mouth of Coal Creek canyon, 1½ miles west of the southwest corner of the quadrangle, the flats cuts across steeply dipping older sediments including the resistant Dakota and Fountain formations.

Rocky Flats is capped by gravel that ranges in thickness from less than 1 foot to about 50 feet, and averages about 10 feet. The thinnest parts are over bedrock ridges, and the thickest are in broad, shallow channels cut into the bedrock. No orderly variation in average thickness of the capping gravel was found from the foothills to the most eastern remnants. Although the bedrock surface on which the gravel rests has a relief of about 50 feet, the top of the gravel cap is smooth.

Rocky Flats has the form of a fan with its apex near the mouth of Coal Creek canyon and its crestline nearly coincident with the south boundary of the quadrangle. The gradient of the surface along the crestline ranges from 70 feet per mile at the most eastern remnants, 5 miles from the foothills, to 140 feet per mile at the apex of the fan (fig. 50). Laterally, from the mouth of Coal Creek canyon at an altitude of 6,500 feet, the flats extends 3 miles north along the foothills nearly to Eldorado Springs, where the altitude is 6,100 feet; here it is about 350 feet above South Boulder Creek. South of the mouth of Coal Creek canyon, Rocky Flats is eroded and not so extensive.

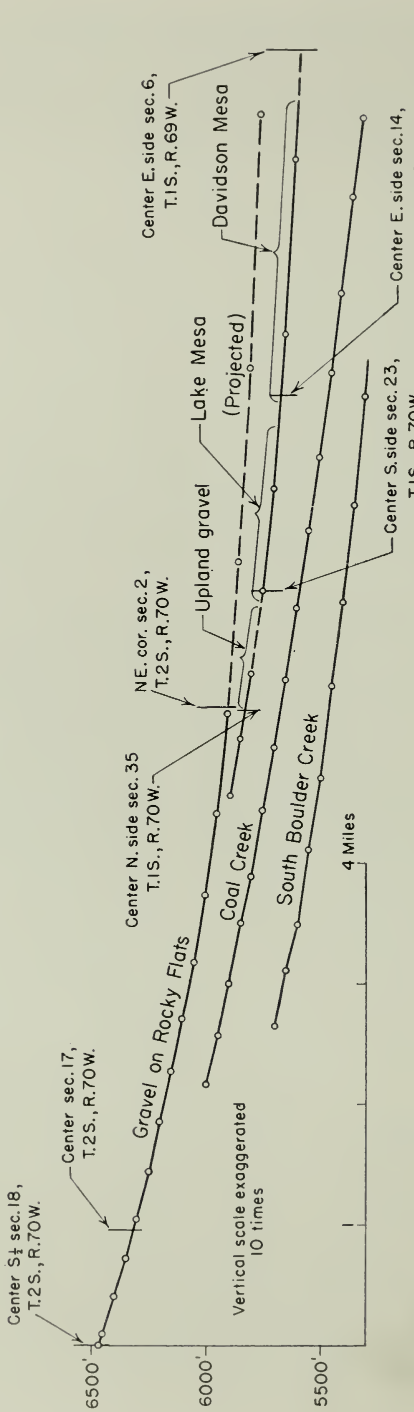

FIGURE 50.—Profiles of Rocky Flats, Davidson and Lake Mesas, Coal Creek, and South Boulder Creek. Horizontal plot was adjusted to make vertical separation correct. Altitude of projected Rocky Flats surface was computed.

The deposit includes coarse sand and boulders. Along the western boundary of the quadrangle, 1½ miles from the mountain front, about half of the deposit is pebble gravel, the pebbles ranging from 2 to 4 inches in size, but boulders as large as 2 feet are common. Along the eastern limit of the flats the gravel is less poorly sorted and finer grained. The average size is about 1 inch; fragments larger than 6 inches are rare. Here, also, are lenses of sand (fig. 51). Faces of quartzite fragments are commonly preserved, but those of less resistant rocks have been rounded off.

Pebble counts of the gravel show that it is composed of about 60 percent quartzite, 20 percent schist and gneiss, 12 percent granite and pegmatite, and 8 percent sandstone and siltstone. These materials, with the exception of the sandstone and siltstone that were derived from hogbacks along the foothills, have their source in the drainage basin of Coal Creek, which extends about 7 miles into the mountains. The chief gravel constituent, quartzite, is derived from the Coal Creek quartzite which crops out only in a small area between Coal Creek and South Boulder Creek just west of the hogbacks. (See Lovering and Goddard, 1950, pl. 2, north half.)

The gravel has been strongly weathered. Quartzite fragments are comparatively fresh internally but have a stained and crumbly rind from 2 to 5 mm thick. Granitic and gneissic fragments crumble easily, and in cross section their outlines are commonly obscured by clay enrichment that grades into the surrounding matrix. Decomposition of the granitic and gneissic fragments, and downward leaching of their soluble weathering products, have resulted in the concentration of their resistant mineral grains in the interstices of the upper part of the deposit.

The weathering profile on the gravel has two facies. One of these, a caliche facies, is marked by intense accumulation of calcium carbonate; the other, a facies of low-lime content, has little or no calcium carbonate as a cement, although it effervesces with acid at depths from 1 to 8 feet below the surface. The calcareous layer of the caliche facies is white and firmly cemented; the calcareous layer of the low-lime-content facies is yellow brown and friable. The transition from one facies to the other is abrupt, a foot of caliche disappearing a quarter of a mile upslope. However, isolated lenses occur short distances above the principal caliche area. The generalized distribution of the two facies, shown on the geologic map (pl. 7), indicates that the change from one facies to the other takes place at successively lower altitudes northward from the crestline of Rocky Flats.

This caliche facies is comparable to that of surficial deposits in the Denver area that are designated on the basis of stratigraphy and fossils as pre-Wisconsin (Hunt, 1954). Moreover, in the Denver

FIGURE 51.—Crossbedded gravel and sand in gravel pit on Rocky Flats in the NW¼SW¼ sec. 23, T. 2 S., R. 70 W. (Golden quadrangle). Dark excavated material at top rests on truncated calcium carbonate layer. Nearby, a brown-red gravelly clay occurs above the carbonate layer. Calcium carbonate is most conspicuous at the top but also fills vertical joints below and is concentrated laterally at depth along contacts between gravel and sand lenses. The coarse prismatic structure and massive accumulation of carbonate near the hammer is typical of pre-Wisconsin soil development on fine-grained parent materials.

area deposits of Wisconsin and younger age do not have weathering profiles with thick, indurated caliche layers. The gravel on Rocky Flats is therefore considered to be pre-Wisconsin (see also p. 247). Because the caliche facies grades into the low-lime-content facies on Rocky Flats, both are believed to date from pre-Wisconsin time. The topographic position of the flats also suggests that the gravel is pre-Wisconsin, as is discussed below.

Gravel-capped bedrock erosion surfaces, such as Rocky Flats, are common along the Front Range foothills drained by the Arkansas and South Platte Rivers. They have been studied in the northern Piedmont (Bryan and Ray, 1940), in the central Piedmont (Van Tuyl and Lovering, 1935), and in the southern Piedmont (Tator, 1952). Because none of these high erosion surfaces can be traced laterally along the foothills, correlation of erosion cycles from one locality to the next is in doubt, and the stratigraphic position of the gravel on Rocky Flats in relation to deposits on other erosion surfaces is unknown.

Rocky Flats is at least as remote from the present-day base level as the highest erosion surfaces to the north and south. When its longitudinal profile is compared with that of Coal Creek, it is seen that the depth of valley incision below Rocky Flats is about 450 feet (fig. 50). This relief is about 200 feet greater than that between modern drainage and the Spottlewood pediment in the northern Piedmont (Bryan and Ray, 1940, p. 21–23) and is comparable to the relief between modern drainage and the Deadman Canyon surfaces in the southern Piedmont (Tator, 1952, p. 260–262). Probably Rocky Flats was cut and veneered with gravel about the time other high-level pediments were forming to the north and south.

PLEISTOCENE

PRE-WISCONSIN

Deposits interpreted as pre-Wisconsin Pleistocene include upland gravel on pediment remnants lower than Rocky Flats; terrace gravel on cut terraces related to the existing drainage system; undifferentiated upland deposits consisting of weathered fluvial, colluvial, and eolian material; and cobble gravel along South Boulder Creek. All of these deposits have developed weathering profiles that resemble those found in the gravel on Rocky Flats. Most of the profiles have thick well-cemented beds of caliche, and they are similar to profiles in the Denver area (Hunt, 1954) that are developed on deposits designated as pre-Wisconsin on the basis of their fossils and stratigraphic position.

UPLAND GRAVEL

The pediment upon which the upland gravel rests is preserved as ridges of varying altitude that are the highest areas between the main valleys. However, these ridges are lower than Rocky Flats and do not extend as far westward, their limits being 2 miles or more from the mountain front. They radiate outward to the east and northeast from Rocky Flats in directions parallel to its slopes, but their gradients are from 30 to 40 feet per mile greater (fig. 50, Davidson and Lake Mesas).

Where these pediment remnants merge with the Rocky Flats, a gentle bedrock escarpment is either exposed or thinly veneered by material derived from gravel on the flats. Only the larger areas of gravel traceable to these escarpments are mapped as upland gravel. Gravel on some isolated knobs may once have been continuous with the upland gravel, but because correlation is uncertain it is mapped as undifferentiated upland deposits (p. 233). The upland gravel is mapped both in areas drained by the main streams and by streams that head only in Rocky Flats. Because of their different sources, these gravels are dissimilar lithologically; correlation is based upon topographic position, gradient, continuity with the escarpment around the flats, conformity in trend to the slope of the flats, and lack of relationship to a single stream valley.

Relative coarseness of the upland gravel depends less upon the slope of pediments upon which it rests than it does upon the source from which the gravel was derived. In the southeast part of the quadrangle the upland gravel is no larger than the gravel on Rocky Flats but is richer in quartzite. Evidently it was reworked from the Rocky Flats gravel. Between Coal Creek and South Boulder Creek, however, material larger than any found immediately adjacent to Rocky Flats is abundant, and its composition indicates derivation from the mountains. For example, upland gravel in the vicinity of Marshall (SE¼SW¼ sec. 15, T. 1 S., R. 70 W.) contains 50 percent granitic material, 40 percent quartzitic material, and 10 percent sandstone. A common large size for this gravel is about 15 inches, represented chiefly by quartzite and sandstone. In the gravel pit west of Harper Lake on Davidson Mesa cobbles of 8-inch size are common. Contiguous to the main streams the gravel is very coarse. On the upland gravel surface 1 mile south of Marshall subangular quartzitic and sandstone boulders as much as 3 feet long are abundant, and rounded granitic and gneissic cobbles as much as 10 inches in diameter are common. The deposit along Coal Creek in sec. 8, T. 2 S., R. 70 W., immediately below Rocky Flats, is similar. None of the upland gravel deposits exceeds 5 feet in average thickness, which is only one-half the average thickness of the gravel on Rocky Flats.

Like the gravel on Rocky Flats, the upland gravel is strongly weathered. Differences in degree of weathering between the two deposits cannot be distinguished in the field, and the weathering facies are coincident. A calcium carbonate facies on upland gravel is adjacent to the caliche facies on Rocky Flats, and the low-lime-content facies of the two deposits are adjacent (fig. 52). These similarities in degree of weathering and location of weathering facies suggest that the pedogenic environments of the deposits were the same.

Each pediment remnant covered with upland gravel closely parallels the adjacent slope of Rocky Flats. This relationship suggests that the surface was cut by consequent streams that encroached headward into the flats. The grade lines of these streams are below the projected grade of Rocky Flats, indicating that their base level, the South Platte River, was probably 100 feet or more lower at the time the upland gravel was laid down than when the gravel on Rocky Flats was laid down.

TERRACE GRAVEL

Terrace gravel occurs on benches immediately below the upland gravel and from 200 to 250 feet above adjacent valley bottoms. Older deposits in the quadrangle are related to ancestral drainage, but the terrace gravel is related to the present drainage system. The deposits lie within the valleys and slope toward the streams. Although the terrace gravel occupies distinctive topographic positions, correlation from one valley to another is indefinite. Only the most conspicuous high terrace deposits were mapped; other small gravelly areas, included as part of the undifferentiated upland deposits, may be correlative.

Terrace gravel along Coal Creek in the western tier of sections is bouldery and contains abundant granitic and gneissic material from the mountains. The other deposits lie within areas drained by minor streams and are 85 to 90 percent quartzite pebble gravel. Near Marshall Lake the northern edge of a terrace gravel deposit is covered by a thin veneer of younger gravel; this has been mapped with the undifferentiated upland deposits. In the gravel pit southeast of Marshall Lake dam the following section was measured:

FIGURE 52.—Truncated profile of low-lime-content (pre-Wisconsin) soil developed on upland gravel in the SE¼SW¼ sec. 21, T. 1 S., R. 70 W. Layer 1 is dark-gray post-Wisconsin solum developed on layer 2, which is noncalcareous red-brown gravelly loam, a soil horizon possibly of pre-Wisconsin age. The boundary between layers 2 and 3 is sharp, and it truncates decomposed granitic cobbles in 3; relatively unweathered rocks are quartzitic. Layers 3 and 4 are the upland gravel and were weathered in pre-Wisconsin time. Layer 3 is light yellow-brown and noncalcareous, more porous above than below; although it contains iron oxide and clay, the apparent texture profile suggests mechanical eluviation and may indicate compound soil development. The boundary between layers 3 and 4 is gradational. Layer 4 has thin films of calcium carbonate and effervesces with acid. Layer 5 is weathered Laramie formation.

Section in gravel pit in the SE¼ sec. 22, T. 1 S., R. 70 W.

	Ft	in
Grass cover.		
1. Clay, stony, dark red-brown	---	6
2. Gravel, pebble, quartzose, strongly impregnated with calcium carbonate	1	---
3. Gravel, sandy and silty, containing downward-branching veins of calcium carbonate; areas between carbonate veins are stained red brown with iron oxide; in sharp contact with unit 4	1	---
4. Gravel, pebble, silty, strongly impregnated with calcium carbonate and containing vertical prisms of red-brown clay; gradational with unit 5	1	6
5. Gravel, pebble and cobble, either dispersed or occurring as irregular lenses in a silty and clayey matrix; gravel composed of 85 percent quartzite, 12 percent granitic rock, and 3 percent sandstone; common large size of pebbles is 5 inches, the average size about 2 inches	10	---
6. Laramie formation.		

Units 4 and 5 are the terrace gravel. Units 1, 2, and 3 probably are old colluvial material. Units 2 and 3 contain abundant caliche that, by analogy with the Denver area, is believed to be of pre-Wisconsin age. Unit 4 is thought to be the basal part of a still older layer of caliche that was partly eroded away before the deposition of units 2 and 3.

The weathering profile on the terrace gravel is comparable to that in other deposits of probable pre-Wisconsin age, except that only the caliche facies is found. Along Upper Church Ditch in the NE¼ sec. 6, T. 2 S., R. 69 W., a well-developed caliche layer is formed in the terrace gravel and ascends without interruption across thinly buried bedrock onto upland gravel (fig. 53).

The relationship of the terrace gravel to the established drainage system is shown best in the southeast part of the quadrangle where the terrace deposits are east of angular bends in Walnut and Woman Creeks. Above these bends the drainage basins are enlarged. Probably the streams that flowed eastward and deposited the terrace gravel were captured by tributaries of Clear Creek.

The terrace gravel deposit east of Marshall Lake was laid down on a bedrock bench that slopes gently away from upland gravel on Lake Mesa. The stream that deposited the gravel may have cut the notch between Davidson and Lake Mesas. The basin containing Marshall Lake, which is west of the terrace gravel, is much enlarged and deepened, and it now drains into South Boulder Creek through a valley which reverses its direction by nearly 180°. Capture of eastward-flowing drainage by a tributary of South Boulder Creek may account for the anomalies of enlarged drainage basin and reversal of stream course.

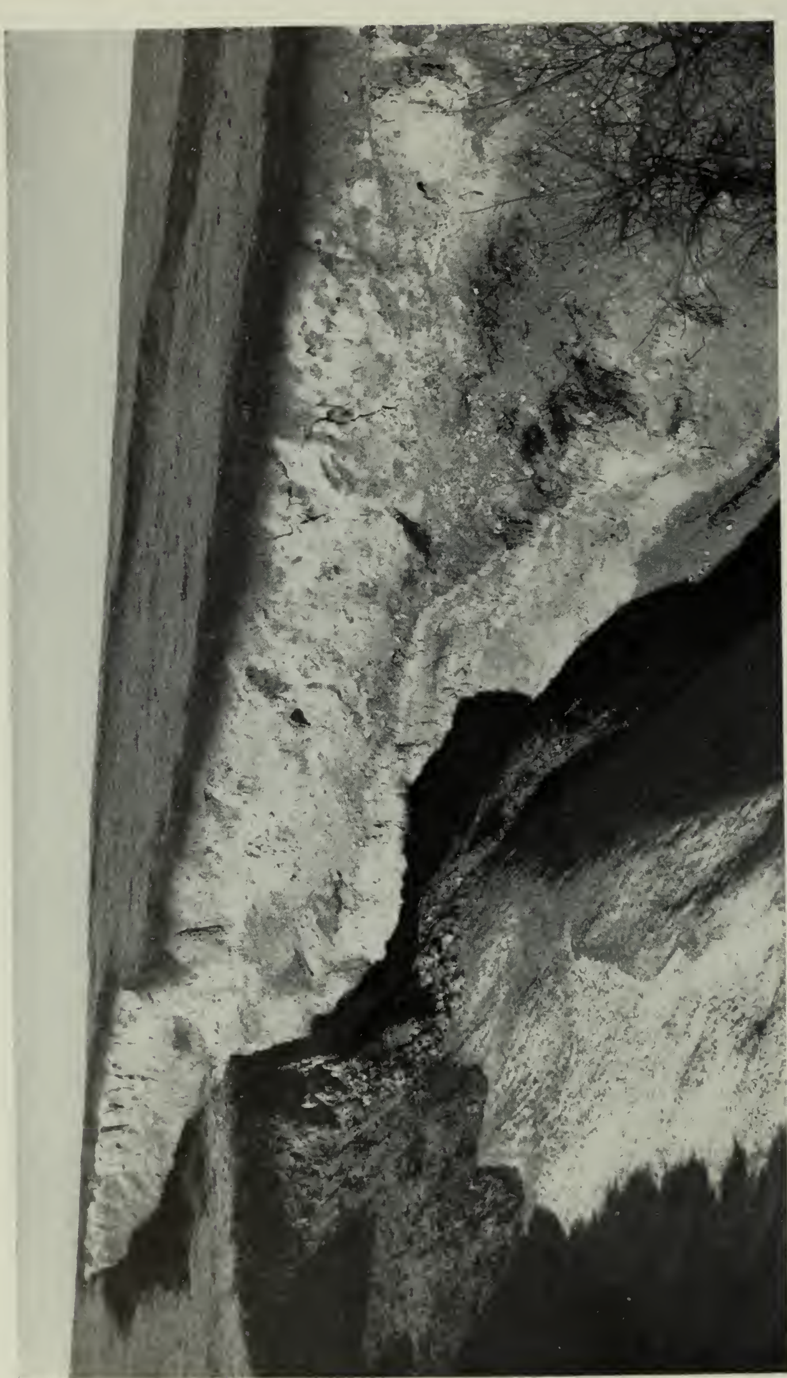

FIGURE 53.—Pre-Wisconsin soil on gently sloping upland along Upper Church Ditch in the NE¼ sec. 6, T. 2 S., R. 69 W. The calcium carbonate layer ascends without interruption from terrace gravel across deeply weathered bedrock and thin colluvium onto upland gravel (at top left). The depth of truncation of this layer increases upslope. The two thin dark zones at the top, separated by a narrow light-colored layer and resting unconformably on the carbonate layer, may represent Wisconsin and Recent soils.

If the two deposits of terrace gravel mentioned above are related to each other and older than the inferred capture of streams, they suggest not only the establishment of an integrated drainage system below the upland gravel, but also down-cutting by the major streams—South Boulder and Clear Creeks—before capture. South Boulder Creek, for example, could not have been more than 5,650 feet in altitude at Marshall for capture to have occurred, and it was probably from 50 to 100 feet lower. This implies a minimum of 200 feet of down-cutting by South Boulder Creek after deposition of the upland gravel and before capture of the terrace gravel drainage. The time when the capture may have occurred is not known.

The terrace gravel near Marshall Lake has a pre-Wisconsin weathering profile, overlapped by younger pre-Wisconsin deposits (p. 231). The terrace gravel in the southeast part of the quadrangle is 100 feet above a deposit that includes two pre-Wisconsin weathering profiles, one unconformable on the other (fig. 54). These relationships suggest that deposition of the terrace gravel and subsequent capture of the streams that deposited the gravel are among the early Pleistocene events in the quadrangle.

UNDIFFERENTIATED UPLAND DEPOSITS

On sloping valley walls in many places and on the lower interfluves are a diversity of alluvial, colluvial, and eolian deposits. They are so thoroughly weathered and intermixed that they are generally indistinguishable one from another, and therefore were mapped as a unit. All have weathering profiles similar to deposits in the Denver area that are believed to be of pre-Wisconsin age. Gravel is the most prevalent material in these deposits. It is preserved in a large number of discontinuous outcrops on bedrock hills and as low mounds surrounded by finer grained material that is locally mixed and interbedded with the gravel.

Massive pre-Wisconsin deposits of gravel-free sand and silt probably are loessial. They are exposed in deep, man-made ditches in at least three places in the quadrangle: In the north-south ditch in the NE¼ sec. 6, T. 1 S., R. 69 W. (fig. 55) ; south of Great Western Reservoir; and in the northeast corner of sec. 17, T. 2 S., R. 69 W. The second and third deposits are possibly related. All are on the north sides of ridges where eolian materials would be thickest if deposited by southwesterly or southerly winds.

The fine-grained alluvial deposits and the probable loessial deposits are not mapped separately, but the conspicuous gravelly areas are shown.

The undifferentiated upland deposits are undoubtedly of several ages, but the stages represented are not known. In the Denver area

FIGURE 54.—Pre-Wisconsin soils (layers 4 and 5) separated by an unconformity and overlain by younger soils; gully in sec. 13, T. 2 S., R. 70 W. Layer 1 is post-Wisconsin solum. Layer 2 is noncalcareous brown clay loam with prismatic structure. Layer 3 is calcareous clay loam with scattered pebbles that have carbonate crusts only on their undersides. Layer 4 contains areas thoroughly impregnated with calcium carbonate but is otherwise red (iron oxide) and clayey; layer 4 truncates the dense carbonate layer of an older pre-Wisconsin soil (layer 5).

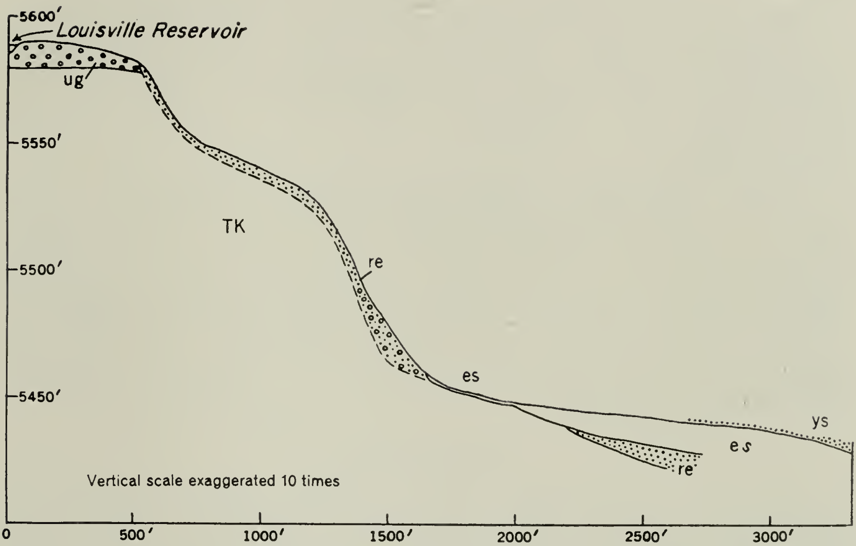

FIGURE 55.—Diagram of surficial deposits at northeast end of Davidson Mesa in sec. 6, T. 1 S., R. 69 W.: *ug*, upland gravel; *re*, undifferentiated upland deposits; *es*, eolian silt and sand; *ys*, younger eolian(?) sand (not mapped); *TKu*, bedrock. For full description of letter symbols see plate 7.

paleontologic evidence indicates that the main valleys were about as deep at the end of Yarmouth time as they are now (Hunt, 1954). Paleontologic evidence bearing on this problem has not been found in the Louisville quadrangle. However, the weathering profiles developed on undifferentiated upland deposits occupying low topographic positions resemble those of probable pre-Wisconsin age in the Denver area, and they suggest that the valleys have not been notably deepened during Wisconsin and later time.

The following section was measured at a road cut along the Denver-Boulder toll road in the north bank of Rock Creek just east of Hodgson-Harris Reservoir:

Composite section in the center, N½ sec. 29, T. 1 S., R. 69 W.

	Ft	*in*
Grass cover.		
1. Silt, clayey, dark-brown; slightly calcareous at base	1	3
2. Silt, sandy, massive, red-brown, containing pipettes and nodules of calcium carbonate 1 inch in diameter or larger	2	6
3. Sand, silty, bedded, impregnated with calcium carbonate; alluvial	2	---
Unconformity.		
4. Sand, clayey, red-brown, interbedded with fine gravel	1	---
5. Gravel, pebble, encrusted with calcium carbonate and composed of 90 percent quartzite, 8 percent granite, and 2 percent sandstone; base of gravel is 15 feet above Rock Creek, resting on terrace cut in bedrock	4	---
6. Sandy shale (with interbedded lignitic shale) of Laramie formation.		

Units 4 and 5 are alluvial gravel believed to have been weathered in pre-Wisconsin time. Following an interval of erosion, alluvial sand and silt (units 2 and 3) were deposited and weathered, also in pre-Wisconsin time. Unit 1 is a colluvial(?) deposit, perhaps of Wisconsin age.

Two pre-Wisconsin(?) weathering profiles, one on top of the other, are present near Woman Creek a few feet above the modern stream (fig. 54). The oldest profile was developed on silty material containing little gravel and is separated by a conspicuous unconformity from a gravel deposit above. The absence of widespread alluvial deposits (except the upland gravel and older gravels) above these localities suggests that there were not long pauses in the cutting of valleys by early Pleistocene streams.

COBBLE GRAVEL

Along the northwest side of South Boulder Creek is a deposit of cobble gravel, the top of which lies 5 to 10 feet above the modern flood plain. The cobble gravel rests on an irregular bedrock floor at depths of from 2 to 10 feet, and it is buried in the flood plain by younger gravel (fig. 56). The cobbles reach a maximum diameter of 8 inches and are enclosed by a matrix of fine clayey sand or of clayey silt. About half of the cobbles are sandstone; the rest are about equally divided among the various crystalline rocks. This high proportion of sandstone is no doubt due to the proximity of sandstone outcrops in the tilted sedimentary rocks to the west, and to the prevalence of sandstone in gravels capping the pediment remnants immediately to the west.

The weathering profile developed on the gravel is red brown and clay-rich throughout the upper 12 to 18 inches. Below this the deposit is grayish brown to a depth of 3 to 4 feet, and it is encrusted and locally cemented with calcium carbonate. Below a depth of 5 feet the deposit is light brown and friable and contains little calcium carbonate. This profile is unlike that found in either the Wisconsin or the pre-Wisconsin deposits of the Denver area. Gravel that can be correlated with it has not been identified along other streams in the quadrangle, but it is likely that some of the low-lying gravel included elsewhere in the undifferentiated upland deposits may be equivalent in age.

WISCONSIN

Deposits interpreted as of Wisconsin age include gravel fill along the main streams, fine-grained alluvial fill, and eolian silt and sand. They are only slightly weathered. Most of the rock fragments found in the weathered zone are hard and firm, in marked contrast to those found in the weathered zone of the pre-Wisconsin deposits. The

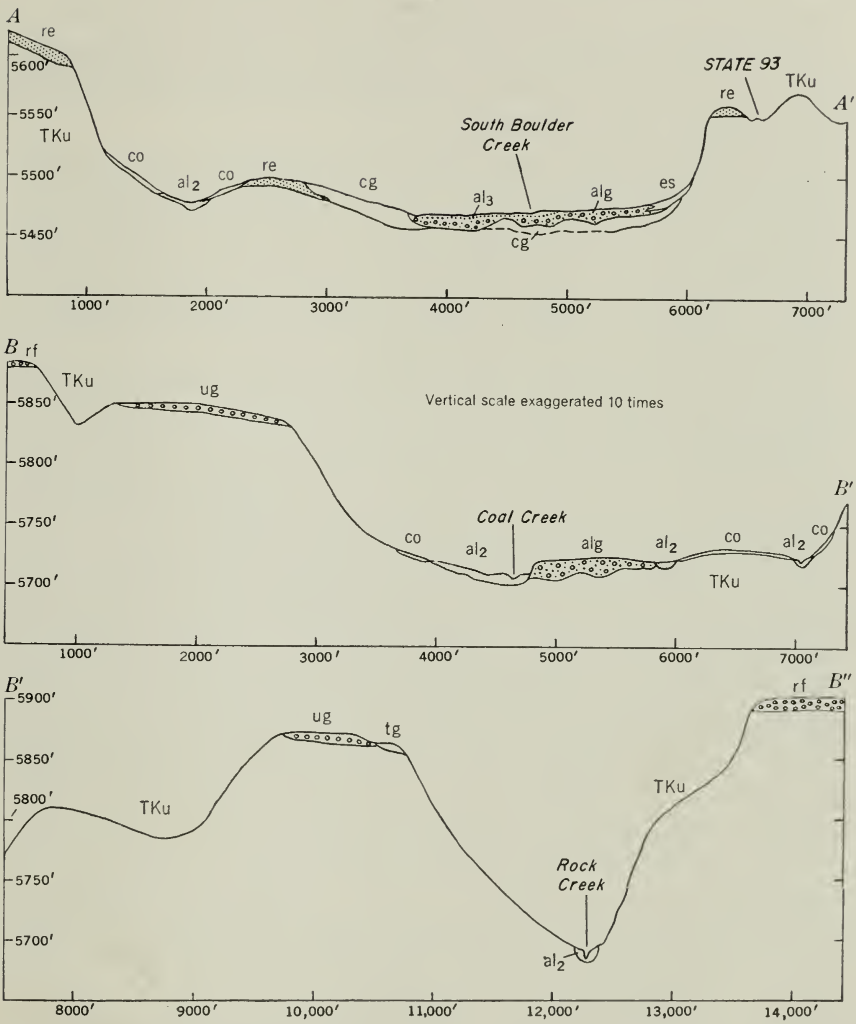

FIGURE 56.—Sections A–A′, B–B′, and B′–B″ across South Boulder Creek, Coal Creek, and Rock Creek, respectively: *re*, undifferentiated upland deposits; *cg*, cobble gravel; *alg*, gravel fill; *es*, eolian silt and sand; *al_2*, Piney Creek alluvium; *co*, colluvium; *al_3*, modern alluvium; *TKu*, bedrock. For full description of letter symbols see plate 7.

weathering profiles lack the thoroughly impregnated calcium carbonate layer of the older deposits, and the clay layer at the top is dark brown, rather than red brown as in the weathering profiles of pre-Wisconsin age. Moreover, the clay layer is present in most exposures, whereas it is found in the profiles on pre-Wisconsin deposits at only a few localities; probably it has been eroded away. Ascription of these deposits to Wisconsin substages is not yet possible because fossils have not been found in them in sufficient quantities, and because the deposits are not directly associated with known glacial stratigraphy.

GRAVEL

Alluvial gravel interpreted as Wisconsin in age is mapped along many of the streams. The chief deposits are along Coal Creek and South Boulder Creek (fig. 56).

The gravel fill along Coal Creek has a maximum depth of 12 feet, the average being about 4 feet. Gravel fragments are subangular to rounded and they range in size from 3 to 16 inches; 4 inches is the average size. On the whole the deposit is well sorted. It is composed of about 65 to 70 percent quartzite, 30 to 35 percent granite and gneiss, and 1 to 3 percent sandstone. Bedding is crude and irregular, but shingle structure is conspicuous locally.

The top of the gravel fill has a gradient steeper than the present grade of Coal Creek. Southwest of Superior the top of the deposit is from 10 to 15 feet above the stream; at Superior it is from 5 to 10 feet. However, the bedrock floor upon which the deposit rests is only thinly covered northeast of Superior, and the gradient of the base of the deposit may differ little from that of Coal Creek.

The weathering profile on the deposit consists of a dark-brown clay-rich zone 1 foot thick overlying a yellow-brown zone 2 to 3 feet thick that effervesces with acid. Calcium carbonate, however, is not evident in the profile. The rock fragments throughout the deposit are fresh.

The gravel fill along South Boulder Creek differs in several respects from that of Coal Creek. Not only is it a larger and deeper deposit, but it is also very little incised by the stream. Large areas, shown by pattern on the geologic map (pl. 7), have been flooded and reworked. The gravel has a maximum depth of slightly more than 14 feet. It consists of pebbles that average from 2 to 3 inches in size and cobbles that are as large as 7 inches. The gravel is composed of 55 to 60 percent granite, 30 to 35 percent gneiss, 5 to 10 percent quartzite, and a few sandstone pebbles. Included in the gravel are scattered cobbles of decomposed gneiss and granite that crumble easily in the hand and that evidently were reworked from older, deeply weathered deposits. All of the pebbles and cobbles are exceptionally well rounded—joint faces of quartzite fragments are rarely preserved, and granitic fragments as round as tennis balls are common.

The weathering profile is comparable to that developed on the gravel along Coal Creek. The upper 2 or 3 feet is dark brown and clayey. Some of the pebbles and cobbles in this zone are partly encrusted with thin films of calcium carbonate. Below the clayey layer the deposit effervesces with acid to a depth of 5 feet but is not noticeably calcareous. Rock fragments are fresh throughout, except for the previously mentioned crumbly granitic cobbles. A few of the cobbles below a depth of 4 feet are fractured but otherwise coherent.

Other gravel fills, consisting almost exclusively of quartzite pebbles, are mapped along Rock Creek near the east border of the quadrangle and along minor streams in the southeast corner of the quadrangle. In stratigraphic position and topographic expression they are comparable to the gravel fill along the main streams.

ALLUVIUM

Fine-grained alluvial deposits are present in the northwest part of the quadrangle and in the valleys of Walnut and Woman Creeks in the southeast part. This alluvium ranges from clayey silt to silty sand and contains scattered pebbles and cobbles. It is more sandy in the southeast part than in the northwest part. The thickness of the deposit east of Base Line Reservoir is about 7 feet. Elsewhere the alluvium is rarely more than 5 feet thick. In the drainage area of Walnut and Woman Creeks the fine-grained alluvium may once have intertongued with gravel. In the northwest part of the quadrangle this alluvium is isolated from the gravel, and the stratigraphic relationship is uncertain.

The weathering profile on the alluvium is comparable to that on the gravel. In the northwest part of the quadrangle the profile consists of 1 foot of dark-brown, slightly calcareous loam underlain by a gray-brown, moderately calcareous layer 3 or 4 feet thick. Between the upper and lower parts of the profile nodules of calcium carbonate are scattered in some places. Prismatic structure is common in the upper part; the calcareous lower part cracks in large joint blocks, and, although it has the appearance of being firmly cemented, pebbles can be broken out with the fingers.

Along Walnut Creek the following section was measured:

Section of alluvium in the SW¼ sec. 6, T. 2 S., R. 69 W.

	Ft	*in*
Grass cover.		
1. Sand, pebbly, gray; colluvial	---	6
2. Sand, clayey, dark-brown, slightly prismatic at base	1	1
3. Sand, friable, light gray-brown, containing scattered quartzite pebbles; nodules of calcium carbonate ranging in size from pinhead to one-fourth inch are abundant at top but decrease in abundance downward	1	2
4. Sand, nearly pebble-free, slightly calcareous but containing no nodules of calcium carbonate	2	6
5. Gravel, quartzite pebbles in sandy matrix	1	6
Covered.		

Unit 1 probably is of Recent age. Units 2, 3, and 4 are interpreted as alluvial material modified by later weathering that probably antedates deposition of unit 1. This profile is similar to that developed in the northwest part of the quadrangle. The soil horizons in the two profiles have similar color and structure and about the same amount of carbonate. Both are believed to be of Wisconsin age. At the base of the alluvium along Dry Creek, 2 miles north of the quadrangle (NW¼SW¼ sec. 30, T. 1 N., R. 69 W.), a Proboscidean tusk was found.

EOLIAN SILT AND SAND

About 7 square miles in the northeast part of the quadrangle is mantled by eolian silt and sand that attains a thickness of more than 12 feet. The deposit is found on the Rocky Flats pediment and elsewhere, but in these places is less than 2 feet thick. It has been mapped only where its thickness is known to exceed 2 feet. Including the thin, unmapped parts, the deposit has a vertical range of several hundred feet, and it extends horizontally from near the foothills eastward beyond the quadrangle limits.

The eolian deposit is thickest on the south, east, and north sides of Davidson Mesa. Exposures along the north-south ditch, in the NE¼ sec. 6, T. 1 S., R. 69 W., show that from a thickness of 12 feet the sand wedges out southward in a distance of 300 feet and buries first a deposit of pre-Wisconsin sand and silt and then bedrock (fig. 55). Eolian sand of about the same thickness can be seen in the east-west ditch in the S½ sec. 5, T. 1 S., R. 69 W. It diminishes in thickness toward the top of Davidson Mesa and is relatively thin west of the mesa.

The areal distribution of eolian sand and silt suggests deposition by westerly winds and a source area to the west, presumably the flood plains of larger streams when they were loaded with debris. From the stratigraphic relationship along the east border of the Broadway terrace in the Denver area, Hunt (1954) has inferred that the terrace gravel intertongues with eolian sand to the east. Split bones, provisionally interpreted as artifacts of Folsom man, are found in the gravel above the sand. A similar stratigraphic relationship has not been found in the Louisville quadrangle, but areal mapping implies that Hunt's interpretation may apply also to this upland area.

A small deposit of eolian sand is present on the southeast valley wall of South Boulder Creek just west of Marshall. Its presence so near South Boulder Creek suggests that it was derived from the flood plain when it was aggraded with alluvial sand and gravel, but one cannot now determine whether the gravel and the eolian sand once intertongued. Along Coal Creek, northeast of Superior, it appears from areal mapping that intertonguing occurred, but both the gravel and eolian sand are too thin at their contact, and exposures too poor, for a definite determination. The contact between the alluvium east of Base Line Reservoir and the eolian sand farther east is inadequately exposed; however, the eolian mantle is believed to thicken eastward and to overlap pre-Wisconsin Pleistocene deposits; farther east, it probably overlaps bedrock. The alluvium fills a valley whose southern end is cut in pre-Wisconsin deposits and whose northern end is cut in bedrock.

The eolian silt and sand have buried irregularities in the former topography, forming a smooth, gently rolling terrain. They mantle large areas of eroded pre-Wisconsin material and are locally present on older gravels. Only in limited areas has the surface relief of the deposit been modified by erosion.

The mean particle size of the eolian deposit ranges from fine sand (0.20 mm) to silt (0.02 mm). The average particle size for the bulk of the deposit is near the lower limit of the sand size (0.05 mm). In most areas the average thickness of the deposit is about 5 feet. Thicknesses greater than 12 feet can be expected where the sand has filled depressions. Pebbles scattered throughout the deposit were presumably incorporated in the eolian material by mass wasting from gravelly areas upslope. All are waterworn, and a few are also scoured and polished by wind abrasion. Many ventifacts were collected from the deposit on the south bank of Walnut Creek just east of the quadrangle boundary.

The eolian deposit has developed a distinctive soil profile (fig. 57), as follows:

Generalized description of soil profile developed on eolian silt and sand—the Fort Collins clay loam of Brighton Area Soil Survey

[Modified after Harper, Acott, and Frahm, 1932, p. 31–32]

Horizon designation on fig. 57	*Description*	*pH*	*Depth (inches)*
AB	1. Loam, sandy, fine, noncalcareous, grayish-brown or brown, and very fine sandy loam; a mellow mulch showing slight lamination, although matted with grass roots	7.25	0–2
	2. Loam or heavy loam, grayish-brown or brown, noncalcareous. The upper part is slightly laminated, and the rest is compacted into a mass of even texture that breaks easily with no regular cleavage	6.15	2–8
B_2	3. Clay, brown, dark-brown, or reddish-brown, compact, noncalcareous, prismatic structure. Oxidation of both mineral and organic material probably shares with the accumulation of carbonaceous material in influencing the darker color. On the surfaces of natural breakage planes the material is rich reddish brown, but when it is finely crushed, a light-brown or olive-brown color predominates	7.59	8–22
B_3	4. Clay, grayish-brown, compact, prismatic structure; similar to the material in the horizon above but grayer in color; moderately calcareous	8.43	22–38
Cca1	5. Clay loam, gray, friable, very rich in lime carbonate; tends to have a massive structure	9.09	38–54
	6. Clay loam or clay, pinkish-gray, rich in lime but containing less than the horizon above. The lime carbonate usually occurs in streaks or pocket accumulations. The color of the more lime-free material is rich brown. The structure tends toward prismatic	9.09	54–96
Cca2	7. Parent material, consisting of light-brown, highly calcareous friable fine sandy loam	9.09	96–120

FIGURE 57.—Soil profile of Wisconsin age developed in eolian silt and sand; ditch, center NE¼ sec. 6, T. 1 S., R. 69 W. Letter symbols interpreting soil horizon genesis follow U. S. Soil Survey nomenclature. Layer *AB* is noncalcareous sandy loam which lies unconformably on a soil profile that is possibly equivalent to mid-Wisconsin soil of Nebraska and Kansas. B_2 is noncalcareous clay with well-developed prismatic structure. B_3 is slightly calcareous clay with crude prismatic structure. C_{ca1} is calcareous clay loam with calcium carbonate films along vertical joints (1 mile to the southeast the carbonate in C_{ca1} is disseminated as nodules in slightly finer textured loamy clay). C_{ca2} is calcareous friable fine sandy loam (see p. 241).

At the depth of 22 inches the pH changes from 7.59 to 8.43. Below this depth calcium carbonate has accumulated. It is commonly in the form of nodules (especially where the deposit is silty rather than sandy), but it also occurs as veinlets. At the depth of 22 inches there is also a structural change: below this depth the material stands in massive vertical blocks 1 foot or more across; above it the dark-brown layer (B_2 horizon) breaks into vertical prisms no more than 1 inch across.

RECENT

Deposits interpreted as of Recent age include an alluvial fill correlated with the Piney Creek alluvium (Hunt, 1954) ; a younger alluvium in flood plains of major streams; and colluvium. Their weathering profiles are thin and inconspicuous compared with those on the Wisconsin and older deposits.

PINEY CREEK ALLUVIUM

In the valley of Coal Creek and in all the minor tributary valleys extending into the dissected uplands, is an alluvial fill named Piney Creek alluvium because of its correlation with exposures along Piney Creek southeast of Denver (Hunt, 1954). In the type area the alluvium overlaps late Pleistocene or Recent eolian sand. Archaeological remains about 1,000 years old have been found in the uppermost part of the alluvium. In the type area and in the Louisville quadrangle the alluvium contains abundant remains of *Bison bison* but no definite Pleistocene fossils.

In the Louisville quadrangle, the Piney Creek alluvium ranges in texture from fine silty sand to clayey silt and usually contains gravel lenses at the base. Finer textured deposits are conspicuous in the upland valleys and coarser ones in the larger valleys. Their thickness usually exceeds 10 feet, even in confined valleys with small drainage basins. In upland valleys the tops of the deposits are remarkably flat and end abruptly along the valley walls. Apparently, little slopewash material was added to the deposits from adjacent valley walls. Interstratified humic layers suggest that stable intervals of short duration occurred during the period of deposition.

The alluvium was deposited in relatively narrow, deep arroyos, implying a preceding interval of erosion. This interval was probably a time of relatively dry climate, and it may correspond to deposition of the late Pleistocene or Recent eolian sand in the Denver area.

The Piney Creek alluvium has been gullied by later erosion. In places, along the arroyo walls, the alluvium has been cut downward to its base and a younger material deposited. In broad valleys having low gradient the younger alluvium may veneer the top of the Piney Creek deposit, but it seems never to have overflowed the arroyos in the upland areas. The persistence of Piney Creek alluvium in upland valleys where there has been almost no younger alluviation suggests that the conditions under which it was deposited were not subsequently duplicated. Nevertheless, the streams that deposited the Piney Creek alluvium in upland valleys were impotent when the main valleys were reached. At these confluences, the alluvium commonly ends as a fan spread upon older deposits.

A typical section of Piney Creek alluvium is as follows (see fig. 58):

Section of Piney Creek alluvium in the SE¼NW¼ sec. 31, T. 1 S., R. 69 W.

	Ft	*in*
1. Sand, fine, gray, laminated, locally crossbedded, noncalcareous; root zone at top is 6 inches thick	2	10
2. Sand, clayey, dark-gray, crudely bedded, jointed in lower part	3	3
3. Sand, silty, light gray-brown, crudely bedded, containing streaks of limonite stain and local pebble lenses	4	----
4. Sandstone and interbedded shale of the Laramie formation.		

Remains of *Bison bison* which occur throughout the deposit are plentiful at this locality. Weathering characteristic of Wisconsin deposits in the Denver area is absent.

COLLUVIUM

Many gentle slopes are mantled by thin colluvial deposits. These are rarely more than 1 or 2 feet thick and in most places rest on bedrock. Where the bedrock protrudes through the colluvium in cultivated areas, it appears as yellow, light-brown, or gray streaks. In spite of inferences that might be made from color, vegetation, and changes in surface soil, the colluvial boundaries are very difficult to map and are shown only diagrammatically on plate 7. Bedrock outcrops in colluviated areas are shown diagrammatically, also.

Composition of the colluvium is wholly dependent upon the kind of source material immediately upslope, and consequently it varies greatly. Materials eroded from bedrock slopes have formed deposits; and bedrock slopes have been inclines down which unconsolidated materials from farther above have slumped. On some slopes, gravel from surficial deposits above has been mixed with chunks of loose bedrock. In sandy areas identification of colluvium is uncertain. Northwest of Davidson Mesa, for example, a layer of friable sand that was mapped as colluvium rests in part with angular unconformity on the eolian silt and sand. Horizon AB of figure 57 is an unmappable, thin expression of this layer of sand. Possibly it is a late Wisconsin or Recent eolian deposit.

POST-PINEY CREEK ALLUVIUM

The flood plain of South Boulder Creek and part of the flood plain of Coal Creek are mantled by post-Piney Creek alluvium. Deposits that are either very thin or limited in area are not shown on the map. The post-Piney Creek alluvium is confined chiefly to areas that were periodically flooded before the advent of irrigation works.

Most of the alluvium ranges in size from fine sand to silt, but lenses of pebble and cobble gravel are commonly interbedded near the base of the alluvium. Along Coal Creek this basal gravel probably was

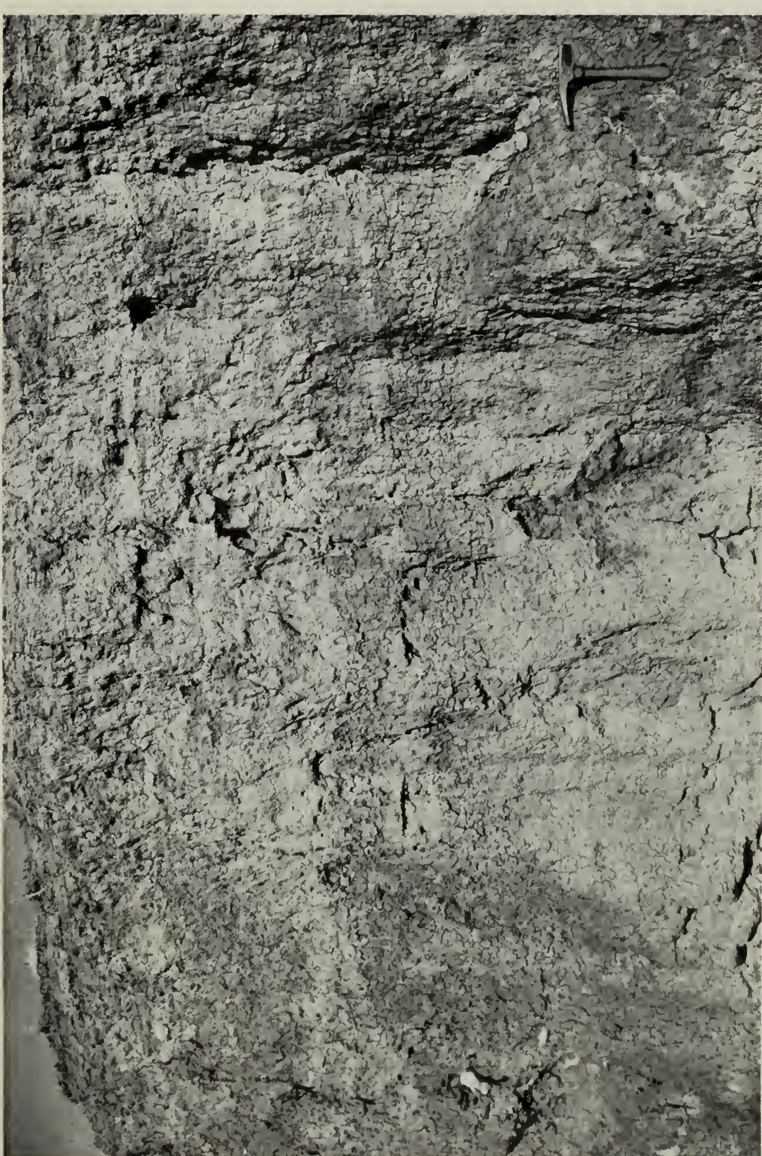

FIGURE 58.—Piney Creek alluvium in gully in the SE¼NW¼ sec. 31, T. 1 S., R. 69 W. The alluvium filled a narrow, steep-walled valley (cut in bedrock) to a depth of about 10 feet; subsequently, it was deeply incised. The deposit is dominantly a silt that is sandy at the top and contains gravel lenses at the base (not in photograph). Blocky vertical jointing in lower half of deposit is not related to soil development. *Bison bison* bones are exposed at left center.

derived from an upstream source and not from the adjacent gravel fill and the Piney Creek alluvium. Along South Boulder Creek the basal gravel was reworked from the gravel fill which underlies the flood plain. Reworked gravel within 2 feet of the surface is shown by pattern on the map (pl. 7). Along stream banks where fine-textured alluvium is exposed, the topmost layer is dark brown to brown black and is rich in mica. The underlying layer is light gray-brown or yellow-brown and is streaked with iron stains and layers of black sand. The alluvium is essentially noncalcareous. A representative section, measured along South Boulder Creek, is as follows:

Section of post-Piney Creek alluvium in the SE¼ sec. 9, T. 1 S., R. 70 W.

	Ft	*in*
Grass cover:		
1. Loam, brown-black, friable, rich in humus; pebble and cobble gravel layer 3 inches thick at base	1	----
2. Sand, yellow-brown, massive, locally whitened with alkali on stream bank; tends to break into vertical blocks	1	8
3. Gravel, sandy, gray-brown, crudely bedded; reworked from underlying deposit; ranges from pebble size at top to cobble size at base	1	10
4. Gravel, probably of Wisconsin age.		

In the foregoing section the thin layer of gravel, unit 1, 1 foot below the surface, may mark the beginning of a period of alluviation distinct from that of the lower alluvium, units 2 and 3.

WEATHERING AND SOILS

Because fossils were not found in abundance, age ascriptions are based chiefly upon weathering profiles, superposition, and topographic position of the deposits. In the Denver area (Hunt, 1954), fossils from a large number of stratigraphic positions indicate the ages of the deposits and demonstrate that the three main groups—pre-Wisconsin, Wisconsin, and Recent—have distinctive weathering profiles. These profiles are believed to be the remnants of soils formed during those times. By reference to them a gross correlation can be made between the deposits in the Louisville quadrangle and those in the Denver area. Deposits within each group are dated on the basis of physical geology.

PRE-WISCONSIN SOILS

The weathering profiles on pre-Wisconsin deposits in the Denver area (Hunt, 1954) have a well-developed calcium carbonate layer below a reddish-brown clay layer. In the Louisville quadrangle similar profiles occur both at the surface and beneath younger deposits. They are present at high and low altitudes, on steep and gentle slopes, and in parent materials of diverse lithologies (fig. 53).

A typical pre-Wisconsin soil for the region is described in detail by Hunt and Sokoloff (1950, p. 111–114). A lime-free reddish-brown clayey layer (usually prismatic) grades downward into a lime-enriched layer. The former is free of stones except for inert quartzose fragments; the latter contains stones, but they are so decayed at the top of the layer that they can be cut with a knife. The total profile may exceed 20 feet in thickness.

In the Louisville quadrangle pre-Wisconsin soils are conspicuous because of their commonly thick calcium carbonate zone. Characteristically this is an indurated caliche unlike the sparsely distributed carbonate in the younger soils. Also, the clay above the carbonate in the pre-Wisconsin soils has a distinctive red-brown color and mineralogical composition (p. 248).

Calcium carbonate in soils of pre-Wisconsin age thoroughly impregnates and cements the surficial material and may comprise more than 50 percent of the total volume. It consists of euhedral and subhedral calcite scalenohedrons mostly less than 0.004 mm in size but commonly joined in acicular aggregates as long as 0.06 mm. The aggregates are cemented by calcite and clay. A few calcite scalenohedrons as large as 0.04 mm were found.

Carbonate is at the surface or only a few inches below it over large areas of pre-Wisconsin soils in the quadrangle. Rainfall might be expected to depress it 1 foot or more below the surface, and the fact that it does not is probably attributable to the same factors that inhibit limestone erosion in the semiarid climate of this region. The carbonate has withstood climatic changes and erosion at least through Wisconsin and Recent time.

Where calcium carbonate in a soil is buried by younger material, it is present from the top of the buried soil downward; it does not extend upward into the overburden. If the buried soil is developed in fine-grained parent material, it commonly has a conspicuous prismatic structure above the firmly cemented carbonate layer. The prismatic layer is primarily red silty clay with a pH of about 7.5; it is lime-free, but lime is present along the vertical openings between prisms. In contrast, where the prismatic structure is developed on Wisconsin deposits, it contains no lime between the vertical joints of the top clay-rich layer. Very likely, at some stage of soil development, the prismatic structure of pre-Wisconsin deposits was also lime-free, and the present features were formed late during soil development. The presence of lime along joints in the prismatic layer of pre-Wisconsin soils in this area contrasts to its presence in the cores of prisms in some pre-Wisconsin soils in the La Sal Mountains, Utah.[1] Perhaps joint filling by lime is an indication of upward migration of the lime caused

[1] U. S. Geol. Survey report on the Quaternary geology of the La Sal Mountains, Utah, by G. M. Richmond (in preparation).

by diminishing effective precipitation during the closing phases of soil development. Because the lime-filled joints end abruptly at, or below, the contact with overlying Wisconsin material, it appears that relocation of the lime was accomplished before deposition of the overburden.

Soil clays subjected to differential thermal analysis

[Soil clay numbers correspond to thermal-curve numbers on figure 59]

No.	Location	Depth (inches)	Position of soil clay in profile	Age of soil	Clay mineral type
1	SE¼NW¼ sec. 11, T. 2 S., R. 70 W.	14	Top of carbonate layer.	Pre-Wisconsin.	Mostly illite; some halloysite.
2	Center, S½ sec. 9, T. 2 S., R. 70 W.	18	Residual red clay on bedrock.	Pre-Wisconsin.	Mostly halloysite.
3	SE¼SW¼ sec. 21, T. 1 S. R. 70 W.	8	Red-brown clay unconformable on decomposed gravel (layer 2 of fig. 52.)	Pre-Wisconsin or Wisconsin.	Illite.
4	NW¼SW¼ sec. 23, T. 2 S., R. 70 W.	7	Clay loam above carbonate layer.	Pre-Wisconsin, perhaps modified during Wisconsin.	Mixed aggregate of illite and montmorillonite.
5	SW¼SW¼ sec. 6, T. 2 S., R. 69 W.	14	Brown prismatic layer above carbonate layer.	Wisconsin.	Calcic montmorillonite.
6	SE¼NW¼ sec. 31, T. 1 S., R. 69 W.	40	Parent material unaffected by post-depositional soil development.	Recent.	Contaminated calcic montmorillonite.

In the Louisville quadrangle the clay in pre-Wisconsin soils is distinguishable from that in Wisconsin soils. In figure 59, thermal curves 1 and 2 each represent more than 20 analyzed samples of pre-Wisconsin soil clays. Curve 3 may also represent pre-Wisconsin soil clay. Curve 2 was obtained from a soil developed on bedrock or on a thin surficial cover obscured by weathering; it is largely halloysite. A sample (curve 1) from the carbonate layer developed in gravel on Rocky Flats (only 3 feet above bedrock), also contains halloysite but is dominantly illite. Curve 3, obtained from a clay that is dominantly illite, is like the curve of pre-Wisconsin soil clays where the bedrock is deeply buried. Curves 2 and 3 have a slight endothermic inflection near 350° C. that may be caused by limonitic material; both samples are red or red brown and evidently contain iron oxides. Curve 4 was obtained from clay in a brown loamy layer, above the carbonate layer, developed in gravel on Rocky Flats; it indicates a mixed aggregate of illite and montmorillonite. Because Wisconsin soil clays that have formed on fresh parent material are, so far as is known, exclu-

FIGURE 59.—Representative differential thermal curves of soil clays. (Thermal curve numbers correspond to soil clay numbers on facing page.)

sively montmorillonite (p. 251), curve 4 may indicate modification of a pre-Wisconsin soil by Wisconsin weathering.

Not all pre-Wisconsin soils are the result of a single soil-forming interval. In places soils with developed profiles were partly eroded away. The deeply buried layers were then exposed to soil forming processes active at or near the surface. Complex profiles were thus built up, an example being the low-lime-content soil on the upland gravel (see fig. 52). In general this profile may be described as noncalcareous gravelly brown loam in sharp contact with decomposed granitic gravel below. The two layers appear to be unconformable. Moreover, the top of the decomposed gravel is relatively porous and appears to have been eluviated, a feature probably not related to the soil-forming interval during which the loam was formed. Thermal analysis of clay separated from the loam (curve 3, fig. 59) indicates that it does not differ notably from clay in undistrubed pre-Wisconsin soils. It is possible that this profile represents two superimposed soil-forming intervals of pre-Wisconsin age, and that it has been little modified by Wisconsin and Recent soil development.

A facies change in pre-Wisconsin soil profiles occurs on the western parts of Rocky Flats and the pediments below the flats. Here the caliche facies grades upslope into a low-lime content facies (p. 225) in a zone little more than a quarter of a mile wide, and a red-brown clay layer at the top of each is continuous from one facies to the other.

Because the caliche facies is found on other deposits at higher altitude nearer the mountain front, the development of a low-lime-content soil on the western parts of Rocky Flats and the pediments below them is difficult to explain. The intergradation of the two weathering facies probably indicates that they were developed at the same time. The two facies seem to indicate differences in available moisture, and they may also indicate an earlier forest environment in the low-lime-content soil area. These possibilities will be discussed in turn.

Available moisture, which probably affected development of the low-lime-content soil facies, was perhaps controlled by ground-water conditions. The contact between the two soil facies descends in altitude north and south from the central east-west axis of the fan-shaped flats. Also, the contact between the facies swings eastward as it is followed away from the central axis. If the low-lime-content facies owes its origin to a more abundant ground-water supply, the form of its contact with the caliche facies was probably controlled by the ability of this water to migrate in the gravel. For example, surface water at the mouth of Coal Creek canyon would spread through the gravel and migrate downslope; however, where the gradient diminishes, the flow of water would be inhibited and evaporation would occur. It is thought that the zone of transition from migrating water to evaporating water corresponds roughly to the contact between the low-lime-content and caliche soil facies.

Two other observations indicate the probable former presence of ground water in the gravel on Rocky Flats. One mile east of the contact between the two facies, caliche occurs in the gravel at depths well below the main caliche layer and is concentrated laterally along boundaries between gravel and sand lenses (fig. 51). Farther east the firmly cemented caliche layer, exposed in the abandoned railroad cut in the N½ sec. 12, T. 2 S., R. 70 W., is finely laminated and crenulated.

Available moisture affecting development of the two soils may have been dependent upon a former forest cover. Although the two soils are present on both Rocky Flats and the pediments below, environmental conditions common to the two areas probably once existed. A likely soil-forming factor shared by both is vegetation. It is supposed that forests once stood on those parts of Rocky Flats and the upland gravel where low-lime-content soil is found.

WISCONSIN SOILS

Soils on Wisconsin deposits in the Denver area are thinner and are in less well-developed layers than are those of pre-Wisconsin age. They present few problems of identification in the field and can be traced from the Denver area into the Louisville quadrangle.

A typical weathering profile in eolian sand and silt of Wisconsin age is described on pages 241 and illustrated on figure 57. This profile is comparable in stratigraphic position to the Brady (mid-Wisconsin) soil in Kansas and Nebraska (Frye and Leonard, 1949, 1951, 1952; Frye, 1951; Schultz and Stout, 1948; Schultz, Lueninghoener, and Frankforter, 1951), and like the Brady soil, is intermediate in development as compared with the profiles on older and younger deposits.

As far as is known, clay developed by soil processes in the upper part of the Wisconsin deposits is dominantly montmorillonite. Myrle E. King of the U. S. Bureau of Reclamation has interpreted thermal curves of these clays (curve 5, fig. 59, is representative) as similar to calcic montmorillonites that he has analyzed (personal communication). Where pre-Wisconsin soil clays are in positions subject to Wisconsin soil processes, the clays are mixtures of montmorillonite and illite (curve 4, fig. 59). This relationship and the dominance of illite in pre-Wisconsin soil clays suggest that the Wisconsin pedogenic environment not only formed montmorillonite on fresh material but also modified the older soil clays.

Facies changes in parent material—for example, the change from sandy to silty texture at increasing distance from source areas of eolian silt and sand—produced gradational changes in soil profile. In the example cited, development of carbonate nodules is favored by silty texture.

Wisconsin soil of very clayey texture, if in thin layers and rich in carbonate nodules, can be confused with soil of pre-Wisconsin age. Figure 60 illustrates the problem and should be compared to figure 57 which shows a well-developed Wisconsin soil profile. From the local-

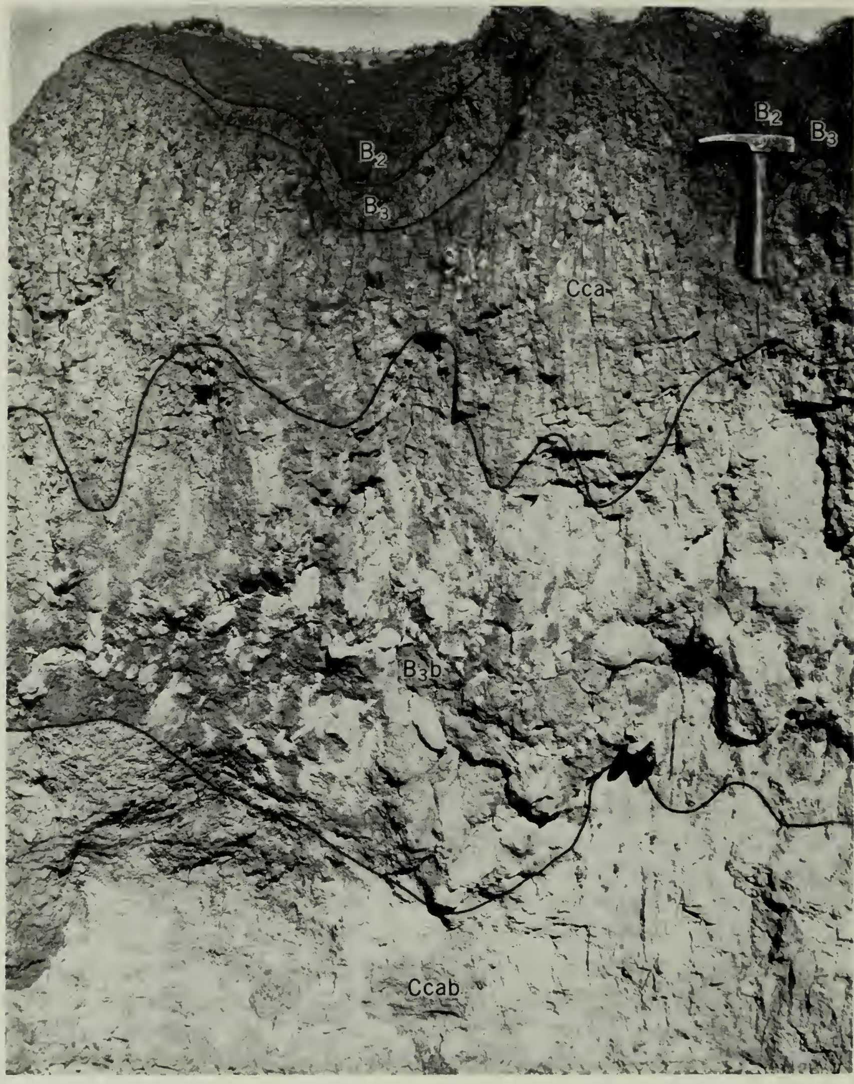

FIGURE 60.—Pre-Wisconsin soil buried by loess of Wisconsin age in gully in the NE¼SW¼ sec. 19. T. 1 S., R. 69 W. Letter symbols interpreting soil horizon genesis follow U. S. Soil Survey nomenclature. Top layer is post-Wisconsin solum. B_2, B_3, and C_{ca} are Wisconsin loess interpreted as possibly equivalent to mid-Wisconsin soil of Nebraska and Kansas. C_{ca} is gray-buff silty clay, finely prismatic at left and with carbonate nodules at right; parent material of horizon C_{ca} may have been the *B* horizon of the underlying pre-Wisconsin soil. B_{3b} is clay, coarsely prismatic in upper half of layer, partly cemented with calcium carbonate in lower half, and red brown (iron oxide) where not whitened by calcium carbonate; it contains nonquartzitic gravel that is much decomposed. The properties of B_{3b} and the intense carbonate accumulation in C_{cab} indicate pre-Wisconsin soil forming processes.

ity illustrated in figure 60 the upper soil profile can be traced laterally into sand and silt (interpreted as an eolian deposit of Wisconsin age) which rest unconformably on pre-Wisconsin gravel. The photograph illustrates soil development at a point near the thin edge of the eolian deposit. The contact between the upper and lower soils is determined by a structural change from finely prismatic to jointed, a color change from dark brown to red brown, a texture change from silty clay to gravel, and a great difference in amount of carbonate. Moreover, nodules in the carbonate layer of the upper soil do not extend downward to the contact but end several inches above.

Although these two soils are distinct and the contact between them may be determined within 1 or 2 inches, the very well-developed joint system in the carbonate layer (horizon Cca in fig. 60) of the upper soil is not characteristic of the similar profile nearby. The structure and texture of this layer may have been inherited from the older soil below. If so, modification by Wisconsin soil processes changed the color of the pre-Wisconsin soil and deposited calcium carbonate in a layer which may formerly have been lime free. The presence of carbonate in the upper soil, however unimpressive when compared to carbonate deposition below, is puzzling. The source of the carbonate could not have been the thoroughly leached red clay layer of the buried soil. Unless fresh material was laid down on the buried soil, the carbonate must have been brought upward from the underlying calcareous layer. Why, then, does carbonate in the pre-Wisconsin soil end more or less abruptly at the contact between the two soils?

Wisconsin soil profiles developed on thick deposits of light-textured eolian material (p. 241 and fig. 57) show an increase in carbonate from the top of the B horizon downward to a depth of about 3 feet; the lower part of the horizon is gray, and the carbonate is evenly disseminated. Carbonate content increases abruptly at the C horizon. In the top of the C horizon much of the carbonate is concentrated as light-colored films along vertical joints; the less calcareous material within joint blocks is a rich brown. Lower in the C horizon these joints gradually disappear; the soil is uniformly light brown, and carbonate is evenly disseminated. Concentration of carbonate in widely separated vertical joints at the top of the C horizon, where it is bracketed above and below by more evenly distributed carbonate, is peculiar. Perhaps this distribution results from relative dryness during the closing phase of soil formation. Dryness would elevate the level at which products of leaching are deposited. The shift in pedogenic environment toward relative dryness may have been similar to the inferred dry periods at the close of pre-Wisconsin soil-forming intervals (p. 247–248).

RECENT SOILS

Deposits designated as Recent have thin soil profiles with very weakly developed layers and commonly contain interstratified humic beds. Clay development is slight or absent, and continuous calcareous layers are not present. The clay included in the deposits was derived from older materials; it can be attributed to Recent soil development only if in the upper few inches of the solum. A sample of Piney Creek alluvium contained calcic montmorillonite (curve 6, fig. 59). The thermal curve shows slight endothermic and exothermic inflections in the high temperature range, reflecting contamination with other clay types.

SUMMARY OF LATE GEOLOGIC HISTORY

The geologic history recorded by surficial deposits in the quadrangle is shown diagrammatically in figure 61. A generalized reconstruction of the late geologic history follows:

1. Old gravel on a knob above Rocky Flats, possibly equivalent to gravel on benches farther west, may be a remnant of a once extensive pediment that existed along the mountain front in this area during the late Tertiary.
2. Probably the Rocky Flats pediment was cut, and its surficial gravel laid down, under a long-continued stable environment.
3. Upland gravel on pediment remnants below Rocky Flats was derived both from older surficial deposits and from the mountains. Its position and gradient indicate a base level of erosion lower than that established when the gravel on Rocky Flats was deposited. The base level may have been lowered by crustal movement, but more likely as a result of climatic change at the beginning of the Pleistocene.
4. Most of the gravel on high cut terraces antedates capture of upland drainage by tributaries of major streams that had deeply incised their valleys. Two pre-Wisconsin weathering profiles developed on the gravel before capture suggest that capture occurred during the early Pleistocene.
5. Alluvial, colluvial, and loessial deposits mantle the broad valleys and interfluvial areas below the high terrace gravel. Profound alteration of these deposits by pre-Wisconsin weathering has combined with erosion to obscure details of geologic events they represent. The deposits span a time during which the valleys were incised nearly to their present depth, and probably represent more than one pre-Wisconsin glacial stage.
6. Pre-Wisconsin cobble gravel adjacent to, and partly under, the flood plain of South Boulder Creek indicates that this valley had reached its present depth in the quadrangle before the Wisconsin stage.
7. The Wisconsin stage is recorded by fluvial and eolian deposits. Gravel was deposited in the valleys of South Boulder and Coal Creeks to a depth of 12 feet or more, and fine-grained alluvium was deposited in upland valleys. An eolian mantle, spread upon the uplands, was probably derived from the flood plains while they were being aggraded with alluvium.

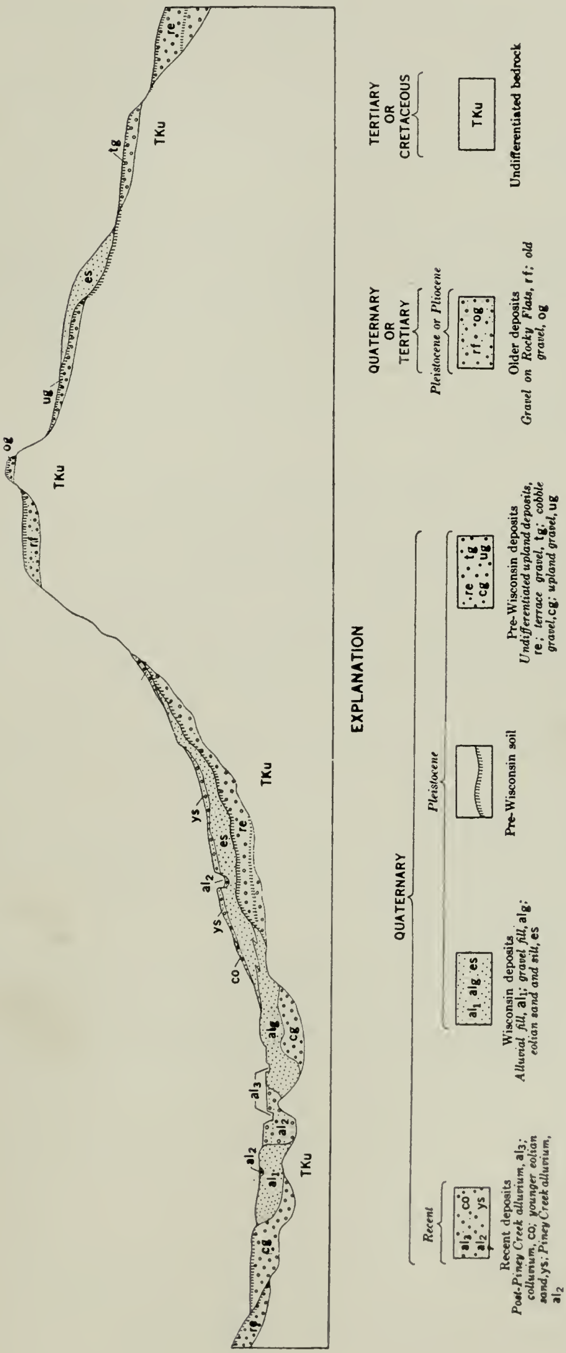

FIGURE 61.—Diagram showing stratigraphic and topographic relations of surficial deposits in the Louisville quadrangle. For full description of letter symbols see plate 7.

8. A soil developed on the eolian mantle may correlate with the mid-Wisconsin soil recognized in Nebraska and Kansas; the soil on the fluvial deposits is probably stratigraphically equivalent.

9. Late Wisconsin deposits have not been recognized but may be recorded by reworking of gravel fill along South Boulder Creek and reworked eolian sand on the upland.

10. Deposition of Piney Creek alluvium began before Christ and ended by A. D. 1000. It occurred in upland arroyos, suggesting that the climate changed from a relatively dry to a relatively wet one. The alluvium is dissected locally, but little or no younger material has been deposited. This dissection suggests that the modern climate is somewhat drier than that which prevailed when the Piney Creek alluvium was laid down. Before irrigation works were installed, however, periodic floods along the main streams laid down thin deposits of post-Piney Creek alluvium.

LITERATURE CITED

Brown, R. W., 1943, Cretaceous-Tertiary boundary in the Denver Basin, Colorado: Geol. Soc. America Bull., v. 54, p. 65–86.

Bryan, Kirk, and Ray, L. L., 1940, Geology of the Lindenmeier site, Colorado: Smithsonian Misc. Coll., v. 99, no. 2.

Emmons, S. F., Cross, Whitman, and Eldridge, G. H., 1896, Geology of the Denver basin in Colorado: U. S. Geol. Survey Mon. 27.

Fenneman, N. M., 1905, Geology of the Boulder district, Colorado: U. S. Geol. Survey Bull. 265.

——— 1930, Physiography of the Western United States: New York, McGraw-Hill Book Co.

Frye, J. C., 1951, Soil forming intervals evidenced in the Kansas Pleistocene: Soil Sci., v. 71, p. 403–408.

Frye, J. C., and Leonard, A. B., 1949, Pleistocene stratigraphic sequence in northeastern Kansas: Am. Jour. Sci., v. 247, p. 883–899.

——— 1951, Stratigraphy of the late Pleistocene loesses of Kansas: Jour. Geology, v. 59, p. 287–305.

——— 1952, Pleistocene geology of Kansas: Kansas Geol. Survey Bull. 99.

Gilbert, G. K., 1896, Underground waters of the Arkansas valley in eastern Colorado: U. S. Geol. Survey 17th Ann. Rept., pt. 2, p. 551–601.

Gude, A. J., 3rd., 1950, Clay minerals of Laramie formation, Golden, Colo., identified by X-ray diffraction: Am. Assoc. Petroleum Geologists Bull., v. 34, p. 1699–1717.

Harper, W. G., Acott, Lloyd, and Frahm, Elmer, 1932, Soil survey of the Brighton area, Colorado: U. S. Dept. Agriculture, Bur. Chemistry and Soils, ser. 1932, no. 1.

Hunt, C. B., 1954, Pleistocene and Recent deposits in the Denver area, Colorado: U. S. Geol. Survey Bull. 996–C.

Hunt, C. B., and Sokoloff, V. P., 1950, Pre-Wisconsin soil in the Rocky Mountain region, a progress report: U. S. Geol. Survey Prof. Paper 221–G, p. 109–123.

Lovering, T. S., and Goddard, E. N., 1950, Geology and ore deposits of the Front Range, Colorado: U. S. Geol. Survey Prof. Paper 223.

Schultz, C. B., Lueninghoener, G. C., and Frankforter, W. D., 1951, A graphic resume of the Pleistocene of Nebraska: Neb. Univ. Mus. Bull., v. 3, p. 1–41.

Schultz, C. B., and Stout, T. M., 1945, Pleistocene loess deposits of Nebraska: Am. Jour. Sci., v. 243, p. 231–244.

——— 1948, Pleistocene mammals and terraces in the Great Plains: Geol. Soc. America Bull., v. 59, p. 553–588.

Sweet, A. T., and Dodson, C. H., 1930, Soil survey of the Longmont area, Colorado: U. S. Dept. Agriculture, Bur. Chemistry and Soils, ser. 1930, no. 29, 35 p.

Tator, B. A., 1952, Piedmont interstream surfaces of the Colorado Springs region, Colorado: Geol. Soc. America Bull., v. 63, p. 255–274.

Van Tuyl, F. M., and Lovering, T. S., 1935, Physiographic development of the Front Range: Geol. Soc. America Bull., v. 46, no. 9, p. 1291–1350.

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Douglas McKay, *Secretary*

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W. E. Wrather, *Director*

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