Geology of the Kassler Quadrangle Jefferson and Douglas Counties, Colorado

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Quaternary Geology And Geomorphic History Of the Kassler Quadrangle Colorado

GEOLOGICAL SURVEY PROFESSIONAL PAPER 421-A

Quaternary Geology And Geomorphic History Of the Kassler Quadrangle Colorado

By GLENN R. SCOTT

GEOLOGY OF THE KASSLER QUADRANGLE, JEFFERSON AND DOUGLAS COUNTIES, COLORADO

GEOLOGICAL SURVEY PROFESSIONAL PAPER 421-A

Study of the Quaternary deposits and their fossils in relation to the geomorphology of the east flank of the Front Range, Colorado

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

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QUATERNARY GEOLOGY AND GEOMORPHIC HISTORY OF THE KASSLER QUADRANGLE, COLORADO

By Glenn R. Scott

ABSTRACT

The Kassler quadrangle lies along the east flank of the Colorado Front Range, where it contains a variety of landforms and deposits. The principal landforms are mountains, hogbacks, pediments, and canyons and valleys. The deposits range in age and composition from Precambrian crystalline rocks to Paleozoic, Mesozoic, and Cenozoic lithified sedimentary rocks and surficial deposits.

The surficial deposits were laid down during several geomorphic cycles that consisted of downward stream cutting, followed by sideward stream cutting, alluviation, wind erosion and deposition, and soil formation. Soil stratigraphy, physical geology, geomorphology, fossils, artifacts, and radiocarbon age determinations were the criteria used to differentiate and correlate the deposits.

Soils formed at six times. Calcium carbonate enriched Brown soils are the most widespread; acid Podzolic soils are found only in the higher parts of the area where surficial deposits are uncommon.

The earliest event directly related to the surficial geology was the uplift of the Rocky Mountains in Late Cretaceous and early Tertiary time. The mountains were lowered considerably by erosion in middle and late Tertiary time, and high level erosion surfaces were cut on the Precambrian rocks.

The geologic and geomorphic history of the Pleistocene in the quadrangle can be well detailed. The oldest deposits, the Rocky Flats alluvium, the Verdos alluvium and a Pearlette ash equivalent, and the Slocum alluvium, overlie broad stream-cut pediments that slope gently away from the mountains. On the three pre-Wisconsin alluviums are developed Brown soils of Sangamon(?), Yarmouth(?), and Aftonian(?) age that have lime-free clay-enriched B horizons overlying thick layers of caliche. Soil of Sangamon(?) age also is developed on an older loess that overlies the Slocum alluvium. Stream channels into the Slocum alluvium were refilled with a strath of Louviers alluvium, which is coarse grained along the major streams but fine grained along the small arroyos. A large assemblage of fossil mollusks and vertebrates, including mammoth, camel, giant bison, and other extinct animals, is found in the Louviers alluvium. The Louviers alluvium is further characterized by a thick layer of iron- and manganese-stained micaceous silt containing wavy bedding and compaction structures called flow rolls. The Louviers, which is more than 10,000 years old, is overlain locally by a younger loess. A calcareous Brown soil of Wisconsin age is developed on the early Wisconsin deposits. Channels in the Louviers alluvium are filled with Broadway alluvium along the large streams and with pre-Piney Creek alluvium along the small streams.

Recent deposits are primarily alluvium but include some eolian sand and loess. Pre-Piney Creek alluvium, the oldest Recent deposit, was dated by radiocarbon as 5,500 years old. The pre-Piney Creek alluvium contains an Archaic culture. Eolian sand blown from soft bedrock and from stream alluvium overlies the pre-Piney Creek alluvium. An early Recent Brown soil is developed on the alluvium and on the eolian sand. Arroyos cut in late Recent time are filled with silty humic Piney Creek alluvium about 2,800 years old; a late Recent Brown soil is developed on this alluvium. Small arroyos in the Piney Creek alluvium are partly filled with sandy post-Piney Creek alluvium, which contains pottery and artifacts of the Woodland culture about 1,500 years old. Small unmappable deposits of late Recent eolian sand and loess also contain artifacts of the Woodland culture. Modern arroyos are cut in Piney Creek and post-Piney Creek alluvium. Bog clay and landslides occur at several places in the area.

Deposits of alluvium contain sand, gravel, and boulders that may be suitable for use as aggregate for concrete, as road metal, and as riprap.

INTRODUCTION

The Kassler quadrangle is mantled by surficial deposits of Quaternary age that provide an important geomorphic record which is broadly applicable along the east flank of the Front Range. This report describes the deposits, and their soils and landforms, and explains the methods by which they have been distinguished. The section "Origin of the landforms" gives an interpretation of these physical features in terms of their geomorphic evolution.

The deposits were studied to obtain essential geologic information for engineering works planned by the Denver City Water Board and the U.S. Bureau of Reclamation.

The Kassler quadrangle, an area of 57 square miles in central Colorado, is 18 miles south of Denver (fig. 1).

The surficial deposits were mapped in 1953; fossils were collected and studied in 1954. The geology was plotted on aerial photographs and then transferred to

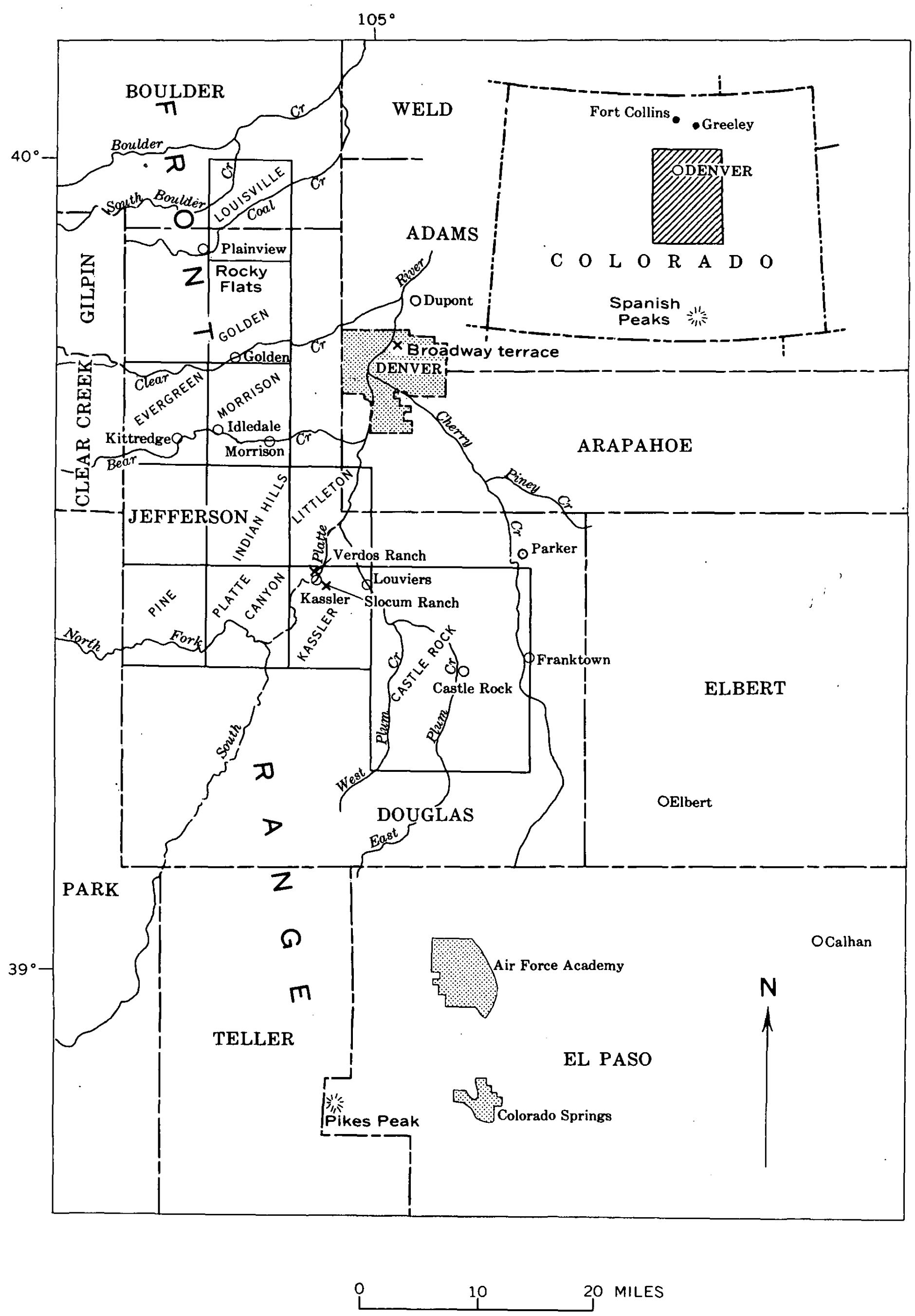

FIGURE 1.—Map showing location of Kassler quadrangle and other places mentioned in text.

the topographic map of the quadrangle at the scale 1:20,000. The distribution of the surficial deposits is shown on the surficial geologic map (pl. 1).

Most of the deposits are well exposed in natural cuts such as arroyos or in artificial cuts such as roads and canals. Some pits and augerholes were dug to find the thickness and character of the surficial materials. Deposits that are more than 3 feet thick are mapped; those less than 3 feet thick are included in the underlying unit.

ACKNOWLEDGMENTS

Many ranchers made their lands accessible for this survey. Ray E. Johnson, forest ranger at the Indian Creek ranger station in Pike National Forest, gave helpful information on roads and trails in the National Forest. James Slocum and E. H. Sterling, of pioneer families, gave much information on the history of the area and dates of arroyo cutting and deforestation.

Specialists helped me on several parts of the investi-

gation. Arnold Withers, archaeologist of Denver University, examined several archaeological sites and with the assistance of his students, particularly David Breternitz, excavated four of the sites. Dwight W. Taylor and Cornelia C. Cameron, of the U.S. Geological Survey, identified the mollusks and prepared a large report on them from which I abstracted the passages in this report. More than 200 vertebrate fossils were identified by Edward Lewis, of the U.S. Geological Survey, in collaboration with C. B. Schultz, T. M. Stout, and L. G. Tanner, of the University of Nebraska State Museum and Geology Department. The fossil seeds were identified by R. A. Scott, of the U.S. Geological Survey. The ostracodes were identified by I. G. Sohn, of the U.S. Geological Survey, and the charophytes by R. E. Peck, of the University of Missouri.

I am particularly grateful to Gerald M. Richmond, of the U.S. Geological Survey, for advice given in the field and in the office on soils and on the Quaternary stratigraphy.

PREVIOUS PUBLICATIONS

The surficial deposits of the quadrangle were not previously described or mapped. Members of early Survey teams described in a general way the topographic features, particularly the even summits of the mountains and the knifelike truncation of the hogbacks. The lack of publications on the local geology is compensated by a large literature on the regional geology.

Nearly all the regional reports describe the geomorphology. The so-called peneplains in the mountains have aroused the most interest. The pediments in the plains are the subject of fewer papers; the surficial deposits of the plains were neglected until recently when several articles were published by the U.S. Geological Survey.

GEOGRAPHIC SETTING

TOPOGRAPHIC FEATURES

All the landforms of the quadrangle lie within two physiographic divisions (Fenneman, 1931): the Colorado Piedmont section of the Great Plains physiographic province at altitudes of 5,500 to 6,500 feet and the Rocky Mountain Front Range at 5,600 to 8,050 feet. Streams have eroded these two divisions into mountains, hogbacks, pediments, and canyons and valleys. These landforms are the product of late Tertiary and Quaternary erosion, which was controlled by the structure and the hardness of the rocks.

MOUNTAINS

The mountains can be subdivided into those composed of Pikes Peak granite and those composed of metamorphic rocks. Those composed of Pikes Peak granite in the south end of the quadrangle are gently rounded except for local rugged peaks of hard granite. Their slight local relief, which is only about 500 feet, results from deep weathering and erosion of the coarse-grained granite. Weathered granitic debris covers the hills, which slope gently downward to broad debris-filled valleys.

The mountains to the northwest, which are composed of metamorphic rocks, are rugged, especially where cut by the canyons of the South Platte River and its tributaries. Locally, small, gently rounded hills of granite lie within the rough terrane of the metamorphic rocks.

An erosion surface of Pliocene age beveled the mountains at altitudes between 7,000 and 8,000 feet. This surface is now preserved as smoothed ridge tops and knobs of nearly equal height. Stream-deposited gravel lies on some of these knobs in nearby areas of the Pine and Indian Hills quadrangles (fig. 1) at altitudes ranging from 7,500 to 8,000 feet. As viewed from the east, the mountains present a rather even summit line except for some irregularities, some V-shaped canyons, and an east-facing escarpment that slopes steeply down to the level of the hogbacks.

HOGBACKS

The hogbacks, sharp ridges of upturned sedimentary rocks that lie parallel to the mountain front (figs. 2, 6), range from 5,500 to 6,500 feet in altitude; some have more than 500 feet of relief. They are composed of the hardest sedimentary rocks in the area—sandstone, conglomerate, and limestone. Their continuity is broken by water gaps, and their summits are truncated by pediments.

PEDIMENTS

The pediments, alluvium-covered broad bedrock floors of ancient streams, were eroded across both hard and soft rocks in early and middle Pleistocene time. Three pediments are recognized; the oldest and highest pediment truncates the hogbacks and lies 350 feet above the streams; the middle pediment truncates only the softer rocks and lies 250 feet above the streams; the lowest pediment also truncates only the soft rocks and lies 100 feet above the streams. Only small remnants of the pediments have survived later stream erosion. The slope of all three pediments, estimated from the slope of the material that covers them, is at least 100 feet per mile. The bedrock surface itself may be steeper. The

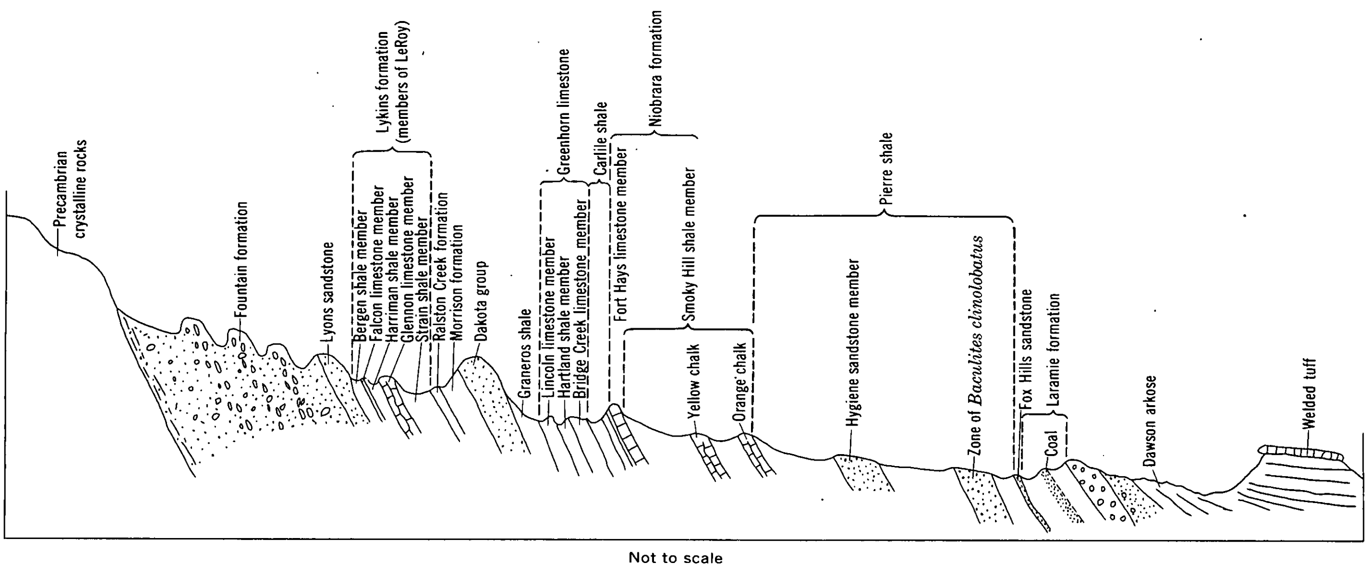

FIGURE 2.—Diagrammatic sketch of outcrop expression of bedrock showing the relative prominence of the ridge-forming units.

cover on the pediments, locally more than 35 feet thick, consists of coarse alluvium that was deposited by streams.

CANYONS AND VALLEYS

Deep V-shaped channels cut through the Precambrian rocks in the western part of the quadrangle are called canyons; broad shallow channels cut through the sedimentary rocks and surficial deposits in the eastern part of the quadrangle are called valleys.

The canyons are characterized by steep gradients, great depth, thin alluvial fills, and large blocks of bedrock that litter the slopes and bottoms. Gradients range from 70 feet per mile along the South Platte River to 500 feet per mile along small tributaries. Waterfalls plunge nearly 60 feet to the level of the river near the mouths of some tributaries. The river lies more than 2,000 feet below the summit level of the surrounding mountains; smaller canyons are more than 500 feet deep and generally contain many 5- to 10-foot cascades over bedrock. Alluvium is rarely more than 10 feet thick along these canyons, but along the river it may be 20 feet thick; there it contains many large boulders that partly block the river. Boulders also clog the small streams and create small waterfalls and large brush piles, which block the paths along the streams. The source of the boulders is the adjoining slopes, where rocks are perched in various degrees of stability. Talus is uncommon, possibly because the climate is too wet or because the rocks are softened too much by faults to stand steeply.

Most of the canyons are along faults; only a few are superposed across faults. Where a canyon extends from hard unfaulted into soft faulted rocks, the stream emerges from a sharply constricted valley with a bedrock floor and passes into a broad alluviated valley. Where a stream in a fault valley nears the mountain front or the South Platte canyon, the broad valley is breached by the stream's abrupt plunge to a lower altitude. Whether faulted or not, the South Platte canyon and the other canyons change to broad valleys where they leave the mountains.

The valleys east of the mountains are wide flat-floored terrace-bordered channels occupied by quiet, braided streams, that flow over thick deposits of fine- to medium-grained alluvium. Here, the valley walls of the larger streams are only about 100 feet high and slope gently down to broad terraces that border the stream and then down to a flat flood plain. Nearly 100 feet of alluvium underlies the flood plain of Plum Creek and more than 30 feet underlies that of the South Platte River. Smaller valleys also are broad and contain thick accumulations of alluvium. The size of the valleys is proportional to the size of the streams that cut them.

DRAINAGE

The plains area of the quadrangle is drained by five perennial streams and many ephemeral streams. Ephemeral streams are powerful cutting agents in the spring. No surface water flows in these ephemeral stream valleys the rest of the year, but an underflow continues even in the summer in the ephemeral stream beds east of the mountains. In the small mountain canyons, springs enter here and there and the water flows for a few hundred feet before it evaporates or sinks into the ground.

The flow of water in the ephemeral streams is greatest after cloudbursts, when runoff is fast. Cloudbursts are generally of short duration and confined to small areas, but the precipitation is heavy (as much as 18 inches in a day) and the flash floods swift and destructive. Water runs over the steep pediments in a sheet which may be 6 inches thick. Despite the coarseness of the alluvium, infiltration is probably less than an inch per hour. Most of the bedrock deposits are finer grained than alluvium and have even slower infiltration rates; therefore, a great quantity of runoff enters the streams in a short time.

CLIMATE

The quadrangle is in an area of continental and temperate climate. Summers are long and warm; winters are short and cold. Atmospheric pressure is about 83 percent of that at sea level, and the humidity averages 53 percent. Average rainfall is slight and evaporation is high. Weather is changeable and difficult to predict because of the rain shadow effect of the Continental Divide.

TEMPERATURE

Extremes of temperature can take place within 24 hours; however, extended periods of subzero weather or temperatures above 100°F are rare (see the following table). The extreme maximum for a 10 year period at Kassler was 103°F and the extreme minimum was −32°F. The average date of the last killing frost at Kassler is May 6 and of the first is October 5—an average frost-free season of 152 days. The ground becomes frozen about the middle of December, but the depth of frost penetration (average 2 feet) depends on the exposure and altitude. Frost goes deeper and stays longer on north-facing slopes.

Forty-year precipitation and temperature averages at Kassler, Colo.

[From records of U.S. Weather Bureau]

Period	Precipitation (inches)	Temperature (°F)
January	0.42	32.6
February	.75	36.3
March	1.33	39.5
April	2.63	49.7
May	2.36	58.1
June	1.64	68.4
July	1.91	74.0
August	1.81	72.4
September	1.51	65.8
October	1.36	55.6
November	.75	41.9
December	.87	36.4
Annual	17.34	52.6

PRECIPITATION

The climate is characterized by limited and variable rainfall and high evaporation. Precipitation is barely above 15 inches (see table above), the line between semiarid and humid climate, but it is well distributed, most of it falling between March and October. The precipitation of the winter months falls as snow and is preserved, especially on the north-facing slopes, until spring, when the water soaks into the ground before plant growth begins. Hail, commonly accompanied by strong wind, falls occasionally in early summer and creates a hazard to farm crops.

WINDS

The quadrangle has long been swept by winds. Old eolian deposits are now part of the stratigraphic column. These ancient winds, as inferred from the deposits, blew from the northwest.

The prevailing wind still blows from the northwest, and is strongest in the spring and fall. Gusts of wind precede thunderstorms; dust darkens the sky on successive windy days. The dust is picked up from freshly plowed fields, from dirt roads, and from stream bottoms by winds that blow off the Front Range, funnel down the valleys between pediments, and sweep eastward across eastern Colorado. Small spiraling winds (dust devils) accompany the northwesterly winds, but tornadoes and hurricanes are not known in this area.

SOILS

In describing the surficial deposits of the Kassler quadrangle, some terms are employed in this report that are used by soil scientists to describe certain features usually disregarded in geologic literature. These terms are defined in the Soil Survey Manual (U.S. Dept. of Agriculture, 1951, pp. 189–203).

Designation of color follows the usage suggested by the Soil Survey Manual. The symbols are taken from the Munsell soil color charts (Munsell Color Co., 1954) which were used during mapping.

The predominant soils in the quadrangle belong to two great soil groups: the Brown soils characterized by a horizon of calcium carbonate in the parent material, and the Podzolic soils characterized by a lack of calcium carbonate. The two groups overlap in distribution; Brown soils are found below 6,500 feet altitude, and Podzolic soils are found above 5,900 feet altitude.

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The horizons shown in figure 3 (defined by U.S. Dept. Agriculture, 1951, 1957) were used in the mapping or are described in the report, although not all are superposed in a single profile as they are shown in figure 3.

The duff layer or A_0 horizon and the ashy A_2 horizon are limited to the Podzolic soils in the higher parts of the area. The A_1, B_2, B_{ca}, and C_{ca} horizons are typical of the Brown soils in the lower parts of the area. The G horizon is limited to the soils formed on bog deposits.

In this report, horizon designations indicate what processes have made the soil; for instance, B_{ca} indicates that calcium carbonate of a younger soil has been carried downward and precipitated in the B horizon of an older soil; C_{ca} indicates that calcium carbonate has enriched the upper part of the parent material.

The B horizon is thicker in the older, more strongly developed soils, and is much thicker in a coarse-grained soil than in a fine-grained soil because water can percolate more easily through coarse-grained material than through fine-grained. A clayey soil is likely to have a well-defined structure; a sandy soil, on the other hand, may be structureless. A wet environment speeds aggregation of soil particles by (1) producing more clay by decomposition of parent material and (2) moving the clay down into the B horizon where the greatest structural development takes place.

For identification of soils, color of the B horizon is most reliable, but is different for the soils of each age; the older are dusky red, the younger are, in order, reddish brown, yellowish brown, and grayish brown. The colors of the B horizons are plotted on a graph in figure 4 which shows that color is a diagnostic correlative feature. Color that is the result of soil development generally does not mask original strong colors in parent material. Weakly colored parent material, however, is readily changed to shades of yellow or brown by precipitation of iron and clay in the B horizon.

Structure of the B horizons of the soils of a certain age is the same only in soils of like texture. Coarse-grained soils generally are structureless; fine-grained soils have well-defined prismatic or columnar structure. The size, distinctness, and shape of the structure depends primarily on the amount of clay in the B horizon.

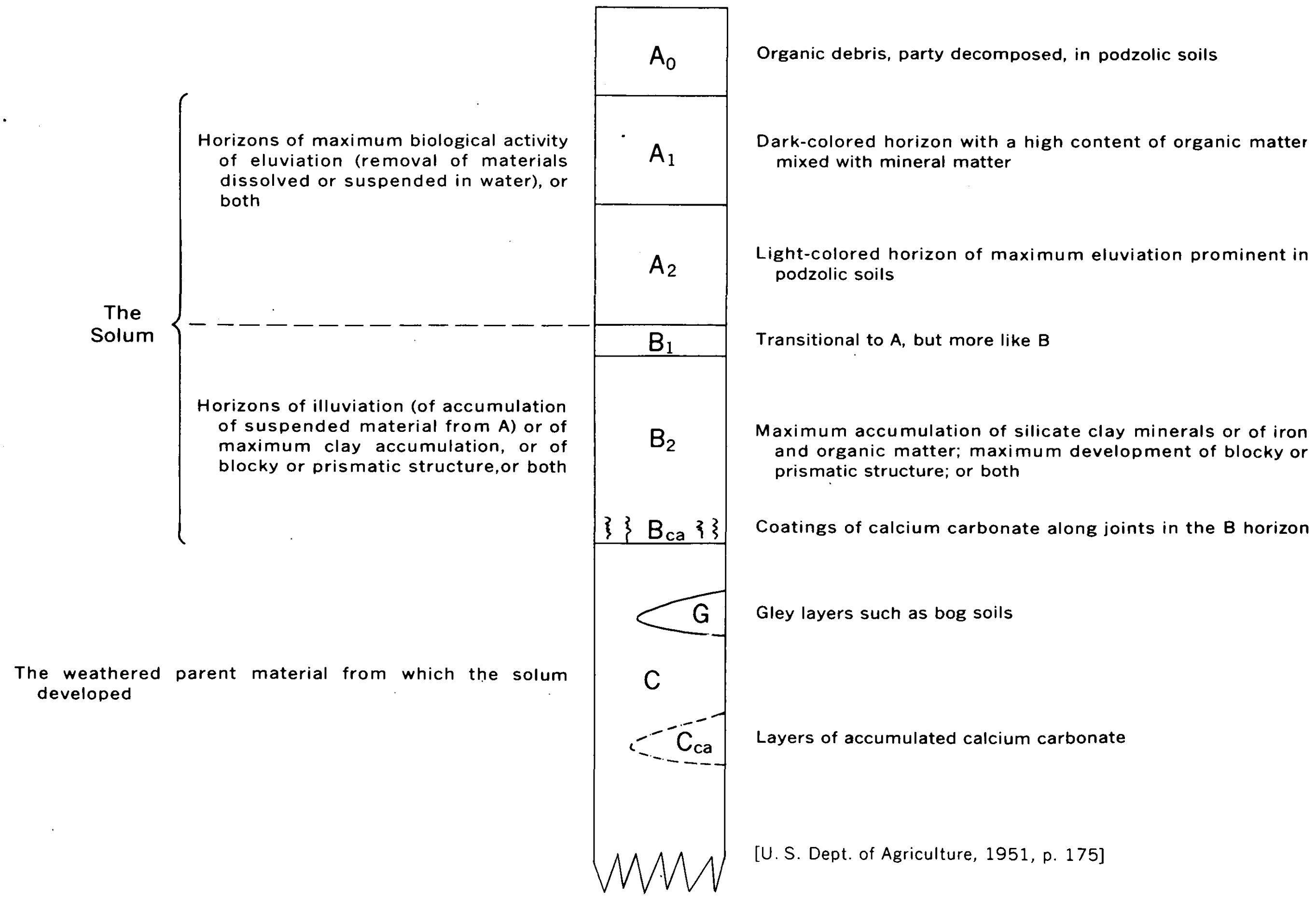

FIGURE 3.—Principal horizons of the soil profile.

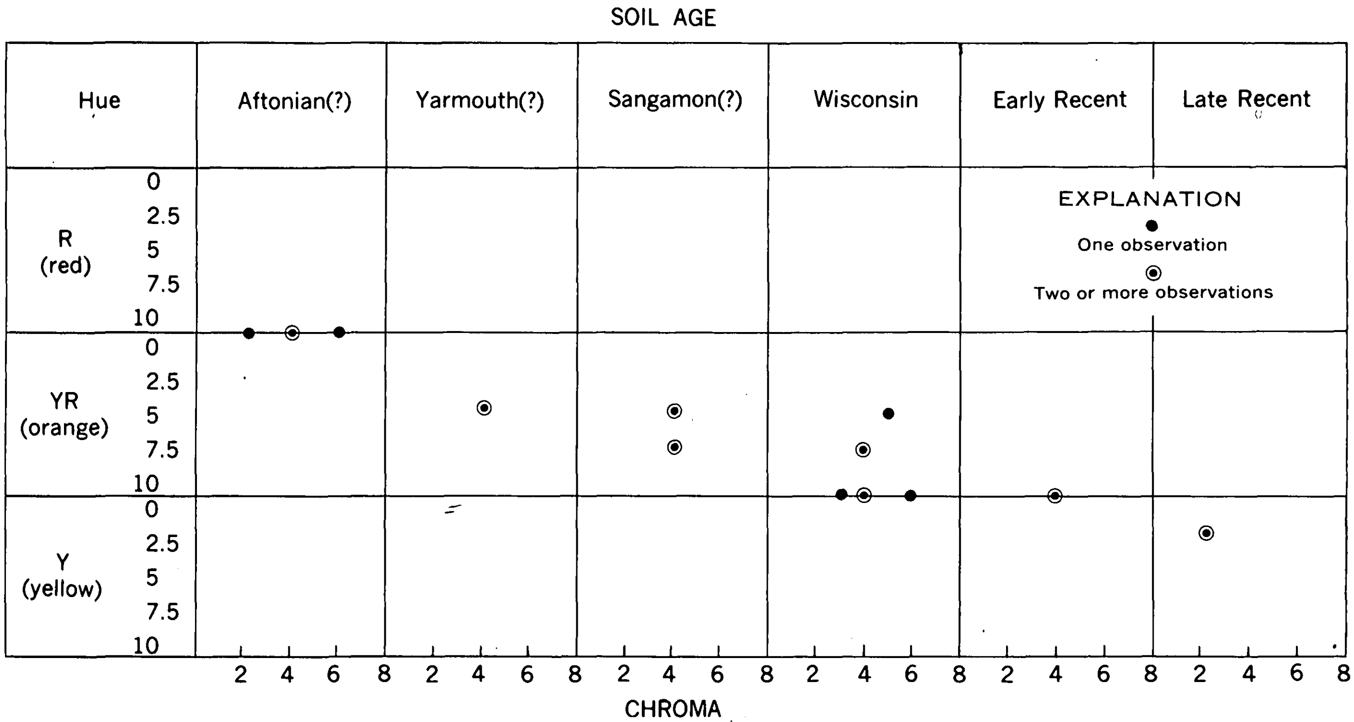

FIGURE 4.—Color of B horizons of soils developed on Quaternary alluvium. (Color symbols from soil color charts, Munsell Color Co., 1954.)

Clay content appears to be proportional to the degree of soil development, but soils that are formed of clayey parent material do contain more clay in the B horizon. Because the degree of soil development is greater in the older soils and less in the younger soils, the older soils have better defined structure.

In such older soils, structure commonly is developed in the A horizon, B horizon, and even in the upper part of the parent material. Some soil scientists would include in the B horizon of such a soil every part of the profile in which structure is developed. Where only a single soil is being described, this practice is all right, but, for instance, where a thin layer of alluvium buries an earlier soil and then a younger soil is formed on the alluvium, the structural features of the younger B horizon may be superposed on the older A horizon, the B horizon, and possibly on the older C_{ca} horizon. The use of the term "B horizon" for all parts of this profile that contain structure would disguise the real genesis of the profile. Where possible the parts of such a profile are so designated that their mode of origin becames clear. This is done by subscripts. The term "A_b horizon" means that a younger B horizon was developed on an older A horizon. The term "B_{ca}" means that calcium carbonate from a younger soil accumulated in the B horizon of an older soil. Other horizon designations are compounded in like manner for other problems of superposition.

Consistence of the B horizon is nearly the same in soils of the same age and texture, but varies as the amount of clay varies. Clayey B horizons are sticky and plastic regardless of their age, but their hardness correlates well with age. The beds in an old clayey B horizon are extremely hard; in a young clayey B horizon they are soft. As the texture becomes coarser, the B horizon becomes less sticky, less plastic, and softer, but the older soils of a particular original texture are more sticky, plastic, and hard simply because the older soils are more strongly developed and clay has had more time to form.

Reaction of the soils was measured in the field in terms of pH with a small commercial colorimetric kit. Because pH was not determined in the laboratory and may be only a close approximation of the true value, it is expressed in words that represent a range of pH as measured in the field as follows:

	pH
Strongly acid	5.1–5.5
Medium acid	5.6–6.0
Slightly acid	6.1–6.5
Neutral	6.6–7.3
Mildly alkaline	7.4–7.8
Moderately alkaline	7.9–8.4
Strongly alkaline	8.5–9.0

Reaction of undisturbed B horizons developed in identical parent material is the same in soils of the same age, but is more acid in the older soils. B horizons of older soils generally are disturbed by erosion if at the surface or by the later accumulation of calcium carbonate if buried. The detailed stratigraphic sections in this report, which were chosen because they showed the superposition of several deposits and soils, show secondary calcium carbonate in the B horizon of almost every soil. Obviously then, the only soils in which the reaction of the B horizon is not changed are uneroded soils at the surface.

USE OF ANCIENT SOILS AS STRATIGRAPHIC MARKERS

Ancient soils were used as markers in the Quaternary stratigraphy of the quadrangle because they are widespread and easily differentiated from each other as a result of development during several widespread Quaternary climatic intervals of slope stability and weathering. Regardless of parent material or topography, each weathering interval produced a soil that is distinguishable from the soils of the other intervals. The soils were identified by their uniform profile characteristics, which were not changed by later environments but are much the same whether the soils are buried or relict at the surface. The soil horizons were affected differently by such subsequent influences as superposition of weak soils, slight erosion, or burial.

The A horizon is readily changed by plants, by the deposition of humus, and especially by slight erosion. The lack of A horizons as part of most of the old soils is generally attributed to this erosion; however, the absence of a humic layer may be due to leaching or oxidation of the organic matter or to fixed carbon in the A horizon. A marked progressive decrease in grayness that may be due to leaching or oxidation was observed between the A horizons of the younger and the older soils in the area. If a chemical process can reduce the grayness of the A horizon, then leaching or oxidation rather than erosion may be the reason why no original A horizons are seen in the oldest soils.

The B horizon was found to be the most reliable horizon to describe and correlate; it is very little affected by the addition of humus, by slight erosion, or by the superposition of later weak soils. The diagnostic features of the B horizon include the thickness, color, structure, consistence, and reaction. The intensity of these features determines what is called the "degree of development" of the soil. The B horizon of one soil may be consistently thicker, redder, more blocky, and more plastic, and may have a lower pH than the B horizon of another soil. The profile of the first soil is said to be better developed than the profile of the second. The terms that are used in this report to express this relative degree of development are: "weakly developed," "moderately developed," "strongly developed," and "very strongly developed."

The C_{ca} horizon in the parent material generally is very little disturbed by subsequent burial, slight erosion, or superposition of a weak soil. The amount of calcium carbonate in the C_{ca} horizon depends on the amount available nearby. Near a source of calcium carbonate, the C_{ca} horizon is generally thicker and contains a greater concentration of calcium carbonate than the average for a particular soil.

At a particular altitude, the soils of different geologic ages differ considerably in degrees of development. Generally the older soils—whether buried or exposed at the surface—are more strongly developed than the younger. The soils that were used as stratigraphic markers in the Kassler quadrangle from old to young progress from very strong to weak; their names and sequence of development are:

Soils of the Kassler quadrangle

Age	*Development*
Late Recent	Weak.
Early Recent	Moderate.
Wisconsin	Strong.
Sangamon (?)	Very strong.
Yarmouth (?)	Do.
Aftonian (?)	Do.

A strongly developed soil exposed at the surface was little affected by later soil-forming processes that only produced a weakly developed soil on fresh parent material. Therefore, because most of the older soils are the most fully developed and did not lose their identity because of later soil-forming processes, the older soils exposed at the surface were used as stratigraphic markers with as much confidence as were the older soils buried by younger deposits.

PROBLEMS IN THE USE OF SOILS AS STRATIGRAPHIC MARKERS

Problems arise in the use of soils as stratigraphic markers owing to differences in the original degree of development of the soil and to disturbances of the profile after the soil was formed, especially by climatic, vegetational, and geologic processes. Differences in the original soil resulted from differences in the altitude and the vegetation under which the soil developed. These major differences in the soil, herein called facies by analogy with the use of that term for lateral changes in rocks, range from a Podzolic facies in the mountains to a Brown soil facies on the plains. These different facies, related to a change in altitude, are typical of mountain soils. For instance, Marbut (1935, pl. 78) described four soil belts in the mountains of western United States where Brown soils encircle the base of the mountains and Podzolic soils are near the top. Thorp (1931) described a similar succession of soils in the Big Horn Mountains of Wyoming where soils enriched with calcium carbonate lie near the base of the mountains and Podzolic soils lie near the top. These mountain soil facies are almost the same as the great soil groups, which cover a wide range of latitude, but in the mountains the great soil groups are telescoped into narrow altitude zones.

Although each facies is related closely to an altitude zone, the soils differ primarily because they were developed under different vegetation. A soil developed under grass has a calcareous profile; a soil developed under deciduous or coniferous trees has an acid profile. The boundary between these two facies is interfingering and gradational because it follows the boundaries between zones of vegetation. The two facies are not easily recognized as soils of the same age, although a strongly developed soil of one facies is also strongly developed in another facies; generally one facies can be traced into the other, or their physiographic identity can be demonstrated.

Disturbances of the profile after a soil was formed were caused mainly by changes in climate. A change in climate altered the soil by driving the deciduous trees out onto the Brown soils of the plains or the grass up onto the Podzolic soils of the mountains. Similarly an increase in temperature and a decrease in precipitation caused calcification of some soils, and a decrease in temperature and an increase in precipitation caused podzolization. Climatic fluctuations in Pleistocene time must have caused many such facies changes, but because climatic change completely converted all the soils over a widespread area, facies changes resulting from climatic changes were not as difficult to interpret as the disturbances caused by local geologic processes.

Erosion and deposition were the two main geologic processes that disturbed the soil. Many changes were made in the soils by combinations of erosion, deposition, and later soil formation. Some of the possibilities are listed:

1. The soil at the earth's surface remained undisturbed.
2. A later soil was superposed, on the older soil.
3. The soil was buried under a later deposit, and thus removed from the surface environment.
4. A soil that developed on the later deposit extended down into the older uneroded soil.
5. The soil was completely eroded.
6. The soil was partly eroded.
7. A later soil was developed on an erosion surface cut across the older soil.
8. A partly eroded soil was buried by a later deposit.
9. A soil that developed on the later deposit extended down into the older soil.

All these combinations were seen in the Kassler quadrangle.

The following are some of the principles that have been worked out to solve the problem of combinations of erosion, burial, and later soil formation: (1) if a soil remains undisturbed at the earth's surface, it is the product of all soil-forming periods since the parent material was deposited; (2) if the upper part of a soil (A horizon or part of B horizon) is missing, the soil probably was eroded after development; (3) either an eroded soil or a buried soil may have been the product of several periods of soil development; (4) a buried soil is not necessarily ancient and a soil at the surface is not necessarily modern.

Distinctive ancient soils are preserved, as shown in table 1, at six separate horizons, and the oldest soils are the most strongly developed. The soils of Wisconsin and Recent ages are less strongly developed than the pre-Wisconsin and may be differentiated from them, but the pre-Wisconsin soils can be differentiated from each other only by their geomorphic or stratigraphic associations. Where they are not separable in this way they are simply called pre-Wisconsin soils.

GEOLOGY

PRE-QUATERNARY ROCKS

The surficial deposits are underlain by both crystalline and sedimentary rocks which are listed below and shown on figure 2. The oldest of the crystalline rocks are several very complex Precambrian gneisses and migmatites, which are cut by two granite bodies of later Precambrian age. The sedimentary rocks are marine and nonmarine shale, sandstone, and limestone ranging in age from late Paleozoic to early Cenozoic. The Precambrian crystalline rocks were intruded by early Paleozoic sandstone dikes and early Cenozoic dark igneous dikes. The following table shows the detailed sequence of pre-Quaternary bedrock units that crop out in the Kassler quadrangle.

STRUCTURE

The Kassler quadrangle contains a large fold and many faults that have affected the geomorphic evolution of the area. The fold is the monoclinal fold along the east flank of the Front Range that formed as the mountains rose. The core of the fold is occupied by Precambrian crystalline rocks in the mountainous western half of the quadrangle. The flanks of the fold are

Pre-Quaternary stratigraphy of the Kassler quadrangle

Era	System	Series	Formation and member	
Cenozoic	Tertiary	Paleocene	Dawson arkose	
Mesozoic	Cretaceous	Upper	Laramie formation	
			Fox Hills sandstone	
			Pierre shale	Hygiene sandstone member
			Niobrara formation	Smoky Hill shale member
				Fort Hays limestone member
			Graneros shale, Greenhorn limestone and Carlile shale, undifferentiated	
		Lower	Lytle and South Platte formations, undifferentiated (Dakota group)	
	Jurassic	Upper	Morrison formation	
			Ralston Creek formation	
	Triassic(?)		Lykins formation	Strain shale member of LeRoy
Paleozoic	Permian(?)			Glennon limestone member of LeRoy
				Harriman and Bergen shale members of LeRoy, undifferentiated
	Permian		Lyons sandstone	
	Pennsylvanian		Fountain formation	
	Cambrian	Upper	Sandstone dikes	
Precambrian			Pegmatite	
			Pikes Peak granite	
			Biotite-muscovite granite	
			Quartz diorite and hornblendite	
			Gneissic granite	
			Hornblende granite gneiss	
			Sillimanite granite gneiss	
			Granite gneiss and migmatite	
			Lime silicate gneiss	
			Amphibolite	
			Biotite-quartz gneiss	
			Sillimanitic biotite-quartz gneiss	
			Quartzite	

represented by the steep ridges of eastward-dipping sedimentary rocks.

The faults have strongly influenced the topography of the quadrangle. Most of the faults in the mountains are northwest-trending and the streams have excavated their valleys in the weakened rocks along these faults. The minor faults and fractures did not soften the rocks as much; consequently they are not followed by streams, but do make saddles where the faults cross the ridges. The faults in the sedimentary rocks are north-trending strike faults that generally thin the stratigraphic section. One of these faults follows the Fountain formation (see stratigraphic chart) across the quadrangle and has weakened it so that this faulted belt was eroded more easily than the rest of the Fountain. At the south end of the quadrangle another large fault cuts out all the shale and other fine-grained sedimentary rocks, and brings sandstone and conglomerate of the Dawson arkose (see stratigraphic chart) into contact with the Precambrian rocks. For this reason, the surficial deposits from this small area lack fine-grained sediments. In summary, the rocks of the Front Range monocline and the local faults have established the framework that controlled the location, the kind, and the arrangement of all the later geomorphic features.

QUATERNARY DEPOSITS

The Quaternary deposits in the Kassler quadrangle are of four principal kinds: alluvium and colluvium,

Species	Formation				
	Pleistocene			Recent	
	Slocum alluvium	Louviers alluvium	Younger loess	Pre-Piney Creek alluvium	Piney Creek and post-Piney Creek alluvium
Citellus sp. (ground squirrel)		?			
Cynomys sp. (prairie dog)	×	×			
Thomomys sp. (western pocket gopher)		×			×
Ursus horribilis (grizzly bear)				×	
Mammuthus (Parelephas) columbi (mammoth)		×			
sp		×			
Equus sp. (horse)		×	×		
Camelops sp. (camel)	×	×	×		
Tanupolama sp. (llama)		×			
Odocoileus hemionus (mule deer)		cf		×	×
Bison antiquus (bison)		×			
sp	×	×			
bison					×

FIGURE 5.—Stratigraphic occurrences and ranges of Pleistocene and Recent mammals in the Kassler quadrangle

windblown sand and loess, bog deposits, and landslides (table 1; pl. 1). Only a few alluvial deposits in the mountains are large enough to be mapped. Although rocks on the steeper slopes in the mountains are generally covered by colluvium, the cover, which commonly is soil, is so thin that it was not mapped.

Fossil mollusks were systematically collected in 50- to 100-pound samples, washed from their matrix on a No. 20 screen (U.S. standard series), dried, and separated. As a general rule, mollusks were found only in the parent material of Quaternary deposits (the lower part of the deposit); they had been leached out of the soil above the parent material. Table 2 shows the stratigraphic distribution of all the mollusks in the quadrangle.

Fossil vertebrate remains were excavated systematically at one richly productive area, but were collected from other deposits only in the course of mapping. Most of the rodent bones came from samples washed for mollusks. Vertebrate fossils are abundant and diagnostic in the younger alluvium but are too scarce and poorly preserved to be of much help in dating the older alluvium. Figure 5 summarizes the stratigraphic occurrences and ranges of the vertebrate fossils.

Fossil seeds were collected from fine alluvium of three different ages. Ostracodes and zygospores of *Chara* were found in one sample of alluvium that was collected for mollusks; however, the seeds, ostracodes, and charophytes are not well enough known nor abundant enough to be of stratigraphic value.

Archeology and radiocarbon dating were useful for differentiating the youngest deposits. The older artifact-bearing deposits contain no pottery; the younger contain two kinds of pottery that are of slightly different patterns and ages. Stone artifacts were of some use because the shapes of projectile points varied enough between one deposit and the next younger to be diagnostic. The younger deposits were susceptible to dating by radiocarbon. Sufficient charcoal, wood, and bone were found to date four different deposits.

TABLE 1.—*Quaternary deposits, sequence of events, and history of life in the Kassler quadrangle*

System	Series	Stage or substage		Formation (pl. 1)	Maximum thickness (feet)	Geologic event	History of life
Quaternary	Recent	Late				Valley cutting	Historic—Upper Republican culture.
				Loess and eolian sand	5	Deposition by wind	Protohistoric—ceramic Woodland culture.
				Post-Piney Creek alluvium	11	Alluviation (1,490±160 [1])	Do.
						Valley cutting	
						Soil formation (late Recent)	
				Piney Creek alluvium	25	Alluviation	Preceramic Woodland culture.
				Bog clay	6		
				Landslides			
						Valley cutting	
		Early				Soil formation (early Recent)	
				Eolian sand	10	Deposition by wind	
				Pre-Piney Creek alluvium	40	Alluviation (5,450–5,780±160 [1])	Archaic culture, warmth-loving mollusks.
						Valley cutting	
	Pleistocene	Wisconsin	Late	Broadway alluvium	35	Alluviation	Early man in North America.
						Valley cutting	
						Soil formation (Wisconsin)	
			Early	Younger loess	5	Deposition by wind	
				Louviers alluvium	91	Alluviation (10,200±350 [1])	Mammoth, camel, giant bison, and cold-loving mollusks.
						Valley cutting	
		Sangamon				Soil formation (Sangamon?)	
		Illinoian		Older loess	4	Deposition by wind	
				Slocum alluvium	90	Alluviation	Warmth-loving mollusks.
						Pedimentation	
						Valley cutting	
		Yarmouth				Soil formation (Yarmouth?)	
		Kansan		Verdos alluvium	35	Alluviation	
						Pedimentation	
						Valley cutting	
		Aftonian				Soil formation (Aftonian?)	
		Nebraskan		Rocky Flats alluvium	40	Alluviation	
						Pedimentation	
						Valley cutting	

[1] U.S. Geol. Survey radiocarbon age, in years (Rubin and Suess, 1956; Rubin and Alexander, 1958).

TABLE 2.—*Stratigraphic distribution of Quaternary mollusks in formations of the Kassler quadrangle*

[Identifications by D. W. Taylor and C. C. Cameron. cf, not certainly identified but resembles the species listed; ?, may be the species listed. Arranged according to Thiele (1931)]

Species	Formation						
	Pleistocene				Recent		
	Verdos alluvium	Slocum alluvium	Louviers alluvium	Younger loess	Pre-Piney Creek alluvium	Eolian sand	Piney Creek alluvium
Gastropods:							
Carychium exiguum (Say)			X				X
Lymnaea bulimoides Lea			X		X		
caperata Say			X				X
obrussa Say			X				
palustris (Müller)			X				X
parva Lea			X	X		X	X
sp			X	X			X
Gyraulus parvus (Say)			X				X
sp		X	X	X			
cf. *Succinea avara* Say			X	X		X	X
cf. *Succinea grosvenori* Lea	X	X	X		X		
cf. *Succinea*		X	X				X
Cionella lubrica (Müller)			X				
Columella alticola (Ingersoll)			X			X	X
Vertigo gouldi basidens Pilsbry and Vanatta			X				
modesta (Say)			X				
ovata Say			X				
sp						X	
Pupilla blandi Morse		X					
muscorum (Linné)		X	X	X		X	X
sp			X				X
Pupoides albilabris (C. B. Adams)			X		X		X
hordaceus (Gabb)		X			X		
inornatus Vanatta		X	X		X		
Gastrocopta armifera (Say)			X		X		X
cristata (Pilsbry and Vanatta)					X		
holzingeri (Sterki)			X				X
pellucida hordeacella (Pilsbry)		X					
procera (Gould)			X				
tappaniana (C. B. Adams)			X				X
Vallonia cyclophorella Ancey		X	X	X		X	X
gracilicosta Reinhardt		X	X		X	X	X
parvula Sterki			X				X
Punctum minutissimum (Lea)			X				
Helicodiscus singleyanus (Pilsbry)			X				
Hawaiia minuscula (Binney)		X	X		X		X
Retinella electrina (Gould)			X				
Zonitoides arboreus (Say)			X		X		X
Zonitid		X					
Deroceras sp			X				
Euconulus fulvus alaskensis (Pilsbry)			X				X
Oreohelix							?
Pelecypods:							
Pisidium casertanum (Poli)			X				
compressum Prime			X				
obtusale Pfeiffer			cf				
sp							X
Sphaerium sp			X				

ROCKY FLATS ALLUVIUM

The term Rocky Flats alluvium was applied by Scott (1960) to that alluvium which lies on the second erosion surface below the Rocky Mountain surface and above the Verdos alluvium. The Rocky Flats alluvium, which consists of 10 to 40 feet of reddish-brown, poorly sorted stony coarse sand, was once widespread over the Kassler quadrangle east of the mountains, but is now restricted to the tops of ridges and knobs from the center to the northeast corner of the quadrangle and in the southeast corner of the quadrangle. A very strong clayey soil was developed on the Rocky Flats alluvium possibly in Aftonian time.

The term Rocky Flats is taken from a pediment (Malde, 1955, p. 223) in the Louisville and Golden quadrangles, Colorado (fig. 1), and the type locality is designated as the gravel pit at the east edge of Rocky Flats in the NW¼SW¼ sec. 23, T. 2 S., R. 70 W. Section 1, measured at the type locality, is proposed as the type section. The total thickness of the Rocky Flats alluvium at the type locality probably is as much as 50 feet.

1. *Section of the Rocky Flats alluvium measured at the type locality in the NW¼SW¼ sec. 23, T. 2 S., R. 70 W.*

[Measured with tape]

	Feet
Rocky Flats alluvium:	
Pre-Wisconsin (Aftonian?) soil:	
Soil horizon B_2:	
Cobbles in a weak-red clayey matrix (10*R* 4/4), sandy, pebbly. Contains much ferric iron oxide. Mostly schist and gneiss fragments that crumble easily. Some quartzite fragments that split readily and have a soft rind. Structure: medium strong granular. Consistence: sticky, plastic, hard. Reaction: medium acid. Boundary: clear	1. 0–3. 4
Soil horizon C_{ca}:	
Pebbles in a very pale brown (10*YR* 8/3) to yellowish-brown (5*YR* 4/8) silty calcium carbonate matrix; sandy. Total deposit appears to be more than one-half sand size or finer material, but cobbles and boulders as much as 20 in. in maximum dimension are fairly common. The calcium carbonate concentration is massive at top and streaky at bottom. A crust of calcium carbonate is on the bottom of each stone. Contains local 2-ft. thick hard bed of calcium carbonate (caliche) at top. Deposit becomes less calcareous toward bottom where it contains 4 ft. of sand or sandy silt layers with few stones. Structure: medium strong platy. Consistence: slightly sticky, nonplastic. Reaction: moderately alkaline	20. 0
Measured thickness	21. 0–23. 4

DESCRIPTION

The Rocky Flats alluvium is a reddish-brown coarse-grained, poorly stratified deposit of locally derived rocks. Most rocks are pink; some are white, gray, black, or very dark green. These colors are masked by brown, reddish-brown and dusky-red iron oxide that coats the rocks. The alluvium is composed of boulders, cobbles, pebbles, and sand bound together by clay. Grain size is coarser toward the mountains. Three boulders greater than 6 feet in maximum dimension were seen and others that exceed 3 feet in maximum dimension are common. Most grains are equant and subangular; the grain surface is irregular or rough. Grains are arranged in layers roughly sorted by size. The grains are 77 to 90 percent granitic rocks and minerals from granitic rocks, 7 to 20 percent biotite-quartz gneiss, amphibolite, and calcium silicate rocks, and 3 percent clay ironstone and sandstone. The matrix and cementing material is kaolinitic clay strongly stained by iron oxide. Clay is most abundant in the upper part where the alluvium is the most firmly compacted.

The greater abundance of clay in the upper part together with a reduction in numbers of metamorphic and sedimentary rocks may be due to weathering. Metamorphic gneiss and sedimentary rocks are more easily destroyed by weathering than are igneous rocks. In a fresh exposure about one-third of the rocks are so soft that they may be crushed by hand. Weathering apparently altered part of the rocks to kaolin and iron oxide.

Section 2 is typical of the Rocky Flats alluvium in the Kassler quadrangle.

2. *Section measured on slope of pediment in the center NE¼ sec. 25, T. 7 S., R. 69 W.*

[Measured with tape by Scott and R. D. Miller]

	Feet
Recent colluvium: Clay, very dark gray (*N*3); sandy, humic	0. 5
Rocky Flats alluvium:	
Sand, very dusky red (10*R* 2/2); hard, very clayey B horizon	2. 0
Sand, dusky-red (10*R* 3/4); with pebbles and cobbles	7. 0
Sand, reddish-brown (5*YR* 5/4); clayey, deeply weathered contains cobbles; pebbles break in hand	12. 0
Sand, reddish-brown (5*YR* 5/4); contains pebbles, clayey layers	1. 0
Sand, reddish-brown (5*YR* 4/4); micaceous, deeply weathered; contains angular to subangular pebbles and cobbles of granitic rock. Most rocks disintegrate readily	15. 0
Sand, red (10*R* 4/6); coarse, very clayey, micaceous	1. 5
Sand, light reddish-brown (5*YR* 6/4); coarse, clayey, micaceous	. 8
Sand, dusky-red (10*R* 3/4); coarse, very clayey, micaceous	1. 1
Total Rocky Flats alluvium	40. 4
Nonconformity.	
Fountain formation.	

Section 2 has the greatest thickness observed in the quadrangle. Measurement of true thickness is complicated at most places by the veneer of slopewash that covers the lower contact. The only complete sections that could be found are near the mountains; many of the outlying remnants have been thinned to less than 10 feet.

DISTRIBUTION

In the Kassler quadrangle, the Rocky Flats alluvium is preserved as rocky knobs and slopes paved with rock.

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The contact between the alluvium and the underlying bedrock, which consists of steeply dipping sedimentary rocks of Tertiary and older age, can be detected by springs that flow from the base of the alluvium and by scattered outcrops of bedrock. The topographic expression of the alluvium, which aids in the mapping and the correlation of isolated outcrops, is that of a pediment cover that slopes away from the mountains. In 4½ miles the alluvium decreases in altitude from 6,600 feet to 5,900 feet; the gradient near the mountain front is about 250 feet per mile but decreases to about 100 feet per mile farther out.

formation and the Dakota group (fig. 17) in this area also are remnants of this surface. Other remnants are along the east side of the Dakota hogback and south of Wildcat Mountain in the southeastern quarter of the quadrangle.

The altitude and gradient of the erosion surface were governed by the streams that flowed from the mountain front. The surface was highest near the mountain front and where the streams were farthest apart, and lowest away from the mountain front and where major streams emerged from the mountains. The present altitude of the erosion surface on the sedimentary rocks

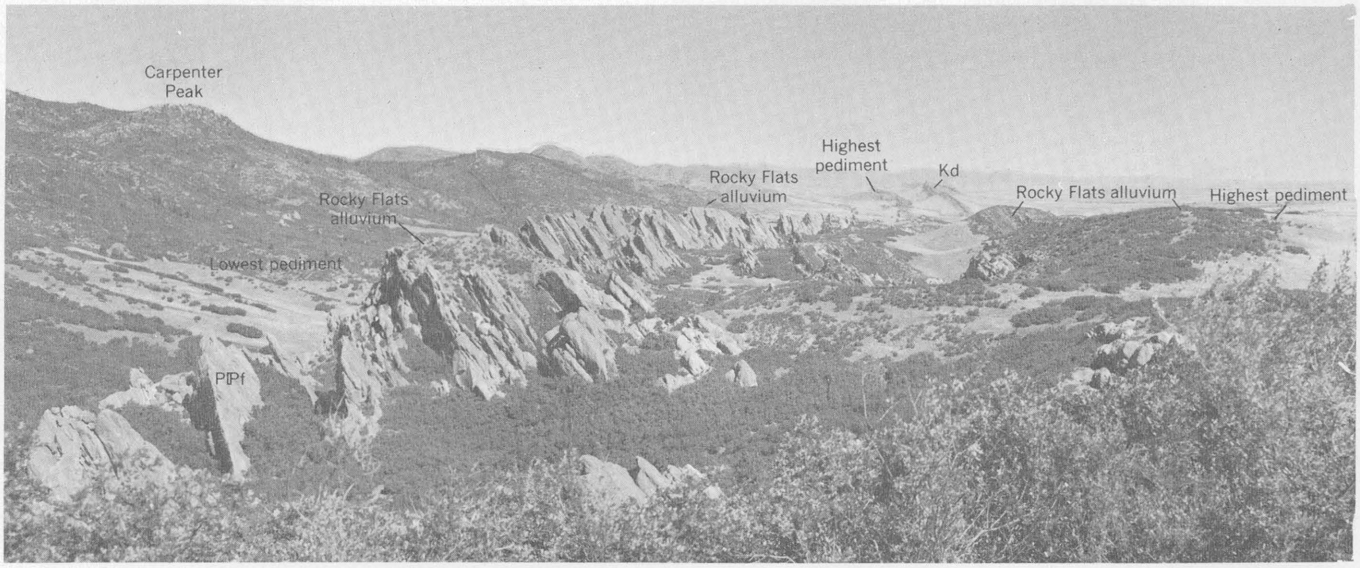

FIGURE 6.—Roxborough Park from the south. Hogbacks of Fountain formation and Dakota group are truncated by the highest pediment. Small remnants of the lowest pediment at middle left. Carpenter Peak on skyline at left.

UNCONFORMITY BENEATH THE ROCKY FLATS ALLUVIUM

The unconformity on which the Rocky Flats alluvium was deposited is a pediment that may be traced for many miles along the mountain front. It is preserved as a gently sloping broad surface (fig. 20) overlain by deposits of Rocky Flats alluvium. It may also be correlated by nick-points—remnants of former valleys of streams that cut the surface—preserved on faceted spurs in the Precambrian rocks (figs. 7, 8). This surface topographically is about 1,600 feet below the Rocky Mountain surface and 100 feet above the erosion surface beneath the Verdos alluvium (fig. 22).

In the Kassler quadrangle, the pediment beneath the Rocky Flats alluvium is well exposed at the south end of Roxborough Park (figs. 6, 17) in the central part of the quadrangle. The accordant tops of the Fountain

ranges from 5,750 feet near Plum Creek to 6,600 feet at the south end of Roxborough Park. The surface can be traced into the Precambrian terrane at the south end of Roxborough Park to an altitude of 6,850 feet. A projection of this surface south from the Littleton quadrangle (fig. 24) shows that it lies about 380 feet above the South Platte River. In Roxborough Park, the surface is about 350 feet above Willow Creek. The grade of the surface is east toward Plum Creek and north toward the South Platte River; the gradients range from 230 feet per mile near the mountain front to 100 feet per mile near Plum Creek.

The streams that formed this surface had a constant base level over a period of time long enough to almost completely level the rocks in front of the mountains and to grade the stream floors for many miles back into the mountains (fig. 21). In the Kassler quadrangle, the only rocks that stood above the completed surface in front of the mountains were a few small ridges of the Dakota group south of Roxborough Park (sec. 30, T. 7 S., R. 79 W.; pl. 1) and the Dawson arkose at Wildcat Mountain. Remnants of the graded floors in the mountain valleys are preserved in the S½ sec. 23, in sec. 25, in sec. 26, T. 7 S., R. 69 W., and along Jarre Creek, Indian Creek, Bear Creek, and Mill Gulch where they now are covered by Recent alluvium. Remnants of the stream valleys are also preserved as nick-points in the mountain front (fig. 7). Later drainage development has isolated these nick-points on top of eastward-facing triangular facets at altitudes of 5,950 to 6,700. Good examples in the Kassler quadrangle are in sec. 25, T. 7 S., R. 69 W.

The erosion surface in the Kassler quadrangle, and its related nick-points and valley floor remnants, may be correlated with the erosion surface below the Rocky Flats alluvium at its type locality north of Golden, Colo., by comparing the accordant eroded surfaces on sedimentary rocks in front of the mountains, and by tracing the nick-points and valley floor remnants along the mountain front.

ORIGIN

The Rocky Flats alluvium was deposited by streams flowing northeastward from the Front Range, and is composed in part of rocks derived from the Front Range. The streams were graded to a base level that was static for a long time, for they previously had cut an extensive flat surface across bedrock. Plum Creek and the South Platte River—local base level—may have filled with sediment from the mountains until they could no longer carry away the load that was being supplied across the pediment. The rising base level caused deposition of alluvium on the pediment. The alluvium on the large remnant of the pediment in the center of the quadrangle is composed mostly of granite derived from the biotite-

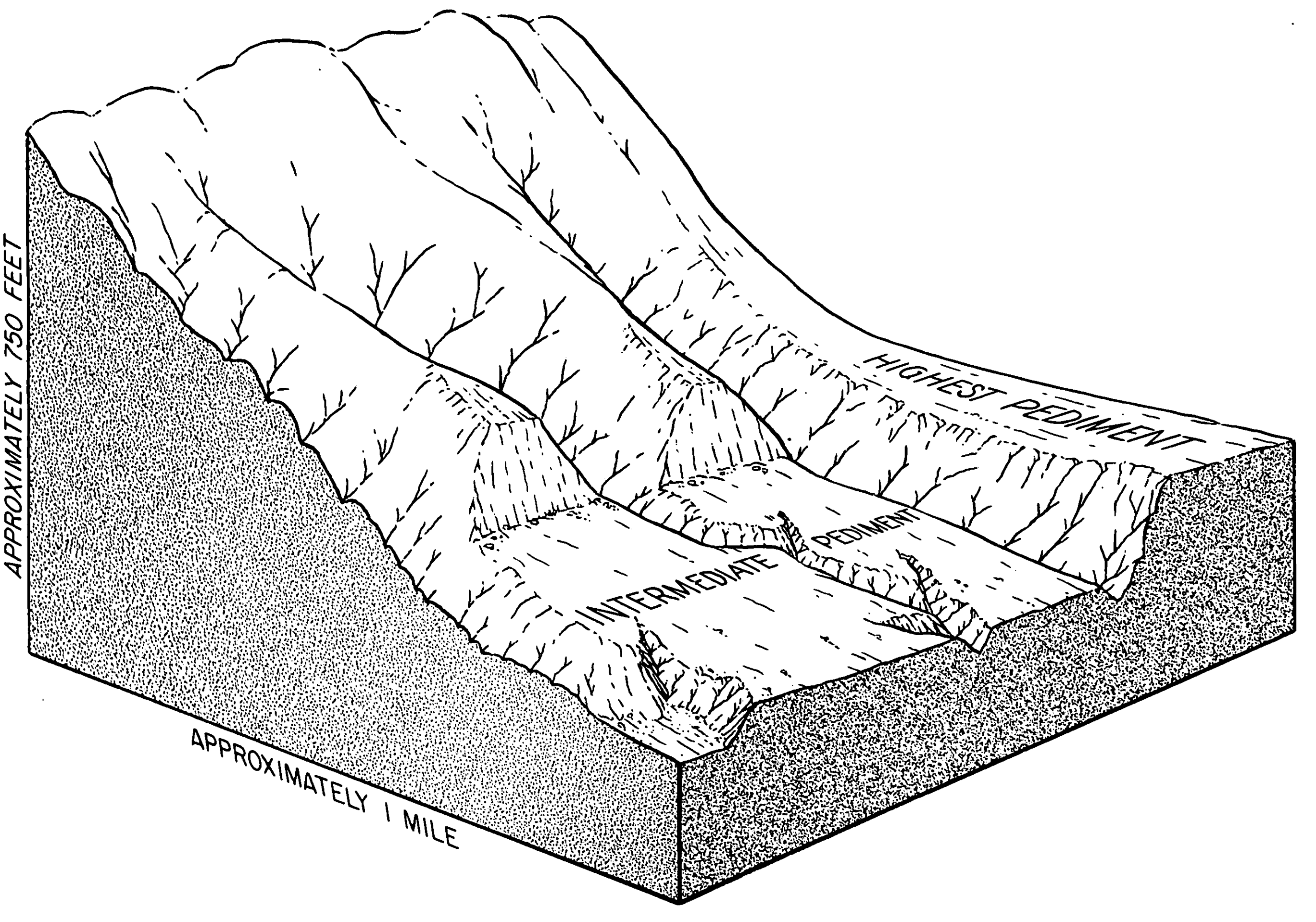

FIGURE 7.—Faceted spurs resulting from dissection of highest pediment.

muscovite granite on which part of the pediment is cut. The small remnants of alluvium south of Wildcat Mountain are composed mostly of Pikes Peak granite. Gneiss, schist, and quartzite form part of every deposit. Each sedimentary rock unit supplied material to the alluvium downstream.

AGE

The Rocky Flats alluvium is considered to be of Nebraskan or Aftonian age because it is older, but apparently not much older, than the Verdos alluvium of Kansan or Yarmouth age.

The Rocky Flats alluvium lies far below the projected surface of Ogallala formation (Pliocene), which must originally have covered the Castle Rock conglomerate on the high area near Franktown and Elbert, Colo. (fig. 1).

SOIL OF AFTONIAN(?) AGE

A very strongly developed soil, probably of late Aftonian age, lies in the upper part of the Rocky Flats alluvium. The soil occurs only in outcrops of the Rocky Flats alluvium, which range in altitude between 5,900 and 6,650 feet. Within this range of altitude, the soil is developed in only one facies, a Podzolic facies. Malde (1955, p. 255) described two other facies of this soil: a Brown soil and a Brown Forest soil facies, neither of which was found in the Kassler quadrangle. The inferred age of the soil is based on its stratigraphic position. The soil has lain at the earth's surface ever since it began to form; therefore it actually is the product of all soil-forming episodes since the original soil was formed.

A good exposure of the Aftonian(?) soil was not seen, but two of the best exposures are described and the climate during development inferred. The best section measured was in Rocky Flats alluvium in the center of the NE¼ sec. 25, T. 7 S., R. 69 W.; it is shown in section 2. Another good exposure was found in the SE¼ sec. 18, T. 7 S., R. 68 W. The soil is exposed there at the ground surface; the original A horizon is eroded away. Recent humic colluvium overlies the B horizon disconformably. The color of the B horizon is dusky red (fig. 4). The texture now is very clayey although it may have been more granular before development of the soil. The structure is coarse, strong, and blocky; the consistence is very sticky, very plastic, and very hard. The reaction is medium acid. The climate that is inferred from this Podzolic soil is wetter and possibly cooler than now. Scrub oak trees may have grown on the Rocky Flats alluvium in the Kassler quadrangle.

VERDOS ALLUVIUM

The term Verdos alluvium was applied by Scott (1960) to that alluvium which lies on the third erosion surface below the Rocky Mountain surface and above the Slocum alluvium. The Verdos alluvium, which consists of 16 to 35 feet of brown well-stratified coarse sand with some larger stones and a possible equivalent of the Pearlette ash bed, was once widespread over the Kassler quadrangle east of the mountains, but is now restricted to the tops of long mesas and isolated hills in the eastern half of the quadrangle. A very strongly developed soil was formed on the Verdos alluvium probably in Yarmouth time.

The term Verdos is taken from the Verdos Ranch in the Littleton quadrangle, Colorado, and the type locality is designated as the exposure on the slope of a pediment in the NE¼NW¼SE¼ sec. 22, T. 6 S., R. 69 W. Section 3, measured at the type locality, is proposed as the type section.

3. *Section of the Verdos alluvium measured at the type locality in the NE¼NW¼SE¼ sec. 22, T. 6 S., R. 69 W., Littleton quadrangle*

[Measured with hand level]

	Feet
Verdos alluvium:	
Yarmouth (?) soil:	
Soil horizons ABC:	
Gravel, clayey, and boulders and cobbles; not well exposed	
Boundary: clear	9.0
Soil horizon C:	
Silt, very pale brown (10*YR* 7/3) to light brownish-gray (10*YR* 6/2); contains volcanic ash.	
Structure: medium moderate prismatic to structureless; bedded.	
Consistence: nonsticky, nonplastic, soft to loose.	
Reaction: mildly alkaline.	
Boundary: gradual	3.0
Ash, white (10*YR* 8/1), clean.	
Structure: platy, bedded.	
Consistence: nonsticky, nonplastic, soft.	
Reaction; mildly alkaline.	
Boundary: abrupt	4.3
(This ash bed is 11 ft. thick on the south side of pediment.)	
Total measured thickness (rounded)	16.0
Nonconformity.	
Pierre shale (Hygiene sandstone member).	

DESCRIPTION

The Verdos alluvium is a thick stratified deposit of firmly compacted brown coarse sand that contains some boulders of metamorphic and igneous rocks. The color is brown, yellowish brown, and, in the zone of calcium carbonate accumulation, yellowish gray. The grain size is predominantly coarse sand in equant rounded to subangular grains. Pebbles and cobbles are common;

boulders larger than 2 feet in maximum dimension are abundant, and a few boulders larger than 5 feet were seen. Silt is more abundant in the upper part of the alluvium. The grains are well sorted in the lower parts of the deposits remote from the mountains but are poorly sorted near the mountains. The alluvium is composed of 50 to 75 percent granite, granite gneiss, and minerals from granitic rocks. A minor part is composed of sedimentary rocks and nongranitic metamorphic and igneous rocks. The metamorphic rocks are most abundant in the northern part of the area; igneous rocks are most abundant southeast of Roxborough Park. Welded tuff derived from the area around Castle Rock was deposited in the Verdos alluvium by Plum Creek as far west as the center of sec. 30, T. 6 S., R. 68 W. Sedimentary rocks are more abundant in the Verdos alluvium than in the Rocky Flats because more hills of sedimentary rock protruded through the Verdos alluvium than through the Rocky Flats.

Most of the rocks in the alluvium are weathered. The weathering took place both before and after the rocks were deposited in the alluvium. The most decomposed rocks are the gneisses and sedimentary rocks which crumble easily in the hands. The granite pegmatite and amphibolite are not decomposed.

The alluvium is weakly cemented by clay or calcium carbonate. Clay is concentrated at the top of the alluvium and is spread through the rest of the alluvium sufficiently to hold it in near-vertical banks. Calcium carbonate generally impregnates the upper one-third of the alluvium and locally cements it to the consistence of soft limestone.

Stratification is well developed in the lower part of the alluvium where individual beds are 1 to 6 inches thick. Many beds are planar cross-stratified, that is, a lower bed is beveled before an upper bed is deposited. Trough stratification—the result of channeling and subsequent deposition—is more rare. The channels in trough cross-stratification may be 2 to 6 feet deep. They are filled with coarse material and some contain perched ground water.

The thickness of the alluvium ranges from 16 to 35 feet. This range is due partly to the difference in depth of longitudinal channels in bedrock beneath the alluvium and partly to the greater thickness of alluvium near the local base-level streams such as Plum Creek and Indian Creek. The alluvium on many bedrock knobs that are remnants of the erosion surface beneath the Verdos alluvium is only a 1- to 2-foot thick pavement of cobbles and boulders, most of the finer alluvium having been eroded.

An ash lens in the Verdos alluvium has been discovered elsewhere in the Denver area. Eight localities are now known. The importance of the volcanic ash to the age and geomorphic history of the Verdos alluvium warrants detailed listing of the localities:

1. Barr Lake, Brighton quadrangle, NE¼NW¼SE¼ sec. 15, T. 1 S., R. 66 W., in cut of Chicago, Burlington, and Quincy Railroad on southeast side of U.S. Highway 6. Discovered by M. R. Mudge.
2. Verdos Ranch, Littleton quadrangle, SE¼ sec. 22, T. 6 S., R. 69 W., on slopes of Verdos pediment. Discovered by Scott.
3. Ralston Reservoir, Golden quadrangle, NE¼ sec. 32, T. 2 S., R. 70 W., in open pit in Ralston pediment. Discovered by Richard Van Horn.
4. Graveyard Hill, Golden quadrangle, SE¼NE¼ sec. 28, T. 3 S., R. 70 W., in excavations for houses. Discovered by Richard Van Horn.
5. North valley wall of Clear Creek, Golden quadrangle, NW¼SW¼ sec. 28, T. 3 S., R. 70 W., in trench prospect for Laramie clay. Discovered by Richard Van Horn.
6. Marston Lake, Fort Logan quadrangle, NE¼NE¼ sec. 12, T. 5 S., R. 69 W., in gravel pit, now backfilled. This is the original deposit discovered by C. B. Hunt (1954, p. 96).
7. Henrys Lake, Fort Logan quadrangle, NE¼SW¼ sec. 2, T. 5 S., R. 69 W., in gravel pit. Discovered by Scott.
8. West of Pleasant View, Morrison quadrangle, NW¼ sec. 11, T. 4 S., R. 70 W., in gravel pit. Discovered by Richard Van Horn.

The volcanic ash generally lies at the base of the alluvium. Pure ash is overlain by, and grades upward into, a thick layer of ash contaminated by silt or clay.

The pure ash is white, of fine or medium sand size, and is composed of small curved triangles, plates, and bubbles of glass that are well sorted by size. Included in the glass at the type locality of the Verdos alluvium is gemmy green pyroxene, black prisms of chevkinite, long needles of deep-brown hornblende, magnetite, and ilmenite, all identified by H. A. Powers (oral communication, 1958) of the U.S. Geological Survey. The other deposits listed above have comparable chemical and mineralogical characteristics.

All the ash examined was deposited by water, and the stratification in the ash resulted from reconcentration by streams.

Quantitative spectrographic analyses of the ash from the Verdos alluvium, and of the Pearlette ash member of the Sappa formation from Nuckolls County, Nebr., and Meade County, Kans., were made by the U.S. Geological Survey to compare the quantities of the minor elements. Samples C581 and E1833 were cleaned and the phenocrysts were removed by Powers. The following table shows the results of the analyses. The quantities of the minor elements in the volcanic ash from the Verdos alluvium are similar enough to indicate that it came from the same vent as the Pearlette ash member and may even have been part of the same ash fall (H. A. Powers, oral communication, 1958).

Quantitative spectrographic analyses, in percent, of Pearlette ash equivalent in Verdos alluvium and of the Pearlette ash member from Kansas and Nebraska

[Analyst, Paul R. Barnett, U.S. Geological Survey]

Constituent	Sample		
	Pearlette ash equivalent (C966)	Pearlette ash member (C581)	Pearlette ash member (E1833)
B	0.001	0.002	<0.001
Ba	.1	.03	.01
Be	.0008	.001	.0008
Cr	.0001	.0001	.0001
Cu	.0007	.0007	.0004
Fe	1	1	1
Ga	.0025	.002	.0026
La	.008	.01	.01
Mn	.02	.02	.02
Mo	.0005	.0007	.0006
Nb	.006	.006	.007
Pb	.004	.004	.004
Sn	.001	.0006	.001
Sr	.04	.001	.0001
Ti	.05	.06	.08
V	<.0002	.0002	<.0002
Y	.007	.008	.010
Yb	.0007	.0007	.001
Zr	.02	.02	.025

C966: Verdos Ranch, Littleton quadrangle, SE¼ sec. 32, T. 6 S., R. 69 W., from Verdos alluvium.
C581: Nuckolls County, Nebr., sec. 34, T. 1 N., R. 8 W. Collected by L. P. Buck, U.S. Geol. Survey.
E1833: Meade County, Kans., NW¼ sec. 21, T. 33 S., R. 28 W., between the Borchers and Cudahy faunas (Hibbard, 1948, p. 594).
Looked for but not detected: Ag, As, Au, Bi, Co, Cd, Ge, In, Ni, Pt, Sb, Sc, Ta, Th, Tl, U, W, and Zn. Phenocrysts not removed from sample C966; therefore, contamination by feldspar is noted in Ba and Sr.

Ada Swineford of the Kansas Geological Survey examined the ash from Marston Lake (loc. 6, p. 17) at the request of C.B. Hunt (1954, p. 97). She found it to be very similar to the Pearlette ash member, but different from the Tertiary ashes of Kansas. However, Hunt (1954, p. 97) reasoned that if the cobble alluvium at the base of the Broadway terrace in Denver is of pre-Wisconsin (Yarmouth?) age, "The high gravels [185 feet above the South Platte River] south of Bear Creek must be much older. They could be as old as Pliocene." The discovery that the youngest pre-Wisconsin pediment which underlies the Slocum alluvium is about 80 to 100 feet above the modern streams indicates that the cobble alluvium at the base of the Broadway terrace can hardly be of Yarmouth age. Rather, it now seems probable that the cobble alluvium is of early Wisconsin age (inasmuch as it contains fossils of Wisconsin age) and that the dense layer of calcium carbonate on the pebbles was concentrated by ground water, for no other parts of a soil profile are present. The high gravels south of Bear Creek are now considered to be of Kansan age, partly because they contain a possible equivalent of the Pearlette ash and partly because of their geomorphic position.

DISTRIBUTION

In the Kassler quadrangle Verdos alluvium crops out as remnants of former valley fills. Remnants of the Verdos alluvium cap long sloping pediments in the southern part of the quadrangle, and cap knobs of bedrock in the northern part. All these remnants lie on a gently sloping but nearly flat surface cut across dipping sedimentary rocks. The topographic expression of the alluvium is a pediment cover that slopes northeastward away from the mountains. The altitude on the alluvium near the mountains is 6,500 feet, near Plum Creek about 5,850 feet. The characteristic slope is 150 feet per mile.

UNCONFORMITY BENEATH THE VERDOS ALLUVIUM

An intermediate widespread pediment, which can be traced for many miles along the mountain front, was cut across bedrock between the time Rocky Flats alluvium was deposited and Verdos alluvium was deposited. It originally was extensive but is now preserved as gently sloping narrow surfaces (fig. 20) overlain by Verdos alluvium. The surface topographically lies 100 feet below the pediment beneath the Rocky Flats alluvium (fig. 7) and 150 feet above the pediment beneath the Slocum alluvium.

In the Kassler quadrangle the pediment lies in the east half and is well exposed on remnants of truncated bedrock near Cann Hill. Short segments lie between the Dakota hogback and the mountains south of Roxborough Park (fig. 8). A few remnants are wide and form well-preserved mesas, but most are eroded to narrow ridges or rounded hills. Bedrock under the pediment is steeply to gently dipping sedimentary rocks. The pediment generally was cut across softer bedrock than the rocks in the surface beneath the Rocky Flats alluvium.

The pediment originally sloped smoothly away from the mountains and had little relief except for protrusions of higher surfaces or of bedrock. The slope averages 150 feet per mile and ranges in altitude from 6,500 feet at the mountain front in sec. 30, T. 7 S., R. 68 W., to 5,700 feet along Plum Creek. The projected surface lies about 250 feet above the South Platte River. The surface configuration of the pediment is smooth except for longitudinal channels and knobs in bedrock. The slopes of the two older pediments appear to con-

FIGURE 8.—Intermediate pediment south of Roxborough Park. It lies below high pediment in foreground and below faceted spurs of high pediment cut on crystalline rocks along mountain front. Short grass in foreground, ponderosa pine on hogback of Dakota group at left center, thick growth of Douglas-fir on north-facing slope in mountains at right center.

verge toward Plum Creek (base level for both pediments) and the South Platte River. The pediment beneath the Verdos alluvium also was graded to Willow Creek, Indian Creek and Jarre Creek.

The pediment in the Kassler quadrangle can be traced to the pediment beneath the Verdos alluvium at its type locality in the Littleton quadrangle north of Kassler, Colo., by the accordance of eroded surfaces of the sedimentary rocks in front of the mountains and by the height above modern streams.

FOSSILS AND ORIGIN

The only fossils found are mollusks, which are sparse because of the coarseness of the alluvium. Cf. *Succinea grosvenori* Lea (table 2) was collected at locality 91. It is a terrestrial gastropod that commonly lives on flood plains near water.

The Verdos alluvium was deposited by streams flowing northeastward from the Front Range and is composed of rocks from the Rocky Flats alluvium and from the sedimentary, metamorphic, and igneous rocks of the Front Range.

AGE

The Verdos alluvium is considered to be of Kansan or Yarmouth age for the following reasons:

1. The pediment under the Verdos alluvium is the second oldest in the quadrangle.
2. The Verdos alluvium has a Yarmouth(?) soil developed on it.
3. The alluvium locally contains an ash bed that is probably the same as both the Pearlette ash member of the Sappa formation of Yarmouth or Kansan age of Nebraska (Condra, Reed, and Gordon, 1950, p. 22–24) and the type Pearlette ash of Kansas (Cragin, 1896).

SOIL OF YARMOUTH(?) AGE

A very strongly developed soil, probably of late Yarmouth age, formed in the upper part of the Verdos alluvium. The soil occurs only in the outcrops of Verdos alluvium and in the older exposed deposits. In all but the highest part of its range of altitude the soil is developed in a Brown soil facies; in the higher range of altitude the soil locally is acid or Podzolic. The inferred age of the soil is based on its stratigraphic position. Except where the soil is buried, it has lain at the earth's surface ever since it began to form; therefore it actually is the product of all soil-forming episodes since the original soil was formed.

From many good exposures (see sec. 3) the following description and climatic inference are presented concerning the soil of Yarmouth(?) age. The Brown soil facies of the soil contains a thick humic A horizon except where it has been eroded, a thick clayey reddish-brown (fig. 4) B horizon which may be partly eroded, and a thick C_{ca} horizon. The B horizon generally is developed on brown coarse pebbly sand that contains enough clay to show a coarse strong columnar structure and a sticky plastic hard consistence. The reaction of the B horizon is medium acid. The C_{ca} horizon of the parent material contains a layer of yellowish-gray calcium carbonate 1 to 2 feet thick. Calcium carbonate also extends downward along cracks in the parent material and coats the undersides of most of the stones. From the presence of calcium carbonate in the soil the inference is made that the soil formed under grass in a somewhat arid climate. The climate may have been slightly cooler than now but warmer than the climate in which the Aftonian(?) soil developed.

SLOCUM ALLUVIUM

The term Slocum alluvium was applied by Scott (1960) to that alluvium which lies on the fourth erosion surface below the Rocky Mountain surface and above the Louviers alluvium. The Slocum alluvium, which consists of 10 to 90 feet of moderate reddish-brown, well-stratified clayey coarse sand with lenticular beds of pebbles and silt, was deposited over about one-third of the northern part of the Kassler quadrangle. A very strongly developed soil was formed on the Slocum alluvium possibly in Sangamon time.

The term Slocum was taken from the Slocum Ranch in the Kassler quadrangle, and the type locality was designated as the exposure in a quarry face of the Fort Hays limestone member of the Niobrara formation in the SW¼NW¼ sec. 35, T. 6 S., R. 69 W. Section 4, measured at the type locality, is proposed as the type section. Two interfingering facies of the alluvium are mapped: alluvium on pediments and alluvium in fill terraces.

DESCRIPTION

The Slocum alluvium on the pediments is a thick, stratified deposit of firmly compacted coarse sand and boulders of igneous and metamorphic rocks. The color is reddish brown, moderate reddish brown, dark brown, grayish brown, or yellowish brown. The predominantly coarse sand-size grains (70 percent in one deposit, table 6) are equant rounded to subangular in shape. Boulders and cobbles are less common than in the older alluvium. The grains are sorted into lenses of pebbles, sand, or silt. Silt, which may be partly of eolian origin, generally constitutes the upper 2 to 4 feet of the alluvium. One-inch pebbles are 78 percent granite and pegmatite, 13 percent quartz, 3 percent biotite-gneiss and amphibolite, and 6 percent sandstone and arkose. Clay, the matrix and cementing material, is most abundant in the lower part where the alluvium is also the most firmly compacted and is stained by iron oxide.

The alluvium on the pediments is well stratified. Planar cross-stratification is characteristic of the thin sand beds in the lower part of the alluvium. Trough cross-stratification is characteristic of the thick channel beds that locally lie in the upper part. Some of the channels are 15 feet wide by 12 feet deep and contain boulders 15 inches in diameter. Most individual beds are only a few inches thick, but some are more than 4 feet thick.

The following stratigraphic sections are typical of the Slocum alluvium on the pediments in the Kassler quadrangle:

5. *Section of the Slocum alluvium in stream cut in the SE¼NE¼ sec. 12, T. 7 S., R. 69 W. (fig. 9)*

[Measured with tape]

	Feet
Slocum alluvium:	
Clay, reddish-brown (5*YR* 5/4), sandy, pebbly; slightly disturbed by colluvial action; bedding mostly destroyed. Very strongly developed soil in upper 3 feet	4.0
Pebbles, reddish-brown (5*YR* 5/4), mostly one-fourth in. in diameter. Unit contains cobbles and some boulders; has a silt and clay matrix. Well bedded. Most stones softened by weathering, and undersides coated with calcium carbonate	6.0
Silt and sand, reddish-brown (5*YR* 5/4); some pebbles. Beds undulating and lenslike. Gastropods in the more calcareous silt beds (loc. 94)	2.0
Pebbles, reddish-brown (5*YR* 5/4), mostly one-fourth in. in diameter and coarse sand	4.0
Bottom of arroyo:	
Measured thickness of Slocum alluvium	16.0

6. *Section of Slocum alluvium in southeast-trending arroyo in the NE¼SE¼ sec. 30, T. 6 S., R. 68 W.*

[Measured with tape]

	Feet
Slocum alluvium:	
Pre-Wisconsin (Sangamon?) soil:	
Soil Horizon A_1:	
Silt, light yellowish-brown (10*YR*6/4), humic, contains one-fourth-in. pebbles	2.5
Soil horizon B_{2ca}:	
Silt, brown (7.5*YR* 5/4), clayey; splotched calcium carbonate accumulation and joint fillings from superposed Wisconsin soil. Structure: medium strong prismatic. Consistence: sticky, plastic, slightly hard. Boundary: abrupt	3.0
Soil horizon C_{ca}:	
Silt, pinkish-white (7.5*YR* 8/2), friable; massive calcium carbonate accumulation. Structure: medium moderate prismatic. Consistence: slightly sticky, slightly plastic, soft. Reaction: moderately alkaline. Boundary: diffuse	3.0
Silt, brown (7.5*YR* 5/4), pebbly; contains bones (loc. 96). Structure: coarse strong columnar. Consistence: sticky, plastic, hard. Reaction: moderately alkaline. Boundary: abrupt	25.0
Thickness of Slocum alluvium (rounded)	33.0
Dawson arkose.	

7. *Composite section of the younger and older loess and Slocum alluvium in two arroyos at Roxborough Park school in the SW¼NW¼ sec. 36, T. 6 S., R. 69 W.*

[Measured with hand level and tape by Scott and R. D. Miller]

	Feet
Younger loess:	
Wisconsin soil:	
Soil horizon A_1:	
Clay, dark-brown (10*YR* 3/3 when moist), silty, humic. Structure: fine weak granular. Consistence: very sticky, very plastic, soft. Reaction: mildly alkaline. Boundary: gradual	1.0
Soil horizon B_{2ca}:	
Silt, brown (10*YR* 5/3 when moist), clayey; one-fourth-in. spots of calcium carbonate spaced 3 in. apart throughout layer; contains mollusks (loc. 99). Structure: fine moderate prismatic. Consistence: sticky, plastic, slightly hard. Reaction: moderately alkaline. Boundary: diffuse	.9

7. *Composite section of the younger and older loess and Slocum alluvium in two arroyos at Roxborough Park school in the SW¼NW¼ sec. 36, T. 6 S., R. 69 W.*—Continued

Younger loess—Continued
Wisconsin soil—Continued
Soil horizon C_{ca}:
Silt, brown (10*YR* 5/3 when moist), clayey.
Structure: medium strong columnar.
Consistence: slightly sticky, plastic, slightly hard.
Reaction: moderately alkaline; ¼-in. nodules of calcium carbonate in upper part ---------- 1.9
Thickness of younger loess ---------- 3.8

Older loess:
Pre-Wisconsin (Sangamon?) soil:
Soil horizon B_{ca}:
Sand, brown (10*YR* 5/3), silty.
Structure: coarse moderate columnar.
Consistence: slightly sticky, plastic, hard.
Reaction: moderately alkaline.
Boundary: clear ---------- 1.1

Slocum alluvium (part):
Soil horizon B_{ca}:
Sand, brown (7.5*YR* 5/4), pebbly, silty; becomes less silty in lower 1 foot, but contains more pebbles. Vertical joints in upper 18 in. filled with 1- to 2-in. veins of calcium carbonate.
Structure: coarse strong columnar.
Consistence: slightly sticky, plastic, very hard.
Reaction: moderately alkaline from secondary calcium carbonate. Reaction of calcium carbonate veins: strongly alkaline.
Boundary: clear, wavy ---------- 3.8
Soil horizon C_{ca}:
Sand, yellowish-brown (10*YR* 6/4), coarse, pebbly; upper part almost entirely white lime in 1- to 2-ft layer; contains rodent bones and burrows; contains aragonite and fossil fragments from underlying Pierre shale.
Structure: very coarse moderate columnar.
Consistence: slightly sticky, slightly plastic, hard.
Reaction: strongly alkaline.
Boundary: abrupt ---------- 6.6
Thickness of Slocum alluvium ---------- 10.4

8. *Section of Piney Creek and Slocum alluvium in an arroyo in the SW¼SW¼ sec. 20, T. 7 S., R. 68W.*

[Measured with tape]

Piney Creek alluvium:
Late Recent soil:
Soil horizon A_1:
Silt, dark yellowish-brown (10*YR* 5/2), clayey, pebbly, humic ---------- *Feet* 0.7

Nonconformity.
Slocum alluvium (part):
Pre-Wisconsin (Sangamon?) soil:
Soil horizon B_2:
Silt, dark reddish-brown (5*YR* 3/4), clayey, pebbly, prismatic structure ---------- *Feet* 1.8
Soil horizon C_{ca}:
Sand, yellowish-brown (10*YR* 5/4), pebbly, cobbly, very calcareous; cobbles 3 to 4 in. in diameter are completely replaced by calcium carbonate ---------- .8
Thickness of Slocum alluvium ---------- 2.6

The Slocum alluvium in the fill terraces is finer grained and better sorted than the alluvium on the pediments. The color is moderate brown, reddish brown, grayish brown, or yellowish brown. The grain size is predominantly sand and one-half inch subangular to rounded pebbles. A 60-foot-thick bed of greenish-gray micaceous clayey silt also was found in an auger hole along the west side of Plum Creek. Most of the pebbles are quartz, feldspar, granite, and gneiss, but limonite, welded tuff, and petrified wood also are common. The alluvium in the terraces is well bedded and finely cross-stratified.

Sections 4 and 9, which follow, are representative of the Slocum alluvium in the fill terraces.

4. *Section of the Slocum alluvium measured at the type locality in the SW¼NW¼ sec. 35, T. 6 S., R. 69 W., Kassler quadrangle*

Slocum alluvium:
Sangamon(?) soil:
Soil horizon A:
Silt, dark-brown (10*YR* 4/3), sandy humic.
Structure: medium moderate columnar.
Consistence: slighty sticky, slightly plastic, soft.
Reaction: moderately alkaline ---------- *Feet* 0.9
Soil horizon B_{1ca}:
Silt, brown (7.5*YR* 5/4), sandy. Contains one-thirty-second-in. veinlets of calcium carbonate throughout.
Structure: medium weak columnar.
Consistence: sticky, plastic, slightly hard.
Reaction: moderately alkaline ---------- 3.6
Soil horizon B_{2ca}:
Sand, brown (7.5*YR* 5/4), silty. Contains mollusks (loc. 93). Becomes quite calcareous at base where it is unconformable on Fort Hays limestone member of the Niobrara formation and contains many 1- to 4-in. chips of limestone.
Structure: coarse strong columnar.
Consistence: sticky, plastic, slightly hard.
Reaction: moderately alkaline ---------- 7.2
Total Slocum alluvium ---------- 11.7
Nonconformity.
Fort Hays limestone member of the Niobrara formation.

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9. *Section of Slocum alluvium in a fill terrace in the SW¼NE¼ sec. 4, T. 7 S., R. 68 W.*

[Measured with tape in an auger hole]

Slocum alluvium (part):	
Pre-Wisconsin (Sangamon?) soil:	
Soil horizon A_1:	*Feet*
Silt, dark-brown (10*YR* 4/3), humic, sandy.	
Structure: fine moderate crumb.	
Consistence: sticky, plastic, slightly hard.	
Reaction: neutral	1.0
Soil horizon B_2:	
Sand, yellowish-brown (10*YR* 5/4), clayey; contains 1-in. pebbles.	
Structure: probably coarse weak prismatic.	
Consistence: sticky, plastic, hard.	
Reaction: slightly acid	1.4
Soil horizon C_{ca}:	
Sand, yellowish-brown (10*YR* 5/4), silty; undersides of pebbles coated with calcium carbonate.	
Structure: probably coarse weak columnar.	
Consistence: sticky, plastic, soft.	
Reaction: moderately alkaline	2.5
Thickness of Slocum alluvium	4.9

Deep weathering is characteristic of all the alluvium; large boulders in the pediment deposits are so rotted that fragments can be broken off and crushed in the hands. Few of the stones can resist abrasion, but break down and augment the sand fraction.

Thickness of the alluvium ranges from 10 to 90 feet. This extreme range in thickness is due to the greater accumulation of alluvium in the base-level streams, particularly Plum Creek, than on the pediments.

DISTRIBUTION

In the Kassler quadrangle the Slocum alluvium is widely distributed over the plains part of the area (pl. 1). Good exposures are in arroyos (fig. 9) in sec. 12, T. 7 S., R. 69 W., in arroyos in secs 19 and 20, T. 7 S., R. 68 W., in a quarry face (the type locality) in sec. 35, T. 6 S., R. 69 W., and in a broad terrace along Plum Creek and Sterling Gulch which trends northward through sec. 30, T. 6 S., R. 68 W. In these exposures the alluvium is preserved as rocky knobs and sheets that are part of a formerly extensive pediment cover that sloped downward to a broad terrace along the main streams. This terrace borders the South Platte River and Plum Creek and extends about a mile up Sterling Gulch from Plum Creek. The top of the terrace is 70 to 80 feet above Plum Creek and 25 to 50 feet above Sterling Gulch. The base of the alluvium under the terrace lies 4 feet above the arroyo floor of Sterling Gulch. The altitude of the alluvium near the mountains is 6,500 feet, near Plum Creek about 5,750 feet. The characteristic slope of the alluvium on the pediment is 150 feet per mile; the characteristic gradient of the terrace is a little more than 40 feet per mile.

UNCONFORMITY BENEATH THE SLOCUM ALLUVIUM

The lowest widespread pediment, which can be traced for many miles along the mountain front, was cut across bedrock between the time Verdos alluvium was deposited and Slocum alluvium was deposited. It originally was more extensive, but is now preserved as remnants of gently sloping broad surfaces overlain by Slocum alluvium (fig. 17). The surface lies 150 feet lower than the pediment beneath the Verdos alluvium and 100 feet above the modern streams.

In the Kassler quadrangle the pediment lies in the eastern half and flanks the valleys of Willow and Little Willow Creeks (figs. 17 and 18), the South Platte River (fig. 24), and Plum Creek, and floors Roxborough Park. Most of these remnants are broad well-preserved benches but some are short steep slopes along the mountain front. Bedrock under the pediment is steeply to gently dipping sedimentary rocks.

The slopes of the pediment remnants range from very steep and irregular near their heads to gentle and smooth near the major base-level streams. The short slopes (fig. 6) that head in the mountain front at 6,500 feet altitude or against remnants of the higher pediments are the steepest and may slope as much as 800 feet per mile. The long gentle slopes near Plum Creek descend only 100 to 150 feet per mile and terminate at about 5,700 feet altitude in a gravel-covered terrace along Plum Creek that slopes downstream only 40 feet per mile. The pediment converges headward with the pediment beneath the Verdos alluvium. Where the two converge, the topographic break ranges from abrupt to barely perceptible.

Major base-level streams were Plum Creek and the South Platte River; minor base-level streams were Willow, Indian, and Jarre Creeks. In addition, four new minor base-level streams, Little Willow Creek, Lehigh Gulch, Rainbow Creek, and Sterling Gulch, were created.

FOSSILS

Fossil remains of land mammals and land and fresh water mollusks were collected from the Slocum alluvium. Teeth and bones of the smaller rodents, *Citellus* cf. *richardsoni* and *Thomomys* sp., were found in a gravel pit in the SE¼SW¼ sec. 29, T. 6 S., R. 68 W.; *Cynomys* sp. was found at localities 92 and 125. Parts of sciurid and microtine rodents and of an undetermined leporid also were identified. Of the larger mammals *Equus* sp. was found at locality 125 and *Bison* sp. at locality 96. All the above are long-ranging forms that do not help to determine the age of the Slocum.

The land and fresh-water mollusks are more common in the fine-grained deposits and in the north end of the quadrangle. The following table lists the mollusks that were collected at five localities in the Kassler quadrangle.

Mollusks from Slocum alluvium in the Kassler quadrangle

[Identifications by D. W. Taylor and C. C. Cameron. Arranged according to Thiele (1931)]

Species	Locality				
	92	93	94	95	97
Gyraulus sp.		X			
cf. *Succinea grosvenori* Lea			X		
cf. *Succinea*		X			
Pupilla blandi Morse		X	X	X	
muscorum (Linné)	X			X	
Pupoides hordaceus (Gabb)		X	X	X	
inornatus Vanatta		X	X	X	
Gastrocopta pellucida hordeacella (Pilsbry)			X		
Vallonia cyclophorella Ancey	X	X		X	
gracilicosta Reinhardt	X	X	X	X	X
Hawaiia minuscula (Binney)		X	X		
Zonitid		X			

The molluscan fauna shown in the table is also typical of the Slocum alluvium in the rest of the Denver area. Collections from the alluvium at several other places in the area show that the species of *Succinea*, *Pupilla*, *Pupoides*, *Gastrocopta*, and *Vallonia* constitute a characteristic and common fauna. Two examples are given:

Mollusks from Slocum alluvium 80 feet above Bear Creek in the SW¼SW¼ sec. 29, T. 3 S., R. 70 W., west of Idledale, Colo., in the Evergreen quadrangle (fig. 1)

[Identified by C. C. Cameron]

cf. *Succinea avara* Say
Pupoides hordaceus (Gabb)
Vallonia cyclophorella Ancey

Mollusks from Slocum alluvium in a gravel pit on the slope of a pediment in the SW¼SW¼ sec. 8, T. 5 S., R. 69 W., in the Indian Hills quadrangle (fig. 1)

[Identified by D. W. Taylor]

Physa anatina Lea
Fossaria dalli (F. C. Baker)
Lymnaea obrussa Say
Gyraulus parvus (Say)
cf. *Succinea*
Pupilla sp.
Pupoides hordaceus (Gabb)
inornatus Vanatta
Gastrocopta pellucida hordeacella (Pilsbry)
Vallonia gracilicosta Reinhardt
Discus cronkhitei (Newcomb)
Hawaiia minuscula (Binney)
Euconulus sp.
Pisidium casertanum (Poli)

The mollusks in the Slocum assemblage that are considered by Taylor (written communication, 1954) to be most diagnostic are *Pupilla blandi*, *Pupoides hordaceus*, *P. inornatus*, and *Gastrocopta pellucida hordeacella.* These four species constitute an index fauna, and their ecological requirements suggest that the climate during deposition of the Slocum alluvium was more arid and winters were warmer than at present, in this latitude and altitude inasmuch as they live today in the upper Sonoran and Transition zones of the southern Rocky Mountains and the Colorado Plateau. In the southern Rocky Mountain and the Colorado Plateau areas, species such as *Pupilla muscorum*, *P.* blandi, and *Pupoides inornatus*, of more northern distribution, meet and overlap the ranges of the southern forms *Gastrocopta pellucida hordeacella* and *Pupoides hordaceus.*

The assemblage from the Slocum alluvium is different from previously recorded molluscan Pleistocene faunas in the United States. The environment suggested by the fauna also differs from environments inferred from most other recorded molluscan faunas. A semiarid, warm-temperate climate is suggested by only one other known Pleistocene fauna—the Borchers local fauna of southwestern Kansas (Hibbard, 1949, p. 1424–1425). D. W. Taylor (written communications, 1957) suggested that the mollusks of the Slocum alluvium are probably correlative with the early Sangamon (?) Cragin Quarry local fauna (Hibbard, 1955, p. 189) in southwestern Kansas, and with the Sangamon (?) Slaton local fauna (Meade, 1952, p. 87–89) of the Texas Panhandle. Undescribed mollusks from the Slaton and the Cragin Quarry faunas also imply a warmer climate than known glacial faunas, but a more arid climate than the Jinglebob local fauna of Kansas (Van der Schalie, 1953, p. 85; Hibbard, 1955, p. 197–204).

ORIGIN

The Slocum alluvium was deposited by streams flowing northeastward from the Front Range and is composed mostly of rocks derived from the Front Range. The streams were graded to a base level that remained stable for a long time for they previously had cut a broad flat surface across bedrock. The local base-level streams, Plum Creek and the South Platte, filled with sediment from the mountains until they could no longer carry the load that was being supplied across the pediment. The rising base level caused the streams to cut laterally at a higher level and caused deposition of alluvium on the pediment.

The alluvium is composed mostly of metamorphic rocks but contains a large proportion of sedimentary rocks. Material derived from the older pediment alluvium and from soft sedimentary rocks is more abundant than it is in the older alluvium. Material from the Fountain, Lykins, Morrison, and Benton formations and from the Smoky Hill shale member of the Niobrara formation and the Pierre shale were identified along with harder rocks from the Dakota group, Lyons sandstone, and the Fort Hays limestone member of the Niobrara formation. The red color in the alluvium is due to the large amount of sand-size and smaller material from the red Fountain and Lykins formations. The alluvium in the terrace fill along Plum Creek is composed of fragments of Pikes Peak granite and pieces of welded tuff from the Castle Rock area.

AGE

The age of the Slocum alluvium is considered to be late Illinoian or early Sangamon for the following reasons:

1. The alluvium, which contains a warmth-loving molluscan fauna that is typically interglacial, is the latest alluvium with a pre-Wisconsin soil.
2. The alluvium is correlated with the Crete formation of Nebraska, which is considered to be Illinoian in age (Condra, Reed, and Gordon, 1950, p. 24–25).
3. The pediment on which the alluvium lies is the youngest pediment in the area.
4. The next older alluvium is Kansan or Yarmouth in age (see p. 19).
5. The loess that overlies the alluvium probably correlates with the Loveland loess of Nebraska, which is considered to be of Illinoian or Sangamon age (Condra, Reed, and Gordon, 1950, p. 27).

OLDER LOESS

Older loess was mapped on the northwest-trending ridges in secs. 25, 26, and 36, T. 6 S., R. 69 W. (pl. 1). Other small outcrops were seen, but not mapped because of their small size, near Roxborough Park school and north of Kassler.

The loess overlies the Slocum alluvium. It is brown or moderate-brown sandy or clayey silt and has well-developed columnar structure where a pre-Wisconsin soil is developed on it. (See section 7.) It ranges in thickness from 2 to 4 feet.

Small streams that cut into the Slocum alluvium probably were the source of the fine material for the older loess. Most of the loess was deposited by the wind, but some small stones in it indicate that it may have been partly colluvial.

The older loess is considered to be Sangamon in age for the following reasons: (a) It is the youngest deposit on which a pre-Wisconsin soil is developed, and (b) channels eroded into it are filled with Wisconsin alluvium.

The loess is correlated on the basis of stratigraphic position with the Loveland loess of Nebraska which is considered to be of late Illinoian or Sangamon age (Condra, Reed, and Gordon, 1950, p. 27). The loess is also correlated with the loessial deposits in Hunt's residuum (1954, p. 101), and with the eolian deposits in Malde's (1955, p. 233) undifferentiated upland deposits.

SOIL OF SANGAMON(?) AGE

A very strongly developed soil, probably of late Sangamon age, has formed in the upper part of the Slocum alluvium, in the older loess (see secs. 6 and 7), and in all older deposits exposed at the surface. The distribution of the soil is limited to outcrops of the Slocum alluvium and older loess. A Sangamon(?) soil, which is the most widespread and best preserved pre-Wisconsin soil, is developed in a Brown soil facies under grass except in the higher part of its range of altitude in Roxborough Park, where it developed in an acid or Podzolic facies under deciduous scrub oak and mountain mahogany. The inferred age of the soil is based on its stratigraphic position. Except where the soil is buried, it has lain at the earth's surface ever since it began to form; therefore, it actually is the product of all soil-forming episodes since the original soil was formed. The effect of superposition of a Wisconsin soil on the Sangamon (?) soil is discussed on p. 37. (See also fig. 14.)

The two facies of the Sangamon(?) soil are described separately. The Brown soil facies contains A_1, B_2, and C_{ca} horizons developed on the parent material. The A_1 horizon was seen at only one place (see section 6) where it is a yellowish-brown humic layer in silt. The clayey B_2 horizon is well preserved and as much as 3 feet thick at many places, although locally it is partly eroded. The color of the B_2 horizon is reddish brown (fig. 4), the structure is weak medium columnar to strong coarse columnar, the consistence is sticky, plastic, but only slightly hard because the soil is generally developed on friable material (fig. 9). The C_{ca} horizon in the upper part of the parent material is impregnated with white chalky calcium carbonate that firmly cements the parent materials and coats the undersides of stones. Calcium carbonate makes up almost 100 percent of the C_{ca} horizon. The massive accumulation of calcium carbonate is about 3 feet thick but stringers of calcium carbonate generally extend 6 to 8 feet lower into parent material.

FIGURE 9.—Soil of Sangamon(?) age developed on Slocum alluvium in ancient channel of Little Willow Creek in the SE¼NE¼ sec. 12, T. 7 S., R. 69 W. (loc. 94). Stratigraphic section 5.

The upper boundary of the C_{ca} horizon is abrupt but undulatory (fig. 14). This boundary is the most striking feature of the pre-Wisconsin soils, but the reason for its sharpness is not understood. The abruptness of the boundary may be due to the depression of the calcium carbonate by post-Sangamon(?) leaching. In the younger soils, the upper boundary of the C_{ca} horizon is not sharp but gradual or clear.

The acid or Podzolic facies of the Sangamon(?) soil contains A_1, A_2, and B_2 horizons developed on the parent material. The A_1 horizon is yellowish brown, the ashy A_2 horizon is light yellowish brown, and the B_2 horizon is reddish brown and very clayey. The whole profile is acid in reaction.

The degree of development and depth of the Sangamon(?) soil appears to be dependent on the grain size and permeability of the material on which it is formed. In a stream cut in the Slocum alluvium in the NW¼SW¼NW¼ sec. 16, T. 7 S., R. 68 W., the soil is developed on both silt and small pebbles. In this exposure the modern humic horizon is uniform in thickness regardless of lithology, but the ancient oxidized B horizon is only 1 foot thick where it is developed on silt and 5 feet thick were it is developed on pebbles. Similarly the calcium carbonate is concentrated in the top 2 feet of the silt, but is disseminated in the top 4 feet of pebbles.

LOUVIERS ALLUVIUM

The alluvium that lies in the first terrace below the Slocum alluvium was named the Louviers alluvium by Scott (1960) (fig. 25). The Louviers alluvium, on which a strongly developed soil was formed in mid-Wisconsin time, consists of two facies: a reddish-brown pebbly facies and a yellowish-brown silty facies. Small patches occur along most streams in the northeastern part of the quadrangle but the largest exposure is in a prominent terrace along Plum Creek.

The term Louviers is taken from the town, which is on the terrace along Plum Creek in the Kassler quadrangle; the type locality is designated as a gravel pit at the northeast edge of Louviers in the SW¼SE¼ sec. 33, T. 6 S., R. 68 W. Section 10 is proposed as the type section.

10. *Section of the coarse-grained facies of the Louviers alluvium measured at the type locality in the SW¼SE¼ sec. 33, T. 6 S., R. 68 W.*

	Feet
Louviers alluvium:	
Wisconsin soil:	
Soil horizon A:	
Silt, dark-brown (10*YR* 4/3), sandy. Structure: coarse weak columnar. Consistence: slightly sticky, slightly plastic, soft to slightly hard. Reaction: neutral	1.2
Soil horizon B:	
Silt, dark-brown (7.5*YR* 4/4), clayey, slightly sandy; contains mollusks but none collected. Structure: strong medium prismatic. Consistence: slightly sticky, plastic, hard. Reaction: moderately alkaline	1.2
Soil horizon B_{ca}:	
Silt, light-gray (10*YR* 7/2), sandy. Structure: coarse weak blocky. Consistence: slightly sticky, slightly plastic, soft. Reaction: moderately alkaline	0.5
Soil horizon C:	
Sand, light yellowish-brown (10*YR* 6/4), fine-grained. Locally iron stained, yellowish-brown (10*YR* 5/8). Grades downward to loose coarse-grained granitic sand containing 8-in. boulders. Structure: stratified. Consistence: nonplastic, loose to slightly hard	5.5
Silt, light olive-gray (5*Y* 6/2), sandy; has pebbles as much as 1 in. in diameter; micaceous. Contains spherical compaction bulges or flow rolls (fig. 10). Structure: laminated. Consistence: sticky plastic, slightly hard. Reaction: moderately alkaline	4.0
Sand, light olive-gray (5*Y* 6/2), coarse-grained, silty; has yellowish-brown (10*YR* 5/8) iron-stained layers	6.0
Sand, reddish-brown (5*YR* 5/4), stained light olive gray by overlying silt; coarse grained. Contains 2- to 6-in. light olive-gray and light yellowish-brown (10*YR* 6/4) silt layers. This and two preceding units become sandy toward center of Plum Creek valley	30.0
Thickness of Louviers alluvium (rounded)	48.0

DESCRIPTION

The Louviers alluvium has two facies; one is coarse grained and related to the large streams, and the other is fine grained and related to the small streams. Both facies are characterized by graded bedding and by iron and manganese oxide stains. The coarse-grained facies also is characterized by contortions in the clay and silt layers and by its excellent terrace (p. 31).

Graded bedding, though also characteristic of the coarse-grained facies, is more evident in the fine-grained facies. There a single outcrop commonly shows the whole gradation, whereas in the coarse-grained facies the gradation must be pieced together from several outcrops. The gradation is from cobbles or pebbles at the base through sand to silt and locally clay at the top. The boundaries between size-grades generally are gradational, but locally are sharp. Locally, the upward trend from coarse to fine is reversed by a single bed, but on the whole, graded bedding is a distinctive feature of the alluvium.

Iron and manganese stains are concentrated in permeable beds where they overlie impermeable beds. The iron and manganese are now in the form of oxides.

The coarse-grained facies is composed of reddish-brown, light yellowish-brown, or light olive-gray stratified coarse sand and dark-brown, light-gray, or light olive-gray silt. Coarse sand and pebbles in the lower part are overlain by fine sand and silt. Each bed is 4 feet or more thick and is well stratified. The grains in each bed are well sorted and subround to subangular. Granitic rocks make up more than half of the alluvium; the other constituents are quartz, welded tuff, ironstone, chert, and pieces of other metamorphic and sedimentary rocks. The grains are poorly cemented excepted in the clayey and silty layers and in the soil at the top. The coarse-grained facies below the water level of the South Platte River consists of a bed of cobbles 40 feet thick that lies in the lower part of the Broadway terrace beneath the Broadway alluvium. Section 10 is typical of the coarse-grained facies.

FLOW ROLLS

Some unusual contortions that I think are the result of compaction are formed in silt layers in the upper part of the coarse-grained facies. These compaction structures are widespread—I saw them in the Louviers alluvium in the Broadway and Kersey terraces at many places between Louviers and Greeley, Colo. In the Kassler quadrangle they are most perfectly formed in the alluvium downstream from the Louviers city dump in the NW¼SE¼ sec. 4, T. 7 S., R. 68 W. (fig. 10). Similar structures have been described as flow casts by Shrock (1948, p. 156–162), as flow structures by Cooper

(1943, p. 198), and as flow rolls by Pepper and others (1954, p. 88). They are called flow rolls in this report although their shape is more like a ball than a roll.

The flow rolls were found only where coarse sand overlies plastic silty clay. The sand is in ball-shaped masses (fig. 10) spaced every 2 to 3 feet in the silty clay. The crude stratification that the sand possessed is preserved as concentric rings in the balls. The outlines of the balls are accentuated by iron and manganese stains that are concentrated at the interfaces between the permeable sand and the impermeable silty clay. The silty clay is wrapped around each ball of sand much like the interlocking pieces of a jigsaw puzzle. Stratification is well developed in the silty clay and closely follows the contours of the cavities into which it was pressed.

The rolls were formed by the folding of a sand bed to form a small isoclinal fold or inverted dome around which flowed the softer clay which the sand had originally covered. The deformation of original stratification shows that the beds were plastic at the time the rolls were formed. Some of the sand balls that are 1 foot in diameter have only a 3-inch neck connected to the bed from which they flowed (fig. 10). The tight folding could not have taken place after the beds were raised above water level, but must have taken place just below the stream as the upper sand was being deposited, inasmuch as the movement which formed the flow rolls was confined vertically to the beds within the flow roll zone and the beds above and below the zone of deformation are not disturbed (fig. 10). Because the movement was confined to this zone, the flow rolls formed almost in place. They are slightly tilted downstream in the same fashion as imbricate pebbles. The only force that could have acted in a downstream direction was the frictional force of the stream on its floor.

The formation of flow rolls is probably due to a difference in specific gravity between two layers of alluvium. Both layers are saturated. The lower clay layer is plastic, and although the upper sand layer is not

FIGURE 10.—Closeup of flow rolls in Louviers alluvium in NW¼SE¼ sec. 4, T. 7 S., R. 68 W., showing spherical shape and flowage of bedding. Photograph by D. R. Crandell.

plastic it flowed because of its large water content. Apparently no deformation takes place if the soft plastic clay is equally loaded by the overlying sand and if no irregularities exist on the surface of the clay. Outcrops were seen in the Louviers alluvium where the clay and sand beds were smoothly tabular in shape and were undeformed. Deformation does take place, however, if the clay is unequally loaded by the overlying sand or if there are any initial irregularities such as channels or depressions on the surface of the less dense clay. The process seems to be a sinking of the sand into the clay or into the voids created by the lateral flowage of the clay.

The fine-grained facies of the Louviers alluvium contains a lower pebble bed, a middle friable sand, and an upper evenly stratified silt. The lower pebble bed is composed of grayish-brown, light-gray, or dark reddish-brown sandy clay studded with pebbles (fig. 11). The pebbles average 1 inch in diameter but an occasional boulder is as much as 18 inches in diameter. Most of the pebbles are in point contact. The composition of the pebble bed varies locally depending on the source of pebbles. Near the mountains it contains more metamorphic and igneous rocks, elsewhere it contains more sedimentary rocks.

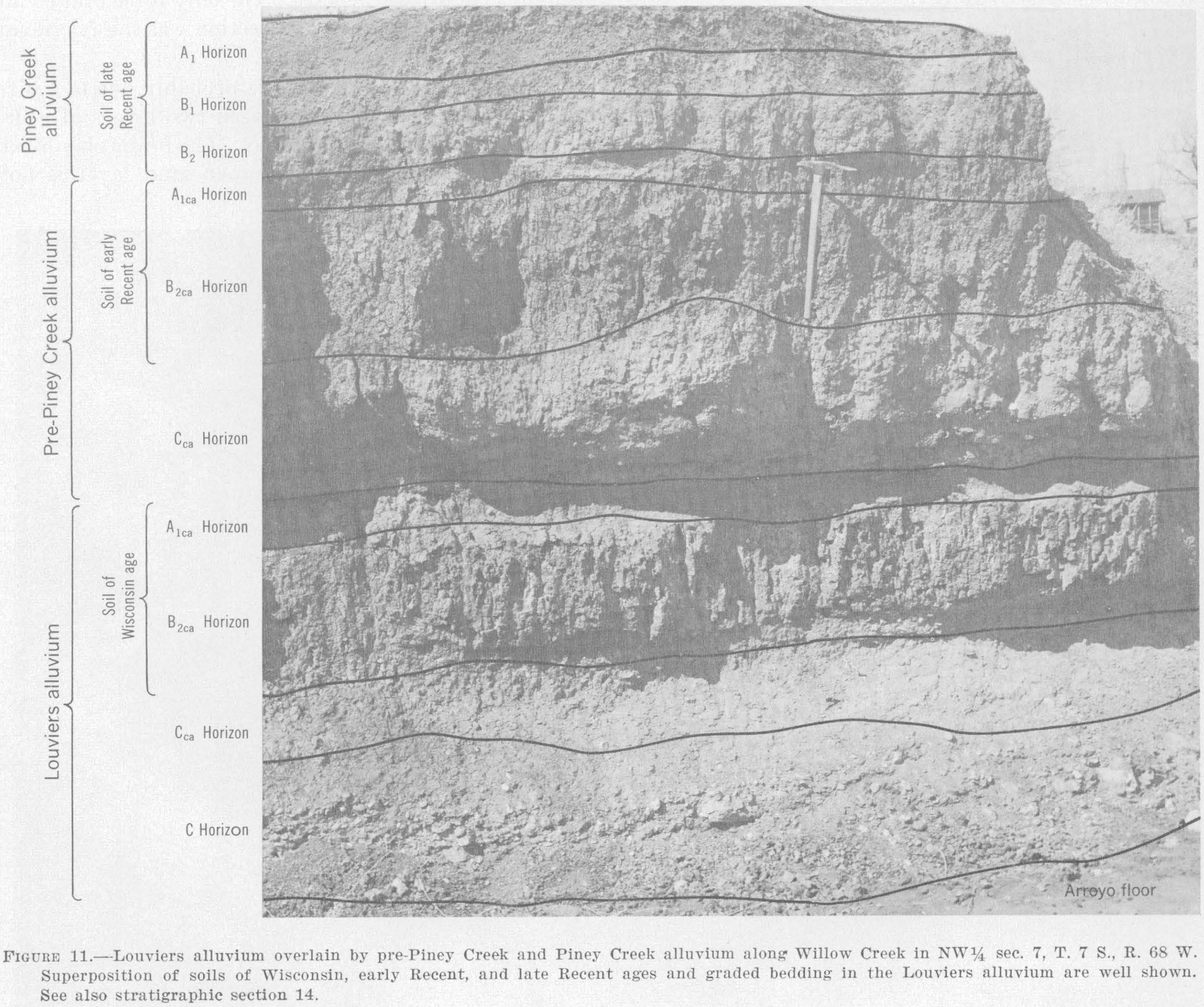

FIGURE 11.—Louviers alluvium overlain by pre-Piney Creek and Piney Creek alluvium along Willow Creek in NW¼ sec. 7, T. 7 S., R. 68 W. Superposition of soils of Wisconsin, early Recent, and late Recent ages and graded bedding in the Louviers alluvium are well shown. See also stratigraphic section 14.

The following stratigraphic sections of the fine-grained facies illustrate its relation to the other alluvial fills, its graded bedding, variability in thickness, and modification by the Wisconsin soil.

11. *Section of Louviers alluvium in arroyo in SE¼NE¼SW¼ sec. 4, T. 7, S., R. 68 W.*

[Measured with tape]

	Feet
Louviers alluvium (part):	
Wisconsin soil:	
Soil horizon A_1:	
Silt, dark grayish-brown (10*YR* 4/2), sandy. Structure: fine crumb. Consistence: slightly sticky, slightly plastic, soft. Reaction: neutral	1.0
Soil horizon B_2:	
Silt, yellowish-brown (10*YR* 5/4), sandy. Structure: medium moderate prismatic. Consistence: sticky, plastic, hard. Reaction: neutral	1.0
Soil horizon C_{ca}:	
Silt, yellowish-brown (10*YR* 5/4) with lighter streaks; calcium carbonate more abundant in upper 2.0 ft. Lower 18.0 ft. consists of thin layers of grayish-brown silty alluvium and thick layers of yellowish-brown silty alluvium. Lower 4.0 ft. of deposit consists of medium-grained sand containing magnetite, and basal pebble layers containing bones (loc. 105a). Structure: coarse moderate prismatic. Consistence: slightly sticky, slightly plastic, slightly hard. Reaction: moderately alkaline	20.0
Thickness of Louviers alluvium	22.0

12. *Section of Louviers alluvium exposed along Rainbow Creek in NE¼NW¼ sec. 29, T. 7 S., R. 68 W.*

[Measured with tape]

	Feet
Louviers alluvium (part):	
Wisconsin soil:	
Soil horizon A_1:	
Sand, reddish-brown, humic, silty	1.5
Soil horizon B_2:	
Sand, oxidized, friable; lower 1 foot pebbly	4.0
Soil horizon C_{ca}:	
Sand, clayey; calcium carbonate enriched	10.0
Thickness of Louviers alluvium	15.5

13. *Section of pre-Piney Creek alluvium and Louviers alluvium in an arroyo along Willow Creek in the NE¼SW¼ sec. 36, T. 6 S., R. 69 W.*

[Measured with tape]

	Feet
Pre-Piney Creek alluvium:	
Early Recent soil:	
Soil horizon A_1:	
Silt, dark gray-brown (10*YR* 4/2), humic	1.4
Soil horizon B_2:	
Silt, dark yellowish-brown (10*YR* 4/4), pebbly; weathers blocky	2.0
Soil horizon C_{ca}:	
Silt, yellowish-brown (10 *YR* 5/4) in upper part, light reddish-brown (5*YR* 6/4) in lower part; pebbly; calcareous; weathers blocky. Contains mollusks (loc. 127)	7.2
Soil horizon C_{ca}:	
Sand, light reddish-brown (5*YR* 6/4)	0.2
Soil horizon C_{ca}:	
Silt, light reddish-brown (5YR 6/4); contains 1- to 2-in. concretions of calcium carbonate	1.0
Thickness of pre-Piney Creek alluvium	11.8
Louviers alluvium (part):	
Wisconsin soil:	
Soil horizon A:	
Silt, very dark grayish-brown (10*YR* 3/2), humic	1.2
Soil horizon BC:	
Silt, reddish-brown (5*YR* 4/5); weathers blocky in upper part and forms massive bed; contains mollusks (loc. 117); contains calcium carbonate concretions in lower 2 ft.; bedded slightly	4.2
Soil horizon C:	
Sand, reddish-brown (5*YR* 4/4), fine-grained, pebbly, bedded; contains 1-in. concretions of calcium carbonate	1.5
Soil horizon C:	
Pebble bed, dark reddish-brown (5*YR* 3/4), clayey, limonitic, with sand and cobbles as much as 4 in. in maximum dimension	1.0
Thickness of Louviers alluvium	7.9

14. *Section of Piney Creek, pre-Piney Creek and Louviers alluvium in arroyo along Willow Creek in NW¼NW¼ sec. 7, T. 7 S., R. 68 W. (see fig. 11)*

[Measured with tape]

	Feet
Piney Creek alluvium:	
Late Recent soil:	
Soil horizon A_1:	
Silt, dark grayish-brown (10*YR* 4/2), humic. Structure: platy. Consistence: sticky, plastic, slightly hard. Reaction: neutral. Boundary: clear smooth	0.7
Soil horizon B_1:	
Silt, dark-brown (10*YR* 4/3), humic clayey. Structure: fine weak prismatic. Consistence: sticky, plastic, hard. Reaction: slightly acid. Boundary: clear smooth	.5
Soil horizon B_2:	
Silt, dark grayish-brown (10*YR* 4/2), humic clayey. Structure: medium weak prismatic. Consistence: sticky, plastic, slightly hard. Reaction: slightly acid. Boundary: clear smooth	.6
Thickness of Piney Creek alluvium	1.8

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14. *Section of Piney Creek, pre-Piney Creek and Louviers alluvium in arroyo along Willow Creek in NW¼NW¼ sec. 7, T. 7 S., R. 68 W.*—Continued

	Feet
Pre-Piney Creek alluvium:	
Early Recent soil:	
Soil horizon A_{1ca}:	
Silt, dark grayish-brown (10*YR* 4/2), humic clayey. Structure: medium moderate prismatic. Consistence: sticky, plastic, hard. Reaction: moderately alkaline. Boundary: gradual, smooth	0.9
Soil horizon B_{2ca}:	
Silt, brown (10*YR* 5/3), clayey; contains some stones as much as 3 in. in diameter. Structure: medium strong prismatic. Consistence: sticky, plastic, hard. Reaction: moderately alkaline. Boundary: clear, smooth	1.5
Soil horizon C_{ca}:	
Silt, very pale brown (10 *YR* 8/3), sandy. Structure: medium moderate prismatic. Consistence: slightly sticky, plastic, slightly hard. Reaction: strongly alkaline. Boundary: clear, smooth	1.7
Thickness of pre-Piney Creek alluvium	4.1
Louviers alluvium (part):	
Wisconsin soil:	
Soil horizon A_{1ca}:	
Silt, grayish-brown (10 *YR* 5/2), humic. Structure: medium weak prismatic; weathers blocky. Consistence: sticky, plastic, hard. Reaction: moderately alkaline. Boundary: abrupt	0.5
Soil horizon B_{2ca}:	
Silt, yellowish-brown (10*YR* 5/6), clayey; calcium carbonate concentrated on outsides of prisms and in three-eighths-in. vertical pipes. Structure: medium strong prismatic; weathers blocky. Consistence: sticky, plastic, hard. Reaction: moderately alkaline. Boundary: clear smooth	1.5
Soil horizon C_{ca}:	
Silt, very pale-brown (10*YR* 7/3), sandy, pebbly. Structure: medium moderate prismatic in upper part, blocky in lower part. Consistence: sticky, plastic, hard. Reaction: moderately alkaline. Boundary: abrupt, wavy	1.0
Soil horizon C:	
Pebble bed, mottled grayish brown and light gray; clayey; stones slightly imbricate, as large as 6 in. in maximum dimension; mostly igneous and metamorphic rocks, some fragments of Pierre shale	1.4
Thickness of Louviers alluvium	4.4
Bottom of arroyo.	

15. *Section of pre-Piney Creek and Louviers alluvium along Lehigh Gulch in NE¼SW¼NW¼ sec. 16, T. 7 S., R. 68 W.*

[Measured with tape]

	Feet
Pre-Piney Creek alluvium:	
Early Recent soil:	
Soil horizon A_1:	
Silt, dark gray-brown (10*YR* 4/2), humic. Structure: structureless. Consistence: slightly sticky, slightly plastic, loose. Reaction: slightly acid. Boundary: gradual	1.4
Soil horizon B_2:	
Silt, dark yellowish-brown (10*YR* 4/4), clayey. Structure: fine weak prismatic. Consistence: slightly sticky, slightly hard. Reaction: neutral. Boundary: gradual	1.5
Silt and sand in layers, grayish-brown (10*YR* 5/2), humic; unit contains boulders as much as 10 in. in diameter; contains seeds of Hackberry tree	18.0
Thickness of pre-Piney Creek alluvium	20.9
Louviers alluvium (part):	
Wisconsin soil:	
Soil horizon A_1:	
Silt, dark gray-brown (10*YR* 4/2). Structure: fine weak prismatic. hard. Consistence: slightly sticky, slightly Reaction: moderately alkaline. Boundary: gradual	0.6
Soil horizon B_2:	
Silt, brown (10*YR* 5/3), clayey. Structure: fine moderate prismatic. Consistence: sticky, plastic, hard. Reaction: moderately alkaline. Boundary: clear	0.7
Soil horizon C_{ca}:	
Silt, pale-brown (10*YR* 6/3), contains mollusks (loc. 104); calcium carbonate throughout upper 1.6 ft but mottled in lower part. Structure: medium moderate prismatic. Consistence: sticky, plastic, soft. Reaction: strongly alkaline. Boundary: gradual	2.5
Soil horizon C:	
Sand, yellowish-brown (10*YR* 5/4, and fine pebbles; grades downward into nonpebbly sand; mottled with calcium carbonate. Structure: blocky. Consistence: slightly sticky, slightly plastic. Reaction: moderately alkaline	1.5
Thickness of Louviers alluvium	5.3

16. *Section of Piney Creek and Louviers alluvium in an arroyo in the SW¼NW¼SW¼ sec. 35, T. 6 S., R. 69 W.*

[Measured with tape by Scott and Ernest Dobrovolny]

	Feet
Piney Creek alluvium:	
Late Recent soil:	
Soil horizon A:	
Sand, very dark gray (10*YR* 3/1), humic; contains sandstone pebbles.	
Structure: structureless.	
Consistence: nonsticky, nonplastic, loose.	
Reaction: slightly acid.	
Boundary: gradual	1.3
Louviers alluvium (part):	
Wisconsin soil:	
Soil horizon A_{1ca}:	
Silt, gray (10*YR* 5/1); stained light gray (10 *YR* 7/2) on outside; humic; contains mollusks (loc. 100c).	
Structure: coarse strong columnar.	
Consistence: slightly sticky, nonplastic, hard.	
Reaction: moderately alkaline.	
Boundary: diffuse	1.5
Soil horizon B_{2ca}:	
Sand, grayish-brown (10*YR* 5/2); has limonite stains and sandstone pebbles from the Morrison formation and the Dakota group.	
Structure: coarse strong columnar, weathers blocky.	
Consistence: nonsticky, nonplastic.	
Reaction: moderately alkaline.	
Boundary: gradual	1.3
Soil horizon G_{1ca}:	
Sand, dark-gray (10*YR* 4/1), fine-grained, humic bog deposit, contains bones and mollusks (loc. 100a).	
Structure: coarse strong columnar.	
Consistence: nonsticky, slightly plastic, extremely hard.	
Reaction: moderately alkaline.	
Boundary: diffuse	1.5
Soil horizon G_{2ca}:	
Sand, gray (10*YR* 5/1), fine-grained.	
Structure: coarse moderate columnar.	
Consistence: slightly sticky, nonplastic, soft.	
Reaction: moderately alkaline	2.0
Thickness of Louviers alluvium	6.3

A count of the pebble bed where it overlies the basal conglomerate of the Dawson arkose in the NW¼NE¼ sec. 36, T. 6 S., R. 69 W., showed quartz and quartzitic sandstone to make up two-thirds of the pebbles. Minor constituents are gneiss, siltstone, sandstone, chalcedony, pegmatite, chert, quartzite, jasper, limonitic sandstone, and petrified wood. The pebble bed is strongly stained by iron and manganese oxide. It locally contains abundant bones and fresh water mollusks.

The middle friable sand of the fine-grained facies is composed of yellowish-brown or reddish-brown clayey fine-grained sand. It is well bedded and contains some pebbles and 1-inch nodules of calcium carbonate. Along the mountain front south of Kassler the middle sand contains abundant mica, probably from gneissic metamorphic rocks which can be seen in the NW¼NE¼ sec. 3, T. 7 S., R. 69 W., and at locality 124 in the NE¼SE¼ sec. 34, T. 6 S., R. 69 W. In this micaceous sandy alluvium are dark yellowish-orange iron-stained layers. Cobbles and boulders of partly decomposed gneiss are common this close to the mountains.

The upper evenly stratified silt of the fine-grained facies is composed of brown, grayish-brown, yellowish-brown, and reddish-brown clayey calcareous silt. It contains some sand and local lenses of pebbles. Along the flanks of trenches that contain the fine-grained facies the silt is underlain by a pavement of pebbles; these were in transport downslope to the valley floor before the silt was deposited. The silt is composed mostly of quartz but contains larger fragments of igneous, metamorphic, and sedimentary rocks. Mica is abundant at the same localities where it is abundant in the middle friable sand. The silt is cemented with calcium carbonate. The upper part is evenly impregnated with a flourlike concentration of calcium carbonate which continues downward as threads and tubes that probably formed around rootlets.

The thickness of the Louviers varies considerably both geographically and in the two facies. The fine-grained facies ranges in thickness from about 6 feet along the mountain front to about 25 feet in the small streams that flow into Plum Creek. The coarse-grained alluvium is much thicker. An auger hole in the SE¼NE¼ sec. 4, T. 7 S., R. 68 W., (pl. 1), where the valley floor of Indian Creek lies about 30 feet below the top of the Louviers alluvium, penetrated 91 feet of coarse-grained sand with some pebbles and cobbles. The coarse-grained facies therefore may be as much as 120 feet thick.

DISTRIBUTION

In the Kassler quadrangle, the Louviers alluvium is preserved as a well-formed terrace along Plum Creek and as small patches of buried valley fill in ancient arroyos along most of the smaller streams (fig. 13). Some of the best of these smaller exposures are (a) along Willow Creek (fig. 11), (b) in the arroyo in the south central part of sec. 4, T. 7 S., R. 68 W., where it overlies Slocum alluvium, (c) in Sterling Gulch in sec. 30, T. 6 S., R. 68 W., where it also overlies Slocum alluvium, and (d) with colluvium of the same age, in the arroyo west of the Dakota group in the SW¼ sec. 35, T. 6 S., R. 69 W. The terrace along Plum Creek is preserved as a flat surface as much as a quarter of a mile in width that lies 40 to 60 feet above Plum Creek and 50 feet below the surface of the Slocum alluvium. The slope of the terrace is slightly steeper than the slope of Plum Creek, so the height of the terrace diminishes downstream.

Outside the quadrangle the terrace can be traced southward toward Castle Rock and northward into the Littleton quadrangle. North of the Littleton quadrangle (fig. 1) only small remnants of the original terrace can be found along the valley walls of the South Platte River, Cherry Creek, and Clear Creek. The terrace apparently was truncated in the Denver area (fig. 12) where according to Hunt (1954, p. 107) early their different elevations at Greeley where the Pleasant Valley lies 50 to 60 feet above the South Platte River and the Kersey lies only 25 feet above. As suggested by Hunt (1954, p. 107), such differences in elevation can be explained by the fact that a terrace is likely to be higher along and immediately downstream from major tributaries than it is between them. This difference in elevation takes place because alluvium is brought in faster from the tributaries than it can be carried away by the main stream. The Pleasant Valley terrace was created north of the South Platte River as the Cache la Poudre River dumped its alluvium in the main channel of the Platte River. The Kersey terrace was created south of the South Platte River where the terrace was not much affected by the influx of alluvium from the north or was leveled off later.

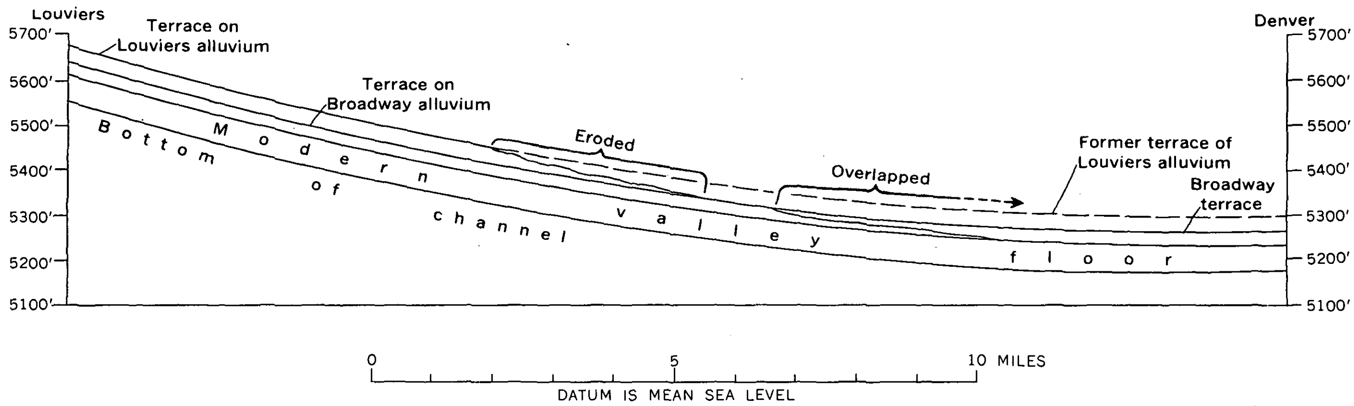

FIGURE 12.—Profile of South Platte River Valley showing erosion of Louviers alluvium and overlap of eroded Louviers by Broadway alluvium from the town of Louviers to Denver.

Wisconsin alluvium lies beneath late Wisconsin alluvium in the lower part of the Broadway terrace.

In order to determine whether the Broadway terrace is equivalent to the Kersey or the Pleasant Valley terrace of Bryan and Ray (1940, p. 25) and what correlative terraces are in the Kassler quadrangle, I traced the Broadway terrace north to the type localities of the two terraces at Greeley. Near Greeley, Colo., I again found the early Wisconsin alluvium lying beneath the alluvium of late Wisconsin age in the Kersey terrace, and I concluded that the Pleasant Valley and Kersey terraces should be grouped together because (a) no significant difference could be found in the alluvium of the two terraces; (b) the Wisconsin soil is formed on the alluvium in both terraces; and (c) the Pleasant Valley terrace becomes lower downstream until it is the same height (25 feet) above the South Platte River as the Kersey terrace. The factor that led Bryan and Ray (1940, p. 25) to separate the two terraces was

UNCONFORMITY BENEATH THE LOUVIERS ALLUVIUM

In the interval of Wisconsin time that followed deposition of the Slocum alluvium and development of the Sangamon(?) soil, erosion was reactivated; existing streams penetrated through the Slocum and deeper into underlying bedrock. These deep valleys were cut before the Louviers alluvium was deposited. Along the South Platte River and Plum Creek the valleys were cut into underlying bedrock to a depth of 60 feet below modern stream level. This erosion, which cut arroyos along the smaller tributaries as well as broad channels along the main streams, was deeper than in any later stage of erosion. The base of Louviers alluvium in these deep valleys has not been exposed by the modern arroyos. As the valleys were cut, adjacent slopes were beveled across Slocum alluvium and bedrock. The slopes range in steepness from 5° to 40° and can be compared to short steep pediments.

FOSSILS

Vertebrate fossils are abundant and diverse in the Louviers alluvium. Almost 50 collections were identified from 11 localities and many other fragmentary bones were seen but not collected. Half of these collections are from the site of a former spring in the NW¼NE¼ sec. 36, T. 6 S., R. 69 W. (loc. 102, pl. 1). Bones are found mostly in the pebbly lower part of the Louviers alluvium; along the South Platte River they are found in the 40-foot cobble layer below the persistent deformed silt beds. The following table lists the mammals that were collected at 11 localities in the Kassler quadrangle.

Mammals from Louviers alluvium in the Kassler quadrangle

[Identification by Edward Lewis, C. B. Schultz, T. M. Stout and L. G. Tanner cf, not certainly identified but resembles the species listed; ?, may be the species listed]

Species	100a	102a	103	104	105a	105b	106	107	108	109	125
Citellus sp.			?								
Cynomys sp.							×				×
Thomomys sp.				×							
Mammuthus (Parelephas) columbi (Falconer)		×									?
Equus sp.		×			×						×
Camelops sp.		×						?			×
Tanupolama sp.											×
Odocoileus hemionus (Rafinesque)	cf										
Bison antiquus Leidy	cf					cf					×
sp.									×	×	

Lewis, Schultz, Stout, and Tanner (written communication, 1955) concluded that these fossils are of Wisconsin age. This conclusion was based on *Bison antiquus*, which ranges from mid-Wisconsin to the end of the Pleistocene, and on *Mammuthus* (*Parelephas*) *columbi*, which ranges throughout the Wisconsin. All the other mammals apparently are long ranging (figure 5).

Invertebrate fossils also are abundant in the Louviers alluvium. Thirty-nine species from 27 localities are listed in the following table.

The invertebrate fossils are all land snails with the exception of two genera of fresh-water snails, *Lymnaea* and *Gyraulus*, and two genera of fresh-water clams, *Pisidium* and *Sphaerium*. The most common species are *Lymnaea parva*, cf. *Succinea avara*, *Pupilla muscorum*, *Vallonia cyclophorella*, *Vallonia gracilicosta*, and *Hawaiia minuscula*. According to Frye and Leonard (1952, p. 169), *Vallonia gracilicosta*, *Succinea avara*, *Pupilla muscorum*, *P. blandi*, and *Hawaiia minuscula* occur at almost every locality of early Wisconsin (Iowan) loess that they studied in Kansas. In the few early Wisconsin alluvial deposits they studied, the same species also were found (Frye and Leonard, 1952, p. 166). Whereas most of the collections of early Wis-

Mollusks from Louviers alluvium of the Kassler quadrangle

[Identification by D. W. Taylor and C. C. Cameron. Arranged according to Thiele (1931), cf, not certainly identified but resembles the species listed; ?, may be the specie listed]

Species	Locality																										
	100a	100b	100c	100d	100e	101a	101b	102a	102b	102c	103	104	106	111	112	113	114	115	116	117	118	119	120	121	122	123	124
Carychium exiguum (Say)	×		×							×																	
Lymnaea bulimoides Lea								×		×																	
caperata Say												×					×										×
obrussa Say										×																	
palustris (Müller)								×		×																	
parva Lea	×								×	×		×			×		×			×						×	×
sp.	×								×									×									
Gyraulus parvus (Say)								×		×																	×
sp.									×																		
cf. *Succinea avara* Say	×								×	×		×	×		×	×	×			×						×	
cf. *Succinea grosvenori* Lea				×																		×					
Succinea sp.								×		×	×							×									
Cionella lubrica (Müller)				×																							
Columella alticola (Ingersoll)																	×									×	
Vertigo gouldi basidens Pilsbry and Vanatta [1]	×									×																	
modesta (Say)																	×									×	
ovata Say										×																	
Pupilla muscorum (Linné)				×	×		×		×		×	×	×	×	×	×	×			×				×		×	
sp.								×		×									×								
Pupoides albilabris (C. B. Adams)	×																		×								
inornatus Vanatta	×			×																	×						
Gastrocopta armifera (Say)				×	×																	×					
holzingeri (Sterki)	×		×	×	×																						
procera (Gould)				×	×			×																			
tappaniana (C. B. Adams)	×		×	×																							
Vallonia cyclophorella Ancey							×	cf	×		×	×	×	×	×	×	×			×		×	cf	×		×	×
gracilicosta Reinhardt	×	×	×	×	×	×			×	×	×		×	×		×	×	×	×		×	×			×		
parvula Sterki				×																							
Punctum minutissimum (Lea)				×																							
Helicodiscus singleyanus (Pilsbry)																					×						
Hawaiia minuscula (Binney)	×	×	×	×	×	×				×												×					
Retinella electrina (Gould)	×																										
Zonitoides arboreus (Say)	×		?	×	×																						
Deroceras sp.											×									×							
Euconulus fulvus alaskensis (Pilsbry)	×			×																							
Pisidium casertanum (Poli)	×							×		×																	×
compressum Prime																											×
obtusale Pfeiffer								cf																			×
Sphaerium sp.																											×

[1] First of two recorded fossil occurrences.

consin mollusks in Kansas are from loess, most of the collections in the Kassler quadrangle are from alluvium.

Many of the fossil mollusks are terrestrial species that were carried into the Louviers after death. The greater abundance of species in the alluvium than in the younger loess probably is due to concentration by water. For this reason mollusks in the alluvium may represent a large proportion of those that were living in the area at the time the Louviers alluvium was deposited. Comparison of the mollusk assemblage in the Louviers alluvium with that from other deposits is shown in table 2.

The habitats and geographic distributions of the living representatives of the species on the chart indicate that the fossils lived in the climate of a glacial stage. Data on distribution and habitat taken from Pilsbry (1946 and 1948), Leonard (1950 and 1952), and Van der Schalie (1953) were interpreted by D. W. Taylor and C. C. Cameron (written communication, 1954) and show that the land mollusks of the Louviers alluvium prefer a cool dry habitat. For instance, *Pupilla muscorum* is living today in the Front Range at cool high altitudes well above timberline; and with *Vallonia cyclophorella* and *Euconulus fulvus alaskensis* lives from the foothills up to timberline. *Vertigo modesta* and *Columella alticola* also live in meadows as high as 10,000 feet. Other species such as *Vallonia gracilicosta*, *Hawaiia minuscula*, *Pupoides albilabris*, *Gastrocopta tappaniana*, *G. holzingeri*, *G. armifera*, *G. procera*, and *Helicodiscus singleyanus* are adapted to drier habitats.

Fresh-water mollusks from the Louviers alluvium suggest an environment such as a flood plain with small sluggish streams and backwater pools containing thick vegetation. A similar environment is suggested by ostracodes and charophytes that were found with mollusks at locality 124. The following ostracode species were identified by I. G. Sohn:

"*Candona*" sp., both males and females, adults only
"*Candona*"? sp. of the *Candona lactea* group
Cypridopsis? sp.
Gen. aff. *Herpetocypris*, very large; two valves, two fragments
Limnocythere sp., one valve

Only a few valves were picked from the alluvium of locality 124, for only an interpretation of the environment was sought.

Seeds of the Hackberry tree (*Celtis* sp.) were found in the Louviers alluvium in Sterling Gulch in the SE¼SE¼ and in the NE¼SE¼ sec. 30, T. 6 S., R. 68 W. The Hackberry tree grows today beside streams in the drier parts of the Colorado.

ORIGIN

The Louviers alluvium was deposited by streams flowing in previously cut valleys northeastward from the Front Range and is composed mostly of rocks derived from the Front Range. The earlier alluvium on the pediments supplied most of the material, but local sedimentary rocks contributed some. Base levels for the streams that deposited Louviers alluvium were Plum Creek and the South Platte River. As shown by the graded bedding of the alluvium, the streams that were capable of carrying large quantities of coarse material during the early part of this depositional cycle became progressively less competent as time elapsed.

The large amount of iron and manganese oxide in the silty layers of the alluvium suggests that the alluvium was laid down in a boggy, possibly cool, environment. Similar accumulations of iron oxides are forming in Colorado today in stagnant beaver ponds and bogs at altitudes of 9,000 or 10,000 feet. No bogs with iron oxide are known at an altitude comparable to that of Plum Creek or the South Platte River in the Kassler quadrangle. Ferrous iron hydroxide is soluble in cold water under reducing conditions with a low pH. The iron was apparently not fixed by bacteria or deposited as small pellets as is bog iron ore, but was precipitated as ferrous iron hydroxide. When the alluvium was dissected and the water table dropped, the iron was oxidized to ferric iron hydroxide.

AGE

The Louviers alluvium is considered to be early Wisconsin in age for the following reasons:

1. The younger loess that overlies it is correlated with the Peorian loess of Nebraska. As stated in the section on correlation and age of the younger loess (p. 35), the soil developed on this loess has been traced across eastern Colorado and probably is the same as the Brady soil that is developed on Peorian loess in Nebraska.
2. The alluvium has a molluscan assemblage almost the same as the assemblage in Kansas called pre-Bradyan Wisconsinan fauna by Frye and Leonard (1952, p. 166).
3. It has Pleistocene mammals that are found only in Wisconsin deposits of Nebraska.
4. The Louviers alluvium was the first alluvium deposited after the pre-Wisconsin Slocum alluvium.
5. A Wisconsin soil is developed on the alluvium.

In hopes of determining the absolute age of the Louviers alluvium radiocarbon analysis was made of some wood fragments found beneath a bone of a mammoth at a former spring in the NW¼NE¼ sec. 36, T. 6 S., R. 69

W. The deposit in which the wood fragments lie is a loess that was probably deposited in a boggy environment. It overlies a pebbly clay that is considered to be the Louviers alluvium; however, the wood fragments gave a radiocarbon age (W–288, Rubin and Suess, 1956, p. 446) of 4,885±160 years, whereas the associated mammoth bone, which must be Pleistocene, is assumed to be at least 10,000 years old. Of all the possible reasons for this discrepancy the most probable explanation is that the wood fragments were pushed into boggy ground at the spring by later grazing animals.

A later radiocarbon analysis (W–401, Rubin and Alexander, 1958, p. 1485) of a mammoth tooth from the pebbly clay gave a date of 10,200±350 years. This age is within the expected age range of mammoths, but is much younger than the supposed 15,000-year date that was expected for the Louviers alluvium. Such variations in apparent ages are not surprising, for animals had congregated around the spring from early Wisconsin to Recent time and their bones undoubtedly were trampled into the older deposits.

YOUNGER LOESS

Younger loess forms a blanket confined to the north-central part of the quadrangle, with the exception of a small outcrop south of Louviers (pl. 1). The surface of the younger loess is gently rounded, but reflects any large irregularities of an underlying surface. Three depressions in the loess south of Roxborough Park school are deflation basins floored by Pierre shale and surrounded by loess. The younger loess overlies and is later than the older loess and Louviers alluvium, but is eroded and the channels filled with pre-Piney Creek and Piney Creek alluvium. An outcrop of loess over Louviers alluvium is well exposed at an ancient spring in the NW¼NE¼ sec. 36, T. 6 S., R. 69 W., south of the South Platte River. The greater amount of loess on the south side of the South Platte River is due to a large source of silt in the flood plain of the river that was picked up and redeposited by southeasterly winds.

The younger loess is moderate yellowish-brown to olive-gray silty sand or sandy silt about 5 feet thick (see section 7). The lower part is crudely stratified; the upper part contains a moderately strong prismatic structure that causes it to stand in vertical banks. Small pebbles and coarse sand were locally incorporated by slopewash from the adjacent pediment alluvium. Calcium carbonate mottles the loess and is common in soft ¼-inch nodules and as coatings on faces of prisms.

FOSSILS

Fossil vertebrates and mollusks are abundant in the loess. *Equus* sp. and *Camelops* sp. were identified from more than 50 bones collected at the site of a former spring in the NW¼NE¼ sec. 36, T. 6 S., R. 69 W. (loc. 98a, b; figure 5). In addition, *Camelops* sp. was found at locality 99. Mollusks were collected at three localities; two of the localities were found in excavating for bones at the spring site. Following is a list of the mollusks from each locality.

Mollusks from younger loess in the Kassler quadrangle

[Identifications by D. W. Taylor and C. C. Cameron. Arranged according to Thiele (1931)]

Species	Locality		
	98a	98b	99
Lymnaea parva Lea	×	×	--------
sp	×	--------	--------
Gyraulus sp	--------	×	--------
cf. *Succinea avara* Say	×	×	--------
Pupilla muscorum (Linné)	×	×	×
Vallonia cyclophorella Ancey	×	×	×

The fossil assemblage in the loess contains only those mollusks that lived on the surface of the loess, on plants growing from it, or in nearby water. The mollusks are the same as the diagnostic assemblage from the Louviers alluvium (table 2). *Pupilla muscorum*, *Vallonia cyclophorella*, cf. *Succinea avara*, and *Lymnaea parva* are most abundant and suggest cold dry conditions during deposition of the younger loess.

AGE AND CORRELATION

The age of the younger loess is considered to be early Wisconsin because it contains the same fauna as the Louviers alluvium, which it overlies, and because a Wisconsin soil is developed on it. The loess is correlated with the Peorian Loess which was traced from Nebraska across eastern Colorado to the Denver area. It thins from more than 100 feet in Nebraska to 5 feet in the Kassler quadrangle. The younger loess is also correlated with the eolian silt and sand of Malde (1955, p. 240–243) and the eolian deposits of Hunt (1954, p. 108–111).

SOIL OF WISCONSIN AGE

A soil, placed stratigraphically as mid-Wisconsin in age, was strongly developed in a Brown soil facies in the upper part of the Louviers alluvium and younger loess. (See sections 7, 11, 12, 13, 14, 15, 16, and distribution on pl. 1.) The inferred age of the soil is based on its stratigraphic position. Buried profiles of the soil can be seen in figure 13 and are described in sections 13, 14, 15, and 16 which were measured in the walls of modern trenches eroded through younger alluvium into the fine-grained facies of the Louviers alluvium. Profiles of the soil that have been continuously exposed at the surface are developed on the coarse-grained facies of the Louviers and on the younger loess (see sections

7, 11, and 12); although these exposed soils were subjected to all later episodes of soil formation, they were not altered much and are easily recognized as Wisconsin soils.

The soil is developed in a Brown soil facies except for some small exposures of unmapped colluvium with a Podzolic facies in Roxborough Park and in the mountains. The Brown soil contains three well-developed and well-preserved horizons, A_1, B_2, and C_{ca}. The A_1 horizon is very dark brown, humic, and about 1 foot thick. The B_2 horizon is brown (see fig. 4), has a strong medium prismatic structure and a sticky plastic hard consistence, and commonly contains splotched secondary calcium accumulation along the prism faces. Thickness of the B_2 horizon ranges from 0.7 to 1.5 feet; thickness is greater where texture is coarser. The C_{ca} horizon in the alluvium is a soft massive accumulation of calcium carbonate that follows joints and is not nearly as concentrated as in the pre-Wisconsin soils. In the younger loess the calcium carbonate is scattered through the parent material in one-fourth-inch spots (loess kindchen) rather than in a massive concentration. Pebbles in the C_{ca} horizon are coated on the undersides with calcium carbonate.

The Wisconsin soil is superposed on pre-Wisconsin soils (fig. 14) and has altered the original profiles in several ways. Calcium carbonate was deposited along joints in the pre-Wisconsin B horizons; the top of the pre-Wisconsin C_{ca} horizon was leached and the calcium carbonate reconcentrated a few inches lower in a thick layer of almost pure calcium carbonate that has a very abrupt but slightly wavy upper boundary. The A horizon of the pre-Wisconsin soil is not visible at any of the outcrops where the Wisconsin soil is superposed on the pre-Wisconsin, such as in the arroyo at Roxborough Park school in the SW¼NW¼ sec. 36, T. 6 S., R. 69W. (fig. 14, and sec. 7) and in the Highline ditch in the NW¼ sec. 25, T. 6 S., R. 69 W., Littleton quadrangle. Evidence that the A horizon was eroded is lacking; therefore, I suggest that the humus in it was bleached chemically and is no longer recognizable as an A horizon.

BROADWAY ALLUVIUM

That alluvium which lies in the first terrace below the Louviers alluvium was named the Broadway alluvium by Scott (1960). This alluvium, on which a Brown soil

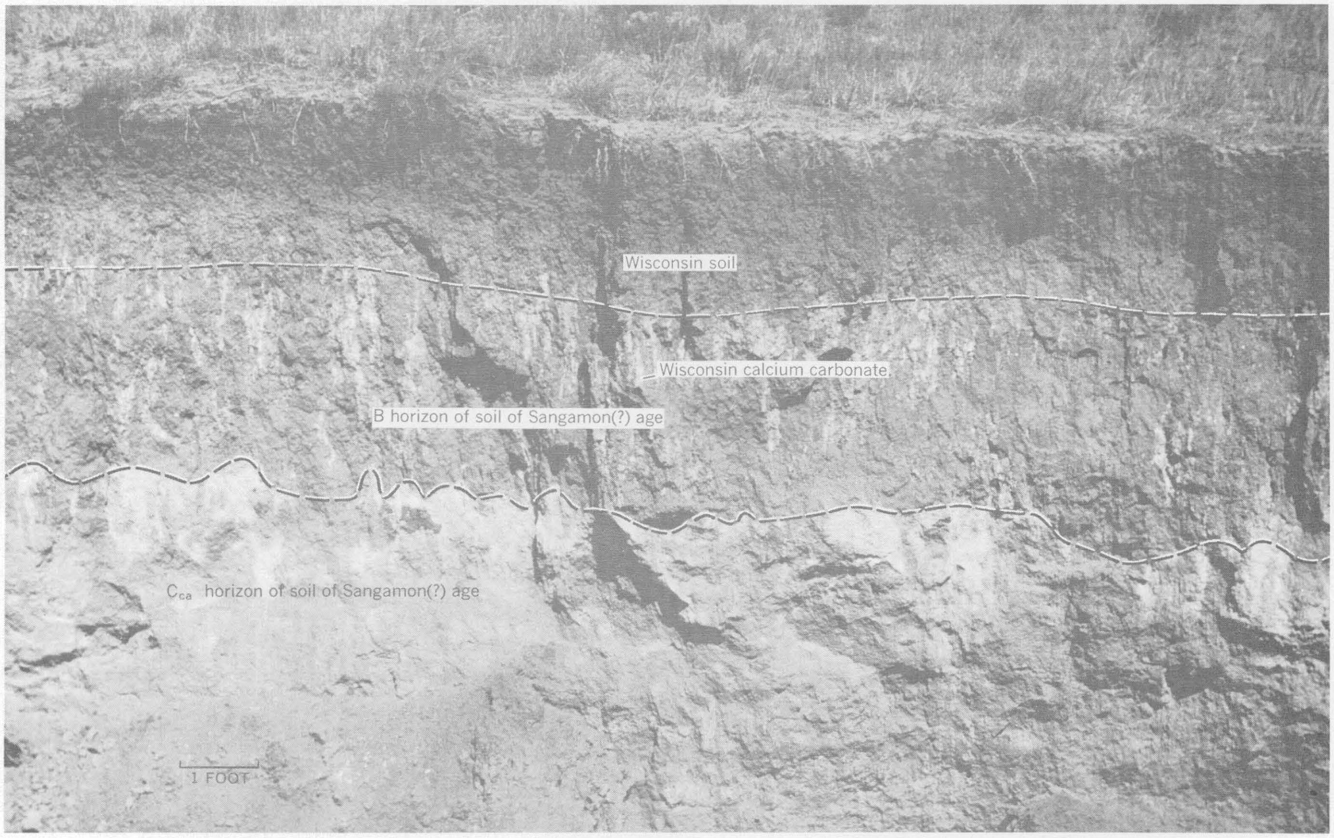

FIGURE 14.—A Wisconsin soil superposed on B horizon of a Sangamon(?) soil. Note abrupt upper boundary of C_{ca} horizon of soil of Sangamon(?) age and Wisconsin calcium carbonate in joints of Sangamon(?) B horizon. At Roxborough Park school, SW¼NW¼ sec. 36, T. 6 S., R. 69 W.

was moderately strongly developed in early Recent time, is composed of reddish-brown fine- and coarse-grained sand with pebbles. The alluvium was deposited only along the South Platte River and Plum Creek. The term Broadway is taken from Broadway Avenue which traverses the Broadway terrace northward through Denver, Colo.; the type locality is designated as a gravel pit in the SE¼ sec. 30, T. 2 S., R. 67 W. near Dupont in Adams County, Colo. Other nearby gravel pits at the north edge of Denver also show typical sections of the Broadway alluvium. Section 17 is typical of the alluvium in the Kassler quadrangle.

DESCRIPTION

The Broadway alluvium is composed of uniform coarse-grained sand near the center of the Plum Creek channel, but grades into silty humic coarse-grained sand near the east edge of the channel. The uniform sand is reddish brown and rather clean, and contains subangular to subrounded pebbles. Most of the pebbles are less than 1 inch in diameter, but some are 4 to 6 inches. Major constituents are granite, quartz, ironstone, and welded tuff; minor constituents are chert, sandstone, quartzite, altered amphibolite, biotite-quartz gneiss, aplite, pegmatite, and granite gneiss. The humic silty sand is grayish brown and obviously has been little washed by stream action. It contains pieces of Dawson arkose from the slopes along the east side of Plum Creek. The alluvium throughout the terrace is crudely stratified in the coarse beds, well-stratified in the fine beds. The thickness is estimated to be about 25 feet.

17. *Section of Broadway alluvium in sand pit in NE¼SE¼ sec. 33, T. 6 S., R. 68 W.*

	Feet
Broadway alluvium:	
Early Recent soil:	
Soil horizon AB:	
Sand, dark-brown (10*YR* 4/3), silty, humic; pebbles, cobbles and boulders as much as 8 in. in length; poorly sorted; stands in vertical banks where freshly exposed	2–3.0
Soil horizon C:	
Sand, reddish-brown (5*YR* 5/4), medium- to coarse-grained; stratified in 2- to 4-in. layers; reddish-brown layers are separated by yellowish-gray layers of slightly finer texture and looser consistence; iron oxide and clay cement the grains slightly. Locally contains streaks of calcium carbonate	16.0
Thickness of Broadway alluvium	18.0–19.0

DISTRIBUTION

In the Kassler quadrangle, the Broadway alluvium is preserved along the east side of Plum Creek at Louviers in a moderately well formed terrace that lies 30 feet above and slopes more steeply than Plum Creek. It also slopes steeply from the valley sides toward Plum Creek. The terrace can be traced north into the Broadway terrace of the Denver area and into the Kersey terrace of the Greeley area. The terrace was removed by later erosion along the South Platte River near Kassler.

UNCONFORMITY BENEATH THE BROADWAY ALLUVIUM

Shallow valleys were cut into the Louviers alluvium in late Wisconsin time along the South Platte River and Plum Creek. The depth of the valleys is generally less than 25 feet and only locally is the width more than 1 mile. The unconformity where the base of the trench is cut in Louviers alluvium is exposed in gravel pits along the South Platte River and can be recognized by a change from large cobbles in the Louviers to small pebbles in the overlying Broadway. Along small tributaries, trenches were cut only a short distance upstream. Upstream from the trenches Louviers alluvium was not eroded.

AGE

The Broadway alluvium is considered to be late Wisconsin in age for the following reasons:

1. The upper part of the gravel capping the Broadway terrace contains late Pleistocene fossils and is considered late Wisconsin in age (Hunt, 1954, p. 104).
2. The Broadway alluvium was the first alluvium deposited after the early Wisconsin Louviers alluvium.
3. The alluvium is older than the pre-Piney Creek alluvium.

PLACEMENT OF PLEISTOCENE-RECENT BOUNDARY AND SUBDIVISION OF THE RECENT DEPOSITS

The Pleistocene-Recent boundary suggested by Hunt (1953) is used in this report. In the Kassler quadrangle the boundary lies between Broadway alluvium and pre-Piney Creek alluvium. This boundary in the geologic column coincides with the disappearance of Pleistocene mammals, such as the elephants and camels, and the appearance of a modern fauna characterized by *Bison bison* which did not occur in the older deposits. The deposits above and below the boundary are distinct lithologically. The older deposits along the main streams are coarse-grained glacial outwash from the mountains, whereas the younger deposits are fine-grained silty alluvium from local sources.

In other parts of the geologic section the most reliable stratigraphic markers separating two stages have been the ancient soils; presumably they should also be useful in separating the Pleistocene from Recent. In the Kassler quadrangle, the first well-developed soil to form after the late Wisconsin deposits is the soil of early Recent age. G. M. Richmond and R. B. Morrison (oral communication, 1959) of the U.S. Geological Survey have used this early Recent soil to mark the end of the Pleistocene in areas they have mapped in the Rocky Mountains, the Colorado Plateau, and the Great Basin. These areas, however, do not contain early Recent deposits (or else the deposits are of glacial origin and are considered to be an extension of deposits that rightly belong in the Pleistocene); Richmond and Morrison consider, therefore, that the early Recent soil—even though it formed only 4,500 to 4,000 years ago—effectively divides Pleistocene from Recent deposits. In the Kassler quadrangle where both alluvium and eolian sand containing Recent mammals were deposited in early Recent time, the early Recent soil cannot be used to divide the Pleistocene and Recent.

Presumably, a soil that could be used to divide Pleistocene from Recent must have formed at the end of the Broadway geomorphic cycle, as it did at the ends of other cycles. Actually such a soil has been found in Nevada. Morrison (1958, table 1) in the southern Carson Desert area near Fallon, Nev., found a very weakly developed soil that may mark the boundary between Pleistocene and Recent at Lake Lahontan.

This late Wisconsin soil may have developed in the Kassler quadrangle and later have been completely obscured by the early Recent soil, which is much stronger. Absence of the soil has not been a deterrent to stratigraphic placement of the early Recent deposits, for charcoal in the pre-Piney Creek alluvium gave an average age of 5,500 years before the present and the alluvium contains only Recent mammals.

Geologists who have worked with Quaternary deposits have divided the Recent epoch differently and have included in it quite different amounts of geologic time. In the Rocky Mountains, Colorado Plateau, and Great Basin areas G. M. Richmond and R. B. Morrison (oral communication, 1959) include in the Recent only the time since the development of the early Recent soil. They divide the Recent into two stages: early Recent, which includes equivalents of the Piney Creek alluvium, and late Recent, which includes equivalents of the post-Piney Creek alluvium. These two informal stages are separated by the late Recent soil.

In the Kassler quadrangle, the soil of early Recent age is used to divide the Recent into two informal ages, early Recent and late Recent, which together encompass about 10,000 years of geologic time; divided they include approximately 6,000 years of early Recent and 4,000 years of late Recent time.

PRE-PINEY CREEK ALLUVIUM

Pre-Piney Creek alluvium, composed of light-brown stratified silt, on which a moderately strongly developed Brown soil was formed, is widespread in the Kassler quadrangle, but was not recognized in any adjoining part of the Denver area.

DESCRIPTION

The pre-Piney Creek alluvium consists of light-brown, moderate-brown, or moderate yellowish-brown silt and sand with thin lenses of pebbles. Quartz is the major constituent of the fine alluvium; rounded to subrounded fragments of igneous, metamorphic, and sedimentary rocks are locally abundant. Stratification is well developed in beds of silt, sand, and pebbles. Calcium carbonate cements the grains and fills rootlet holes, especially in the silt layers, to a depth of 30 feet. The thickness of the alluvium may exceed 40 feet.

Charcoal fragments as large as 1 inch in diameter form layers in the alluvium at several places, probably as a result of forest fires during or before the deposition of the alluvium.

Colluvium of early Recent age, which is mapped as part of the pre-Piney Creek alluvium, consists of a heterogeneous mixture of reddish-brown calcareous sand, silt, and clay with boulders, cobbles, and pebbles lying west of the Dakota hogback. Most of the stones are Dakota sandstone, but there are also pieces of shale and limestone from the Morrison and Lykins formations, and igneous and metamorphic rocks reworked from the older surficial deposits. The colluvium is crudely stratified parallel to the slopes, and flat rocks parallel the stratification. The thickness of the colluvium locally exceeds 10 feet.

18. *Section of pre-Piney Creek alluvium along Rainbow Creek in the NE¼NW¼NE¼ sec. 29, T. 7 S., R. 68 W.*

[Measured with tape]

	Feet
Pre-Piney Creek alluvium (part):	
Early Recent soil:	
Soil horizon A_1:	
Sand, grayish-brown (10*YR* 5/2), humic	1.2
Soil horizon B_2:	
Sand, light-brown (7.5*YR* 6/4), clayey, coarse-grained; contains small pebbles	4.3
Soil horizon C_{ca}:	
Sand, light-brown (7.5*YR* 6/4), pebbly; contains mollusks (loc. 128)	12.0
Thickness of pre-Piney Creek alluvium	17.5

19. *Section of pre-Piney Creek alluvium along Rainbow Creek in the NW¼NW¼ sec. 28, T. 7 S., R. 68 W.*

[Measured with tape]

	Feet
Pre-Piney Creek alluvium (part):	
Early Recent soil:	
Soil horizon A_1:	
Sand, reddish-brown (5*YR* 4/4), silty	1.0
Soil horizon B_2:	
Sand, yellowish-red (5*YR* 5/6), silty, blocky	3.0
Soil horizon C_{ca}:	
Sand, reddish-brown (5*YR* 5/4), silty; calcium carbonate in cracks to a depth of 3 ft, then spread thinly through deposit below 3 ft	37.0
Thickness of pre-Piney Creek alluvium	41.0
Dawson arkose.	

DISTRIBUTION

The alluvium lies in channels cut in Louviers alluvium along Indian Creek and Rainbow Creek (sections 18 and 19), but was deposited on straths of Louviers alluvium along other streams, such as Willow Creek (fig. 11; sections 13 and 14). It lies in the first terrace above the Piney Creek alluvium about 25 feet above stream level along Indian Creek, Lehigh Gulch (section 15), and Rainbow Creek in the southeastern part of the quadrangle. Pre-Piney Creek alluvium along Willow Creek and other arroyos, where it was observed buried by Piney Creek alluvium, is not mapped, but it is described in sections 18 and 19.

UNCONFORMITY BENEATH THE PRE-PINEY CREEK ALLUVIUM

Valleys as deep as 25 feet and as wide as one-quarter mile were cut into Louviers alluvium in early Recent time along the tributaries of the South Platte River and Plum Creek. The unconformity at the base of these channels can be recognized at many places along Indian Creek and Rainbow Creek where outcrops of Louviers alluvium protrude through the pre-Piney Creek alluvium.

FOSSILS

Vertebrate fossils were found in the early Recent colluvium that borders a pit dug into the Lykins shale in the SE¼SE¼ sec. 11, T. 7 S., R. 69 W. (loc. 126, pl. 1). Here *Ursus horribilis* and *Odocoileus hemionus* (Rafinesque) were found associated with fossil mollusks and with artifacts. The grizzly bear and deer probably were killed by man.

Invertebrate fossils from localities 127 and 128 in pre-Piney Creek alluvium and locality 126 in colluvium are listed in the following table.

Mollusks from pre-Piney Creek alluvium in the Kassler quadrangle

[Identifications by D. W. Taylor and C. C. Cameron, arranged according to Thiele (1931)]

Species	Locality		
	126	127	128
Lymnaea bulimoides Lea		×	
cf. *Succinea grosvenori* Lea	×	×	×
Pupoides albilabris (C. B. Adams)	×		
hordaceus (Gabb)		×	
inornatus Vanatta		×	
Gastrocopta armifera (Say)	×		
cristata (Pilsbry and Vanatta)		×	
Vallonia gracilicosta Reinhardt	×	×	×
Hawaiia minuscula (Binney)	×		
Zonitoides arboreus (Say)			×

Gastrocopta cristata and *Pupoides hordaceus* of locality 127 are now living in the warmer states south of Colorado and suggest a nonglacial environment, perhaps an interglacial or postglacial climate. Seeds of the Hackberry tree (*Celtis* sp.) were found in the early Recent colluvium in the pit at locality 126. Hackberry trees grow today beside streams in the drier parts of Colorado.

ARCHEOLOGY AND AGE

The pit at locality 126 also exposed an Archaic culture layer in which artifacts were found 4 feet below the top of the early Recent colluvium. Shallow-bowl metates, manos, projectile points, scrapers, choppers, and bone tools were found in the culture layer. Associated with the artifacts is a concentration of charcoal.

Charcoal from this culture layer and from alluvium were analyzed in the radiocarbon laboratory of the U.S. Geological Survey by Meyer Rubin. The age of the sample (W–272, Rubin and Suess, 1956, p. 446) from the culture layer was found to be 5,780±160 years. Charcoal from a deposit of fine-grained pre-Piney Creek alluvium in an arroyo at the foot of the mountains (W–273) in the SW¼SW¼ sec. 24, T. 7 S., R. 69 W., gave a radiocarbon age of 5,450±160 years. These dates indicate that the pre-Piney Creek alluvium was deposited about 4,500 years after the beginning of the Recent and about 1,000 years before the early Recent soil. The relative age of the alluvium is well known; it overlies Louviers alluvium and is overlain by Piney Creek alluvium.

EOLIAN SAND

Eolian deposits, chiefly medium-grained well-rounded sand, extend southeastward across the uplands from several of the main valleys.

The eolian sand south of Rainbow Creek is reddish yellow to reddish brown, medium to coarse grained, slightly platy, slightly sticky, plastic, and soft. The deposit is 10 feet thick. The soil developed on the eolian sand is acid owing to a thick overgrowth of scrub oak.

The eolian sand north of Rainbow Creek is light brown, silty, fine grained, and massive. Only about 1½ feet of sand covers the Slocum alluvium in the Rainbow Creek area. The soil developed on the sand is enriched with calcium carbonate owing to a cover of grass. This deposit was measured in a small arroyo in the SW¼SE¼ sec. 20, T. 7 S., R. 68 W. and is described in section 20.

The small deposit of eolian sand near Kassler in sec. 34, T. 7 S., R. 69 W., is about 10 feet thick and consists of reddish-brown silty fine-grained sand that is crudely stratified. The sand is mottled with a lacy network of calcium carbonate.

DISTRIBUTION

The sand overlies Louviers alluvium south of the South Platte River in the NE¼SE¼ sec. 34, T. 6 S., R. 69 W. (pl. 1). It overlies Slocum alluvium north of Rainbow Creek in the SW¼SE¼ sec. 20, T. 7 S., R. 68 W., and overlies Dawson arkose south of Rainbow Creek in the NE¼NE¼ sec. 29, T. 7 S., R. 68 W. A smooth thin veneer of eolian sand locally overlies the pediments elsewhere, but generally is too thin to map. The sand is hummocky where it overlies eroded bedrock.

20. *Section of eolian sand in arroyo in the SW¼SE¼ sec. 20, T. 7 S., R. 68 W.*

[Measured with tape]

	Feet
Eolian sand:	
Early Recent soil:	
Soil horizon AB:	
Sand, dark grayish-brown (10*YR* 4/2), humic, clayey; lower 4 in. oxidized	0.9
Soil horizon C_{ca}:	
Sand; upper 6 in. dark grayish brown (10*YR* 4/2), humic; contains snails in lower part (loc. 129). Lower part yellowish brown (10*YR* 5/4), clayey; contains fine granules of calcium carbonate	1.9
Thickness of eolian sand	2.8

Mollusks found in the deposit north of Rainbow Creek (loc. 129) are listed below. All are land snails except *Lymnaea*. Collectively they indicate that the climate was cooler than it now is along Rainbow Creek.

Lymnaea parva Lea
cf. *Succinea ovara* Say
Columella alticola (Ingersoll)
Vertigo sp.
Pupilla muscorum (Linné)
Vallonia cyclophorella Ancey
V. gracilicosta Reinhardt

The eolian sand was derived from nearby streams or from alluvium on the Verdos or Slocum pediments. The wind deposited the sand southeastward from the source. For the wind to be able to move the sand, vegetation must have been sparse, probably as the result of a dry climate.

Inasmuch as the eolian sand overlies Louviers alluvium and has the early Recent soil developed on it, it probably is of either late Wisconsin or early Recent age. In addition, the outcrop south of Rainbow Creek seems to have been derived from pre-Piney Creek alluvium; therefore, the sand probably is about 5,000 years old. Hunt (1954, p. 112) described eolian sand in the Denver area which he considered to be late Pleistocene or early Recent in age; the sand in the Kassler quadrangle probably is correlative.

SOIL OF EARLY RECENT AGE

A soil of early Recent age is moderately strongly developed on Broadway alluvium, pre-Piney Creek alluvium, and on the eolian sand. This soil is developed in a Brown soil facies except on eolian sand south of Rainbow Creek where it is Podzolic. The soil generally is exposed at the earth's surface, but may be seen buried under younger deposits along the walls of trenches cut by Willow Creek (fig. 11).

The early Recent Brown soil is characterized by the A_1, B_2, and C_{ca} horizons (see sections 13, 14, 15, 18, and 19). The A_1 horizon is gray brown and generally lighter in color than the A_1 horizon of the late Recent soil. Structure of the A_1 horizon is platy to very coarse weak columnar and the thickness is 6 to 16 inches.

The B_2 horizon is yellowish brown (fig. 4) or locally reddish brown; the structure is fine weak prismatic to medium strong prismatic, the consistence is sticky, plastic, and hard and the reaction is moderately alkaline because of an accumulation of secondary calcium carbonate from overlying deposits. The thickness of the B_2 horizon is 8 to 18 inches.

The C_{ca} horizon, or calcium carbonate enriched parent material, is yellowish to reddish brown and extends to a depth of 1¾ to 3 feet as reticulated boxworks of hairlike calcium carbonate veinlets. The carbonate also coats the undersides of pebbles, artifacts, and bones. Where the early Recent deposits are near a limestone bed, they are very firmly cemented by calcium carbonate. Mollusks are abundant in the C_{ca} horizon but were leached out of the A_1 and B_2 horizons.

The horizon thicknesses given are average, but as with all soils in the area, the horizons are thicker but weaker where they are developed on more porous materials.

LANDSLIDES

Landslides are of two types: earth flows in soft clayey sedimentary rocks, and rockfalls in hard, blocky, ridge-forming sedimentary rocks. Earth flows move slowly, but they move frequently, if not continuously; they block streamflow temporarily and keep pediment slopes steep. Rockfalls are fast and spectacular, but infrequent in this area. Earth flows and rockfalls of several ages from early Wisconsin to Recent were found in the Kassler quadrangle, but all are mapped and described together as Recent landslides.

Most of the earth flows are in sec. 19, T. 7 S., R. 68 W. They are composed mostly of Pierre shale with a thin veneer of colluvium from the pediment alluvium. The slides are not now in single masses but are broken up into small blocks tilted in many directions, though all moved as a unit. The toes of the slides are the most disturbed; they consist of crushed shale pushed upward and outward in typical earth-flow fashion. The toes of slides are mostly removed by intermittent streamflow in the arroyos; however, one slide is so recent that its toe partly dams the arroyo. An area of discrete broken-up blocks at the heads of the slides behaved like a slump. The slides are 25 to 50 feet wide and 50 to 200 feet long.

The earth flows in Pierre shale were caused by (1) oversteepening of pediment slopes during dissection by streams or (2) action of springs and seeps at contact of pediment alluvium and Pierre shale. In one slide on the edge of the highest pediment the toe was swampy and springs flowed from under the slide in the spring of the year.

One rockfall was observed in sandstone of the Dakota group at the north end of the hogback south of Kassler. The rockfall block is about 40 feet long, 20 feet thick, and 30 feet wide. It now lies on the lower Morrison formation beside the arroyo west of the Dakota hogback. A gap can be seen where the block broke out of the Dakota hogback upslope from its present resting place. The bedding in the block dips to the west.

This rockfall was caused by oversteepening of the slope. The block split away from the hogback along joints perpendicular to the bedding and tumbled downslope into the arroyo. The arroyo was temporarily dammed until the stream cut a new course around the west side of the block.

The earth flows of Pierre shale took place in late Recent time, and displaced Piney Creek alluvium. The rockfall of Dakota sandstone took place in late Wisconsin or early Recent time. The new channel around the west side of the block cuts into Louviers alluvium and is filled with Piney Creek alluvium.

BOG CLAY

Bog clay consists of pond deposits of clay 6 feet or more in thickness that lie in deflation basins surrounded by younger loess and in swampy undrained areas along the floors of several small valleys.

Bog clay was mapped at three swampy places west of the Lyons sandstone in secs. 2, 11, and 14, T. 7 S., R. 69 W; in three undrained depressions (pl. 1) south of Roxborough Park school (sec. 36, T. 6S., R. 68 W. and sec. 1, T. 7 S., R. 68 W.), and in a depression on the Verdos pediment at the corner of secs. 17, 18, 19, and 20, T. 7 S., R. 68 W.

Bog clay is similar in all bogs, but the bogs differ in setting. The bog clay is a foul-smelling, very plastic gray silty clay containing large amounts of organic material. The three deposits of bog clay west of the Lyons sandstone are in poorly drained swamps on Piney Creek alluvium. Hummocks of grass stand on the surface of these bogs. The three bogs south of Roxborough Park school are on Pierre shale. They are alkaline and probably contain sulfates, for they are covered with a white efflorescence during dry weather. None of the bogs in the area contains perennial water, but all contain water for about two months in a rainy spring and after rains in the summer.

The bogs also differ somewhat in origin. The three bogs on Pierre shale were formed when the younger loess closed the drainage outlets and winds eroded soft, weathered Pierre shale from the depressions. The bogs on Piney Creek alluvium may have been started when vegetation built up across the outlet to each little basin and trapped water, but this hypothesis does not explain the sudden steepening in gradient of the top of the alluvium upstream and downstream from the bogs. The saturated clay may have rotated enough in a very gradual earth flow or creep to change the gradient. The possible role of animals in wallowing and stamping out hollows in the alluvium, in which bogs later formed, cannot be overlooked. The small bog on Verdos alluvium probably was created by animals or was dammed by a small deposit of Piney Creek alluvium.

The three bogs on Pierre shale date back to the deposition of the younger loess. The other bogs are of the age of Piney Creek alluvium or younger.

PINEY CREEK ALLUVIUM

Piney Creek alluvium (Hunt, 1954, p. 114), composed of brownish-gray humic silt, sand, and clay, forms a flat-topped fill in almost every valley.

DESCRIPTION

The alluvium is composed of gray, brownish-gray, olive-gray, grayish-orange, and pale yellowish-brown humic silt, sand, and clay. The silt and sand are in well-defined layers that range from 0.5 to 10 inches in thickness. The thickness of the alluvium ranges between 4 and 25 feet and averages about 10 feet.

The lithology of the Piney Creek alluvium varies greatly from arroyo to arroyo, but the diagnostic features are dark-gray color, abundance of humus, silty texture, and steep walls in arroyos. Most of the material is quartz and feldspar; the pebbles primarily are igneous or metamorphic rocks, but where the streams have cut into bedrock, sedimentary rocks are included. In the valleys between hogbacks large blocks of sandstone are common.

Sections 8, 14, 16 and the following section 21 illustrate the typical lithology of the formation.

21. *Section of Piney Creek and pre-Piney Creek alluvium in a stream cut in the SE¼SW¼ sec. 7, T. 7 S., R. 68 W.*

[Measured with tape]

	Feet
Piney Creek alluvium:	
Late Recent soil:	
Soil horizon A_1:	
Silt, grayish-brown (10*YR* 5/2), humic. Structure: platy	0.9
Soil horizon B_2:	
Silt, light yellowish-brown (10*YR* 6/4), clayey. Structure: prismatic, weathers blocky. Consistence: sticky, plastic	.9
Soil horizon C_{ca}:	
Silt, very pale brown (10*YR* 7/4); contains 1-in pebbles and a threadlike concentration of calcium carbonate	3.0
Thickness of Piney Creek alluvium	4.8
Pre-Piney Creek alluvium (part):	
Early Recent soil:	
Soil horizon A:	
Silt, olive-gray (5*Y* 5/2), clayey, humic. Structure: strong columnar. Consistence: sticky plastic	.4
Soil horizon BC:	
Silt, very pale brown (10*YR* 7/4); contains some 4-in. stones and one-eighth-in. veinlets of calcium carbonate which are spread at three-eighths-in. intervals throughout deposit. Structure: coarse weak columnar; weathers blocky	6.0
Thickness of pre-Piney Creek alluvium	6.4
Bottom of arroyo.	

Grain size of the alluvium ranges from clay to cobbles; the material is well stratified and stands in vertical banks. Clay, which is generally concentrated near the middle and in the upper parts of the alluvium, is abundant enough to cement some beds of silt to a very hard consistency when dry. The lower part of the alluvium is generally coarser. Rounded pebbles and cobbles as much as 4 inches in diameter are concentrated in thin layers. The alluvium is very well stratified and has a weak, but coarse columnar structure. Where the alluvium is undercut by streams or the bases of columns weakened by saturation in the wet season, columns as large as 6 feet wide by 2 feet thick break away and tumble onto the floors of the arroyos thereby creating temporary dams.

DISTRIBUTION

The alluvium was deposited in late Recent time in arroyos previously cut in most deposits in the area and was deposited as straths or alluvial fans on older straths of Louviers, Broadway, and pre-Piney Creek alluvium. The broadest deposits are in the valleys of South Platte River and Plum Creek, but the valleys of Willow, Little Willow, Indian, Jarre, and Rainbow Creeks contain sizable deposits. The alluvium is preserved as straths or terraces that border almost every valley, no matter how small. It overlies almost every deposit in the area.

The relation of Piney Creek alluvium to pre-Piney Creek and Louviers alluvium in the area is shown in figures 13 and 25 which show a stream cut in the NE¼SW¼NW¼ sec. 16, T. 7 S., R. 68 W., (pl. 1) where Piney Creek alluvium fills a channel cut into pre-Piney Creek alluvium which overlies the Louviers alluvium. The Piney Creek also lies in a channel cut in Louviers alluvium in the NE¼SE¼ sec. 4, T. 7 S., R. 68 W.

Base levels for streams that deposited the Piney Creek alluvium were local, as they are for the modern streams. The alluvium lies in small perched valleys where a lip of resistant rock is base level; it lies across older terraces where the edge of the terrace is base level. Consequently such a stream has segments with alluvial terraces and other segments with no alluvium.

The topographic position and the slope of the Piney Creek alluvium vary from valley to valley. The flat surface, or strath, on the alluvium is well preserved either in flat-floored scarp-bordered valleys or as terraces, and occupies almost every valley in the quadrangle. The alluvium lies in a terrace below the pre-Piney Creek terrace along Indian Creek and Rainbow Creek, but overlies a strath of pre-Piney Creek alluvium in the smaller valleys. It lies in a terrace above the level of the post-Piney Creek terrace along Plum Creek and Indian Creek but is overlain by post-Piney Creek alluvium in the smaller valleys. The terrace on the Piney Creek alluvium is 15 to 20 feet above the modern streams (fig. 22) and its slope is almost parallel to their gradient. The terrace slope ranges from 900 feet per mile along short segments along the flank of the mountains to 25 feet per mile along the South Platte River on the plains.

UNCONFORMITY BENEATH THE PINEY CREEK ALLUVIUM

Trenches were cut along most valleys sometime after the development of the early Recent soil. Along the South Platte River and Plum Creek these trenches are broad and shallow; along the small valleys they are narrow and deep, and generally have vertical walls and flat floors. Outcrops of Louviers alluvium protrude through these valley walls. This valley system was very extensive—considerably greater than the system of modern arroyos.

FOSSILS

Vertebrate fossils are abundant in the Piney Creek alluvium. Many of the bones are articulated and form complete parts such as a complete leg, a complete upper jaw and skull, or a skull and four vertebra. In most other alluvial units only pieces of bones are found. *Bison bison* is the most abundant of the vertebrates and was found at localities 132, 133, and 136. In a 1-mile section of arroyo, as many as 8 specimens of *Bison bison* have been found.

Invertebrate fossils generally are scarce. Two collections were made at localities that apparently were more favorably situated for the growth of mollusks. One of these (loc. 131) was from a deposit near a spring; the other (loc. 138) was from a deposit downstream from some seeps in the Dawson arkose. These mollusks are listed in the following table.

The mollusks from locality 138 suggest a climate much like that of today along the Front Range, but possibly with slightly cooler summers (see table 2 for comparison with other assemblages). All the species are living in Douglas or adjacent counties today. *Columella alticola* has been collected only from an altitude of 10,000 feet in the Pikes Peak area. The fossil *Lymnaea* in locality 131 indicates a semiaquatic environment.

ARCHAEOLOGY

Artifacts are uncommon in the Piney Creek alluvium although man already had been in the area for several thousand years. A metate was found by C. B. Hunt, of the U.S. Geological Survey, at the base of Piney Creek alluvium where it overlies Louviers alluvium in the NW¼NE¼ sec. 36, T. 6 S., R. 69 W., at the site of a former spring. Pottery was not yet in use in this area at the time of deposition of the Piney Creek alluvium.

ORIGIN

Piney Creek alluvium was derived principally from soil-covered slopes, probably by sheet erosion, and is almost black from contained humic material. Only the post-Piney Creek alluvium contains as much humic material as the Piney Creek alluvium.

Mollusks from Piney Creek alluvium, Kassler quadrangle

[Identifications by D. W. Taylor and C. C. Cameron. Arranged according to Thiele (1931). cf., not certainly identified but resembles the species listed; ?, may be the species listed]

Species	Locality			
	130	131	138	140
Carychium exiguum (Say)	×	-----	-----	-----
Lymnaea caperata Say	-----	×	-----	-----
palustris (Müller)	-----	×	-----	-----
parva Lea	×	-----	-----	-----
Gyraulus parvus (Say)	-----	×	-----	-----
cf. *Succinea avara* Say	×	-----	-----	-----
cf. *Succinea*	-----	×	×	×
Columella alticola (Ingersoll)	-----	-----	×	-----
Pupilla muscorum (Linné)	×	-----	×	-----
sp	-----	×	-----	-----
Pupoides albilabris (C. B. Adams)	-----	-----	×	-----
Gastrocopta armifera (Say)	-----	-----	-----	×
holzingeri (Sterki)	×	-----	-----	×
tappaniana (C. B. Adams)	×	-----	-----	-----
Vallonia cyclophorella Ancey	×	-----	×	-----
gracilicosta Reinhardt	×	cf	×	×
parvula Sterki	-----	-----	×	×
Hawaiia minuscula (Binney)	×	-----	×	×
Zonitoides arboreus (Say)	×	-----	-----	×
Euconulus fulvus alaskensis (Pilsbry)	×	-----	-----	-----
Oreohelix	-----	-----	-----	?
Pisidium sp	×	-----	-----	-----

Deposition of the whole column of alluvium apparently was accomplished quickly. One line of evidence comes from the mollusks which are uncommon in the alluvium, although the flood plain is ordinarily the most favorable environment in an arid region. There probably was not time for them to colonize on the flood plain between floods; furthermore, remains of vertebrates generally are articulated and suggest that the animals may have been swept away and drowned by a flood. Again the abundance of humic alluvium indicates that the streams did not have stable regimens resulting from a perennial supply of water, but were subject to cyclic dryness and flood. The only suggestion of a period of stability comes from a soillike profile near the middle of the alluvium at several outcrops.

The Piney Creek alluvium probably is about 2,800 years old. This is the radiocarbon age of charcoal submitted by G. M. Richmond from a correlative of the Tsegi alluvium (Hack, 1942) in the La Sal Mountains of Utah (W–143, Rubin and Suess, 1955, p. 484).

SOIL OF LATE RECENT AGE

A soil of late Recent age is weakly developed on the Piney Creek alluvium. The soil is developed in a Brown soil facies except at altitudes above 6,000 to 6,500 feet where it is acid and apparently azonal, for zonal horizons could not be detected. This is the soil that is most commonly exposed at the earth's surface, but along Willow Creek and many other streams it is buried under a few inches of unmapped post-Piney Creek alluvium.

The late Recent soil is made up of the A_1, B_1, B_2, and C_{ca} horizons (see sections 8, 14, 16, and 21). The A_1 horizon of the Brown soil is dark grayish brown, humic, and 10 inches or more in thickness; it has a platy structure unlike the prismatic structures of A horizons of older soils.

The B horizon locally can be divided into two subhorizons, the B_1 which is transitional between A and B but more like B, and the B_2 or typical horizon of illuviation. The B_1 is almost identical with the B_2 horizon which is dark grayish brown or yellowish brown (fig. 4) and generally has a clayey texture, medium weak prismatic structure, a sticky, plastic slightly hard consistence, a slightly acid reaction where exposed at the surface, and a moderately alkaline reaction where buried under younger calcareous alluvium. Where only the B_2 horizon was present, the thickness is about 10 inches; where both the B_1 and B_2 horizons are present, the thickness is about 14 inches.

The C_{ca} horizon is a very pale brown weak floury concentration of calcium carbonate about 4 to 6 inches in depth, which is most evident on the joints or faces of peds, but the insides of peds also are moderately alkaline in reaction. Near a local source of calcium carbonate, the C_{ca} horizon may extend as deep as 3 feet into parent material.

POST-PINEY CREEK ALLUVIUM

The post-Piney Creek alluvium, a grayish-brown loose humic sand, includes the alluvium in both the lowest terrace and the flood plain.

The terrace alluvium is finer grained than the flood-plain alluvium and more heterogeneous in composition. The alluvium in the low terraces consists of grayish-brown fine- and medium-grained humic sand, and layers of black magnetite-rich sand. The sand is in layers 3 to 12 inches thick, locally crossbedded. It has a nonsticky, nonplastic, loose consistence and weak columnar structure. It generally stands in vertical banks 3 to 10 feet high despite its lack of clay and silt. Stones as large as 12 inches in diameter can be found in the alluvium. Roots and branches of trees are very abundant in the alluvium along Indian Creek and Plum Creek.

The alluvium in the stream bottoms is considerably coarser than the alluvium in the low terraces because fine particles are washed away and coarse particles are concentrated. Along the South Platte River the alluvium ranges in size from ¼-inch pebbles to 12-inch boulders. Along Plum Creek the alluvium consists of coarse sand with some pebbles and cobbles. The floor of most arroyos is paved with a matrix of sand set with pebbles, cobbles, and boulders. The thickness of sand was measured in a trench dug across the bottom of an arroyo in the SE¼ sec. 4, T. 7 S., R. 68 W. The thickness, which probably is typical of small arroyos, is only 1½ feet to 3½ feet (fig. 15).

DISTRIBUTION

The alluvium is confined to the valleys of the South Platte River and Indian and Plum Creeks and consists of low terraces that lie below the terrace of Piney Creek alluvium. One-half mile north of the Kassler quadrangle on Plum Creek the alluvium makes two terraces and forms the stream bottom (fig. 16). The upper terrace is about 12 feet above the stream and the lower terrace about 3 feet above the stream. Along Indian Creek these two terraces are respectively 10 feet and 2 feet above the arroyo floor. Along the smaller valleys, where arroyos had not been eroded, the alluvium overlies Piney Creek alluvium. Post-Piney Creek alluvium includes the alluvium in both these lowest terraces and in the flood plain.

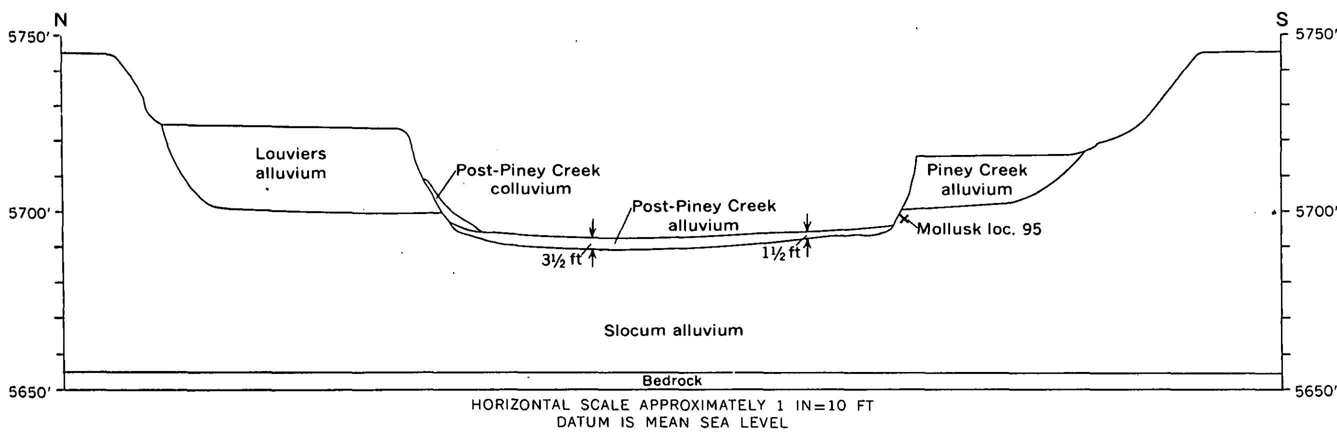

FIGURE 15.—Cross section of arroyo in SE¼ sec. 4, T. 7S., R. 68W., showing topographic relations of Recent to Pleistocene deposits. The base of the channel was exposed in a trench dug from bank to bank. The Slocum alluvium was more than 91 feet thick in an auger hole one-fourth mile to the north.

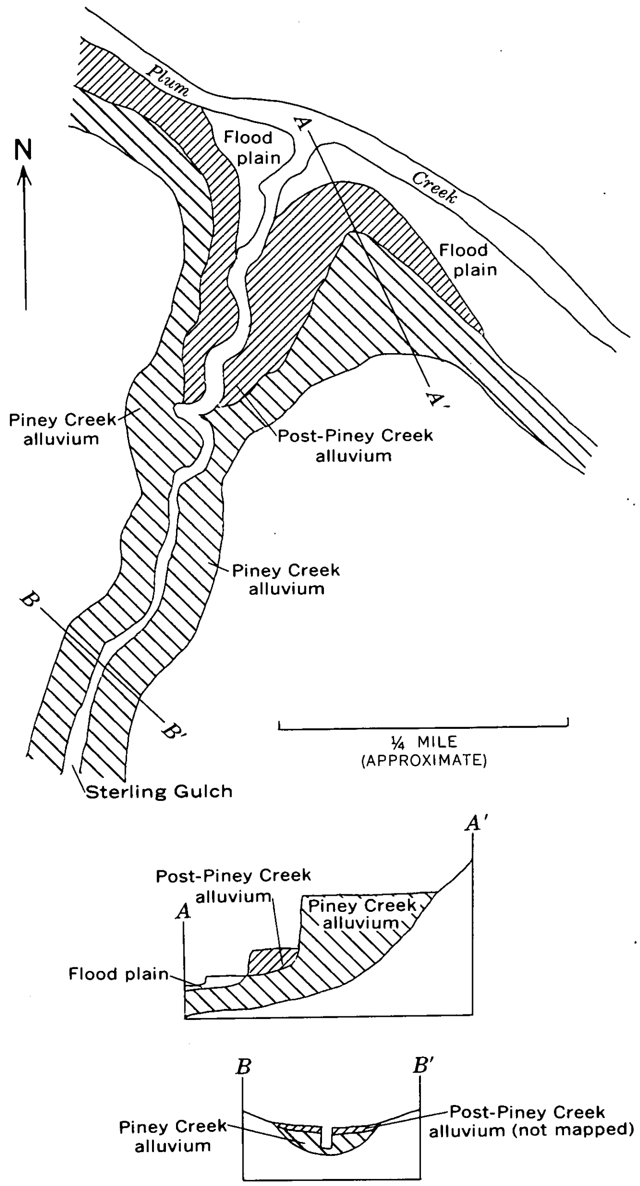

FIGURE 16.—Recent terraces at junction of Sterling Gulch and Plum Creek, SW¼SE¼ sec. 20, T. 6 S., R. 68 W., Littleton quadrangle, Colorado.

UNCONFORMITY BENEATH THE POST-PINEY CREEK ALLUVIUM

Shallow broad valleys were cut into the Piney Creek alluvium in late Recent time along the South Platte River and Plum Creek. The trenches were 8 to 15 feet deep and post-Piney Creek alluvium was concentrated on their floors. Channels extend up tributaries like Willow Creek and Indian Creek a mile or two, but generally were not cut in smaller tributaries.

FOSSILS, ORIGIN, AND AGE

Bones and artifacts are fairly common in the post-Piney Creek alluvium. Bones of *Bison bison* and *Odocoileus hemionus* (mule deer) are most common. In addition to these two species, *Thomomys* sp. was collected at locality 137. In a small deposit of post-Piney Creek colluvium at a spring (loc. 139) in the NW¼NE¼ sec. 36, T. 6 S., R. 69 W., bones of camel, mammoth, horse, and bison reworked from Louviers alluvium are mixed with pottery and artifacts of the Woodland culture and with nails, wire, and pipe of the early settlers. Artifacts and pottery of the Woodland culture also were found in the post-Piney Creek alluvium at a site (loc. 137) in the SE¼SE¼ sec. 11, T. 7 S., R. 69 W., where charcoal is so abundant that the alluvium is almost black. Projectile points, scrapers, choppers, metates, manos, bone awls, dark-gray pottery, and fragments of bones were found at this site.

The alluvium was derived mostly from the Piney Creek alluvium, but partly from older alluvium and bedrock and was deposited very close to its source by ephemeral streams. Sand is abundant because silt and clay was winnowed out. The coarse alluvium in the stream bottoms is a lag concentrate left after the finer alluvium was washed away by torrential floods.

The post-Piney Creek alluvium is late Recent in age and correlates with the protohistoric and historic alluvium of Hunt (1954, p. 117) and the post-Piney Creek alluvium of Malde (1955, p. 244–246). A radiocarbon age determination of charcoal from the archaeological site in sec. 11, T. 7 S., R. 69 W., was made by Meyer Rubin (W–289, Rubin and Suess, 1956, p. 446) and gave an age of 1,490±160 years before the present.

DIFFERENTIATION OF THE PRE-PINEY CREEK, PINEY CREEK, AND POST-PINEY CREEK ALLUVIUM

Differentiation of the pre-Piney Creek, Piney Creek, and post-Piney Creek alluviums is difficult; only the first two have soils developed on them. Piney Creek and post-Piney Creek alluviums may be confused because both are very humic, and where late Recent soil developed on Piney Creek alluvium lacks distinct structure, it is similar to the humic layer at the grass roots of the post-Piney Creek alluvium. The three alluviums can be separated most satisfactorily where each forms a terrace. The relation of the terraces to the alluviums can be seen in the general diagram of figure 22 and in figure 16 which shows the Piney Creek and post-Piney Creek alluviums at the junction of Sterling Gulch and Plum Creek in the Littleton quadrangle. The post-Piney Creek alluvium nearly always consists of loose sand with many tree branches and roots that are lacking in the older alluvium. The pre-Piney Creek alluvium is tan or reddish brown in contrast to the Piney Creek alluvium which is gray.

The presence of pottery in alluvium is diagnostic for differentiation, for only the post-Piney Creek alluvium contains pottery. The absence of pottery is not as helpful because camp sites are not abundant, and in a short occupation pottery might not be broken or left behind. The stone artifacts in the three alluviums are so similar that only large collections are helpful in differentiating the alluviums.

The chronology of the late Recent alluviums was demonstrated by Hunt (1954, p. 114) at the type locality of the Piney Creek alluvium on Piney Creek near Parker, Colo. (fig. 1). There the alluvium is dissected so that its characteristic terrace form is obliterated. Arnold Withers had identified a Woodland Culture site in sand overlying this dissected terrace; so Hunt made this the type locality of his Piney Creek alluvium and correlated it with the alluvial Tsegi formation of northeastern Arizona and with the Kuner terrace (Bryan and Ray, 1940, p. 26) of the Greeley area, Colorado. At the type locality, the Piney Creek terrace is buried by more than 3 feet of post-Piney Creek sand in which artifacts including pottery were found. At this type locality, therefore, Hunt demonstrated the chronology of the two most recent alluviums in the Denver area; they are the silty humic Piney Creek alluvium and the sandy humic post-Piney Creek alluvium that contains a Woodland culture.

LOESS AND EOLIAN SAND

Small, thin unmappable deposits of loess and eolian sand were observed at several places. Although this unit was not mapped, two outcrops will be described because of their stratigraphic importance in dating local archaeological cultures.

Pale-brown fine-grained loose, indistinctly crossbedded eolian sand overlies the Lyons sandstone in the NE¼SW¼ sec. 30, T. 7 S., R. 68 W. It was blown from weathered Lyons sandstone and deposited as hummocky low dunes only a few hundred feet from its source. Section 22 was measured at the above locality, which was the site of a Woodland camp.

22. *Section of eolian sand in a small arroyo in the NE¼SW¼ sec. 30, T. 7 S., R. 68 W.*

[Measured with tape]

	Feet
Eolian sand:	
Modern incipient soil:	
Soil horizon AB:	
Sand, pale-brown (10*YR* 6/3), fine-grained.	
Structure: indistinctly crossbedded.	
Consistence: nonsticky, nonplastic, loose.	
Reaction: medium acid.	
Boundary: clear.	
Topography of boundary: irregular	1.0
Soil horizon C:	
Sand, gray (10*YR* 5/1), fine-grained, humic, lenticular; contains dark-gray pottery, projectile points, stone flakes, scrapers, manos, metates, and fire-blackened stones and charcoal in closely spaced hearths. Contains a few animal burrows; one bone found.	
Structure: structureless.	
Consistence: nonsticky, nonplastic, loose.	
Reaction: slightly acid.	
Boundary: gradual, but broken as a result of human occupation at different levels during deposition of sand	2.0
Sand, pale-brown (10*YR* 6/3), fine-grained. Hearths are interbedded in sand at intervals of 3 to 4 feet horizontally and range vertically from position on Lyons sandstone to top of occupation layer described above. Most stones in hearths are limonitic sandstone from Lyons; a few are metamorphic gneiss.	
Structure: weakly bedded.	
Consistence: nonsticky, nonplastic, loose.	
Reaction: slightly acid	3.3
Thickness of eolian sand	6.3
Nonconformity.	
Lyons sandstone:	
Sandstone, grayish-orange (10*YR* 7/4), friable, fine-grained.	

Loess overlies Rocky Flats alluvium in the NW¼ NW¼ sec. 4, T. 8 S., R. 68 W. The loess is about 10 inches thick and is composed of brown humic silt which is slightly sticky, nonplastic, and soft. It probably was derived from Piney Creek or post-Piney Creek alluvium and deposited as a thin blanket on top of the highest pediment in the area. Both the sand and loess were deposited by wind probably at times of slightly greater aridity.

One leg bone, apparently from a mule deer, was found in the eolian sand. Artifacts were found in both the eolian sand and the loess. Pottery from the loess is slightly younger than the pottery from the eolian sand. The younger pottery (referred by Withers to the Franktown focus) is light gray, and the jars have shallow diagonal corrugations and deep vertical corrugations. The older pottery (referred to the Parker focus of the Woodland culture) is dark gray and has deeply impressed vertical corrugations. Part of an older pottery clay jar almost 2 feet high and 1½ feet in diameter was found in the eolian sand. The walls of the jar range in thickness from ⅛ to ¼ inch, very thin for so large a jar. The stone artifacts in the sand and loess are similar, but some projectile points from the loess are side notched and resemble points from the Upper Republican culture (table 1). Charcoal taken from the pottery jar in the eolian sand was dated by Rubin

(W–290, Rubin and Suess, 1956, p. 446) as 1,360±200 years old, an age which is in agreement with the range of the ceramic Woodland culture. Charcoal from hearths in the loess was dated by Rubin (W–1018) as 900±250 years. According to Withers the cultural material from the Franktown focus is transitional between the Woodland and upper Republican cultures.

VALLEY CUTTING IN HISTORIC TIME

Arroyo cutting started in the lower reaches of streams in the Kassler area about A. D. 1900. According to ranchers in the area it was accompanied and aided by fires along the mountain front that stripped off the vegetative cover that normally retains the rainwater.

Arroyos are more extensive now than they were before the post-Piney Creek alluvium was deposited. Modern shallow wide valleys are cut along the South Platte River and Plum Creek. Along major tributaries like Willow and Indian Creeks, arroyos extend upstream to the mountain front. Along smaller tributaries arroyos are nearly continuous to their headwaters.

Depths of arroyos range from 10 feet in post-Piney Creek alluvium to 25 feet in the thicker Piney Creek alluvium.

ORIGIN OF THE LANDFORMS

The landforms are high level surfaces of Tertiary age, and pediments, terraces, and valleys of Quaternary age (fig. 17). The physical features of the landforms will be summed up briefly here in connection with a discussion of their origin. Some of the evidence for the depth of valley cutting is from stream valleys outside the quadrangle. The landforms are primarily the result of stream action, but hydrothermal alteration along faults, Quaternary weathering, and overgrazing and forest fires were also factors. More than 5½ billion cubic yards or about 1 cubic mile of consolidated and unconsolidated rock was removed from the Kassler quadrangle since the earliest Pleistocene pediment was cut.

GEOMORPHIC CYCLE

The landforms are a result of a series of erosional and depositional events called the geomorphic cycle. The geomorphic cycle is defined in this report as the events that take place within a single cycle of erosion and deposition rather than, in the broader concept, as all events between upheaval of the land and nearly complete reduction to base level. In the broader concept the geomorphic cycle started as a result of uplift; in the more limited geomorphic cycle as defined here, all events are believed to result from climatic change, even though minor uplift may have been taking place.

The cyclic nature of deposits in the quadrangle, indicates that changes in climate, particularly in temperature and precipitation, came in cycles through Quaternary time. The direction of change in climate was the same in one cycle as in the next; therefore, the cycles were repetitive but were not exact duplicates because the intensity and duration of climatic events varied from one cycle to the next.

Just as the climatic events in the cycles were repetitive, so were the resultant physical processes in the quadrangle in each geomorphic cycle. The ultimate effect of the processes in each cycle was controlled by climate, altitude, and time. Each geomorphic cycle was made up of five processes, in chronologic order: downward stream cutting, sideward stream cutting, alluviation, wind erosion and deposition, and soil formation. Table 3 shows the relation of these processes to changes in temperature, precipitation, discharge, and load.

The general effect of each geomorphic cycle was to force the streams to a lower stable base level where they stayed until similar climatic changes generated the next geomorphic cycle.

The number of geomorphic cycles was determined from alluvial deposits in the quadrangle because alluvium was deposited during every cycle and generally was well preserved. Table 1 shows eight geomorphic cycles completed and part of another cycle, historic valley cutting, still in progress. The absence of a particular deposit of any process on the table does not mean that the process was inactive but that it was not vigorous enough to create a part of the stratigraphic record. The last column of table 1 shows some significant events in the history of life.

Climate cyclically changed from hot and dry to cold and wet. The relation of climatic fluctuations to the surficial deposits that lie in the range of the radiocarbon-dating method (from Wisconsin time to the present) are graphed in figure 19. The dates are based on radiocarbon age determinations. The times of maximum wetness are correlated with downward stream cutting, whereas the times of maximum dryness are correlated with the deposition of loess or windblown sand.

The interrelation of the physical processes with temperature, precipitation, discharge, and load will be interpreted for a typical geomorphic cycle, the cycle of which the Slocum alluvium is one product: In the interval preceding downcutting (the first process in the geomorphic cycle), climate had been stable for a long time, streams were at grade, slopes were stable enough

TABLE 3.—*Relation of physical processes in the quadrangle to temperature, precipitation, discharge, and load*

[Order of events from bottom to top of table]

Order of events	Physical process	Temperature	Precipitation	Discharge	Load
1	Downward stream cutting	Coldest	Wettest	Increased	Increased.
5	Soil formation	Still warm	Moister	Small-balanced load, streams at grade.	
4	Wind erosion and deposition	Warmest	Driest	Decreased	Decreased.
3	Alluviation	Warming	Drying	Decreased	No change.
2	Sideward stream cutting	Warming	Drying	Decreased	Increased.
1	Downward stream cutting	Coldest	Wettest	Increased	Increased.
5	Soil formation	Still warm	Moister	Small-balanced load, streams at grade.	

that a Yarmouth(?) soil was able to form. Then the climate became colder and wetter, and, coincident with the onset of glaciation in the mountains, discharge and load increased but discharge overbalanced load and caused streams in the plains to cut downward about 150 feet between the middle and youngest pediments. Downward cutting continued until the climate became warmer and drier and load began to overbalance discharge; by then the major streams on the plains had nearly reached the lower base level that lasted until the next cycle. Mountain streams continued to cut downward throughout the geomorphic cycle because erosion of the crystalline rocks could not quite keep up with the erosion of the sedimentary rocks. Sideward cutting of the pediment beneath the Slocum alluvium began along the major streams in the plains and worked headward up the smaller streams. During lateral cutting streams left a thin veneer of alluvium that frequently was reworked and added to by flash floods. As the climate became warmer and rainfall decreased, load continued to overbalance discharge because the steep-gradient mountain streams carried in outwash that the low-gradient plains streams could not carry away; Slocum alluvium then was deposited (apparently in interglacial time as indicated by warmth-loving mollusks in it) in broad sheets that backfilled the small valleys, covered the pediments, and smoothed out many of the topographic irregularities left by meandering streams. When the climate became the warmest and driest of the cycle and the discharge and load became the smallest, these broad alluvial plains, with practically no vegetation, were easily deflated by the southeast wind which swept silt into the air and deposited it in broad sheets as the geologic unit, older loess. After a subsequent increase in moisture, the climate became stable, streams in the plains attained grade, and a Sangamon(?) soil was able to form. Between the formation of the Sangamon(?) soil and the downcutting at the start of the next cycle, the climate became cooler and runoff increased, stream grade was disturbed, mass wasting commenced, and soil formation was greatly hindered. As streams began to cut downward again, a new geomorphic cycle was started.

The overall result of the foregoing processes is a landscape marked by gently sloping surfaces at three topographic levels: (1) the high, poorly preserved pre-Pleistocene surfaces cut on Precambrian rocks of the Front Range, (2) the intermediate, well-preserved early Pleistocene pediments cut on sedimentary rocks at the mountain front, and (3) the low, well-preserved late Pleistocene fill terraces (fig. 22).

TERTIARY LANDFORMS

Tertiary landforms consist of remnants of two ancient high-level surfaces. They originally were called peneplains by Lee (1917, p. 28), but later were considered by Mackin (1947) to be pediments, and are simply called surfaces in this paper.

The Flat Top surface (Lee, 1917, p. 28) is the highest and oldest of the two; it is not preserved in the quadrangle. The alluvium that originally overlay the Flat Top surface is correlated with the Castle Rock conglomerate, which is equivalent to the Chadron sandstone (lower part of White River group of early Oligocene age) of Nebraska. By this correlation the Flat Top surface would be of early Oligocene age; this age is very close to the estimates of Van Tuyl and Lovering (1935), Little (1925), and Mather (1925).

Remnants of the younger of the two high-level surfaces are preserved as flat, gently sloping spurs and knobs on the Precambrian rocks in the western part of the quadrangle and in the adjoining Platte Canyon quadrangle (figs. 17 and 18). This younger surface, which is probably part of an ancient pediment, lies about 7,500 to 8,000 feet above sea level and is considered to be part of the Rocky Mountain surface described by Lee (1917, p. 28) and shown on figures 17 and 18 of this report. No alluvium was found on this surface in the Kassler quadrangle, but alluvium composed of cobbles and boulders is known to cover the surface locally in the Indian Hills quadrangle, the

FIGURE 17.—View of Roxborough Park and surrounding area. Highest pediment is in foreground overlain by Rocky Flats alluvium. Pediment truncated hogbacks of Dakota group and Fountain formation, and made faceted spurs along mountain front. Lowest pediment is at center right. Rocky Mountain surface lies west of South Platte River. Valleys of Willow Creek, Bear Gulch, and Cottonwood Gulch west of river are along faults.

Platte Canyon quadrangle, and the Pine quadrangle, all of which lie north or west of the Kassler quadrangle.

Alluvium on the Rocky Mountain surface is correlated with the Ogallala formation of Pliocene age that mantles the High Plains. The surface on which the alluvium rests is probably the same age inasmuch as each surface should have a corresponding alluvial deposit (Lee, 1922, p. 15–17). Large deposits of coarse alluvium of the Ogallala formation underlie the plains east of the mountains. Deposition of this alluvium required considerable erosion in the mountains; the surfaces from which the alluvium was eroded and across

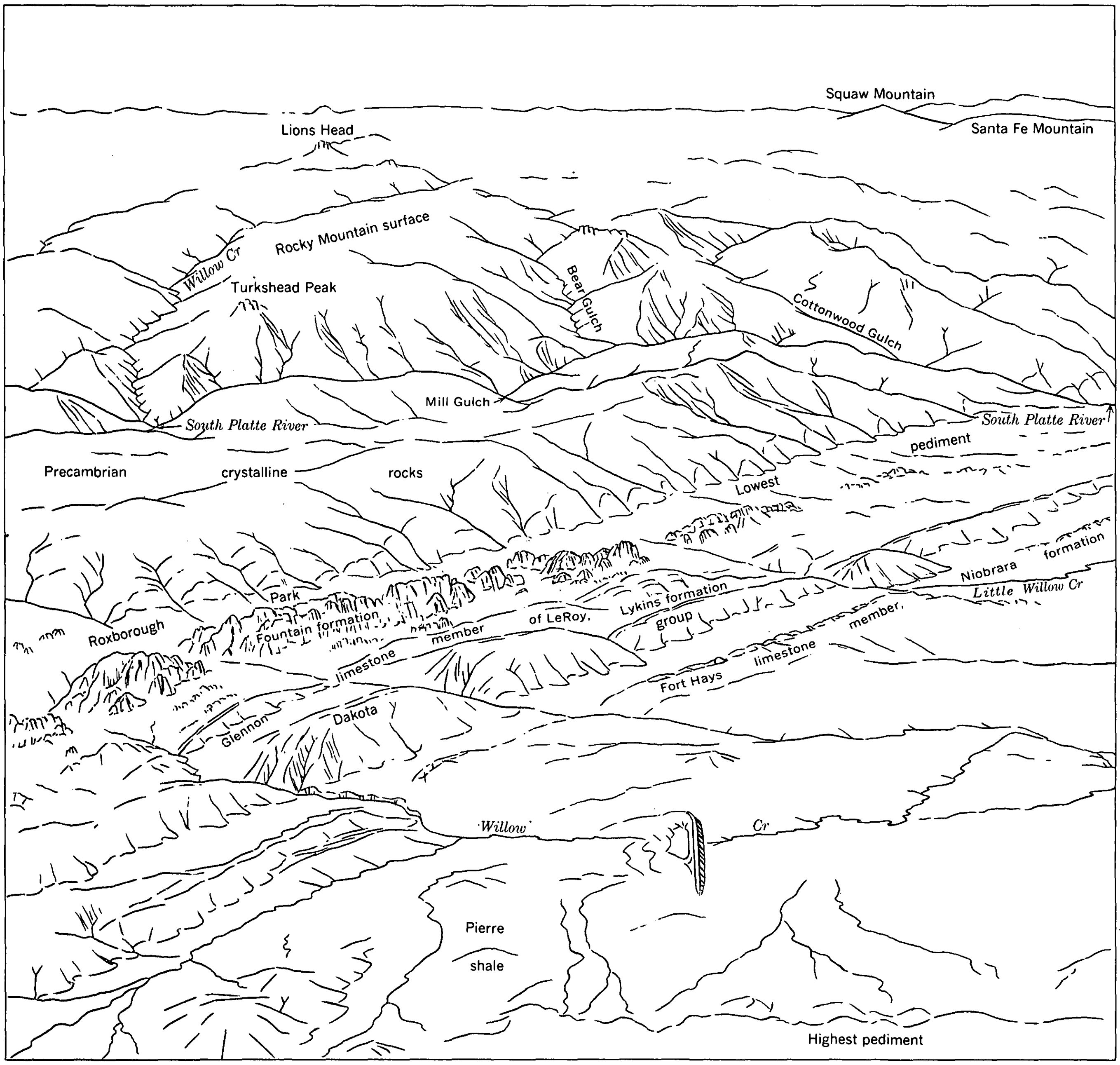

FIGURE 18.—Generalized line drawing of area shown in figure 17.

which it was carried are probably still preserved. Projection of the surface of the Ogallala formation from the plains near Calhan, Colo. (fig. 1), 50 miles southeast of the Kassler quadrangle to the Front Range, shows that a slope of only 35 feet per mile would bring the Ogallala onto the Rocky Mountain surface. No major surface between the highest pediment under the Rocky Flats alluvium and the Rocky Mountain surface is known, and no major alluvium between the Rocky Flats alluvium and the Ogallala formation is known; therefore the Ogallala formation is probably the alluvium that resulted from the cutting of the Rocky Mountain surface, and the Rocky Mountain surface must be of Pliocene (probably early Pliocene) age.

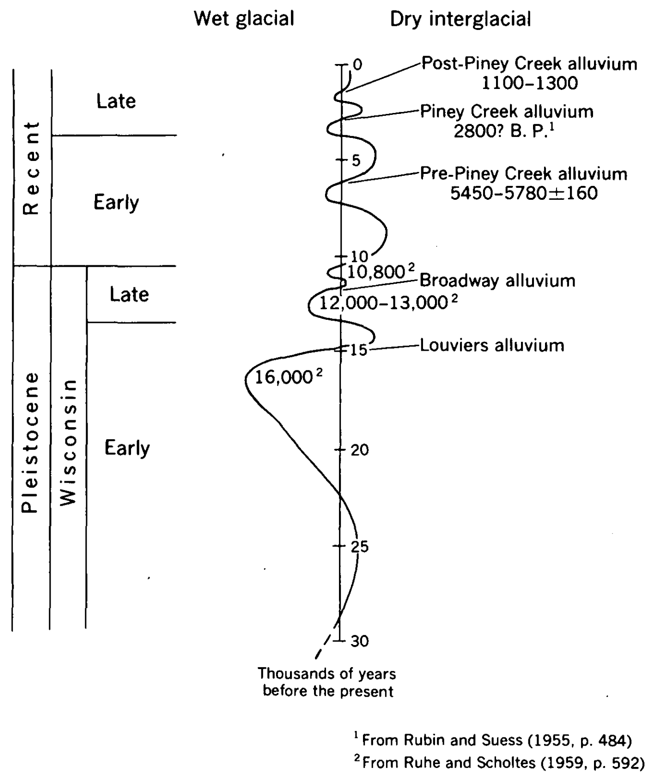

FIGURE 19.—Graph of late Quaternary climatic cycles and related deposits, based on radiocarbon dates. Curve shows interpretation of degree and duration of wetness and dryness.

QUATERNARY LANDFORMS

Quaternary landforms are pediments, terraces with discontinuous arroyos, and valleys. Pediments were cut in early Quaternary time, terraces in late Quaternary time, and valleys throughout Quaternary time.

PEDIMENTS

Pediments of three levels are well preserved at many places along the mountain front in the quadrangle (fig. 20). Block diagrams in figure 21 show the sequence of formation of pediments beneath the Rocky Flats alluvium, the Verdos alluvium, and the Slocum alluvium of the Kassler quadrangle. They are correlated with other pediments of the Front Range region on table 4. The relation of these pediments to the Rocky Mountain surface, to Wildcat Mountain, and to each other is shown on figure 22. Although Wildcat Mountain rises above the highest pediment and may be a remnant of an old erosional surface, no surface is preserved on it and it cannot be identified with an older surface.

An earlier pediment, which lies outside the quadrangle, was not formed or is not preserved in the Kassler quadrangle, but, because of its bearing on the geomorphology, its topographic position and relation to the younger pediments are summarized briefly here. This old alluvium-covered pediment is well preserved near Plainview (fig. 1) between Coal Creek and South Boulder Creek north of Golden, Colo., where it lies about 100 feet above the surface of Rocky Flats in sec. 5, T. 2 S., R. 70 W. This slight difference in elevation means that it is only slightly older than Rocky Flats, but probably also of Nebraskan age. Because of its great age, remnants of it are even fewer than of the three younger pediments.

I examined the Mount Morrison berm (Van Tuyl and Coke, 1932) near Morrison, Colo., which I had suspected to be another remnant of a pre-Rocky Flats pediment, and found it to be not a pediment at all, but a structural bench controlled by overturned, almost flat-lying beds of the Fountain formation. The berm lacks a typical pediment-gravel veneer. It apparently is not related to any widespread cyclic geomorphic surface, and therefore its identification as part of a sequence of Front Range physiographic surfaces should be abandoned.

Pediments in this area were formed mainly by the process of sideward stream cutting or lateral corrasion (fig. 23). Lateral corrasion reached its maximum effectiveness when streams stopped cutting downward in each cycle and a balance was approached between carrying capacity and load. As sediment was deposited at slack points such as point bars along a stream or at junctures of tributaries, irregularities developed along the banks and the stream was forced sideward against its valley walls. After it removed any accumulated slope wash, the stream cut into bedrock along the outer arcs of its meanders. The meanders of the stream acted as a slow sharp knife that cut a slice off the valley wall as the meanders migrated downstream like a standing wave in a rope. Most of the streams impinged on bedrock in both banks as they meandered across their valleys.

Some streams, however, impinged on only one bank; for instance, most of the modern streams flowing into the South Platte River from the south have been moving northeastward and cutting into their southwest-facing valley walls. The southwest-facing valley walls are steep, and bedrock is exposed in many places even along the smaller streams. The northeast-facing valley walls are gently sloping and most of them have a cover of loess. One possible reason for the streams' being pushed northeastward is that more alluvium and col-

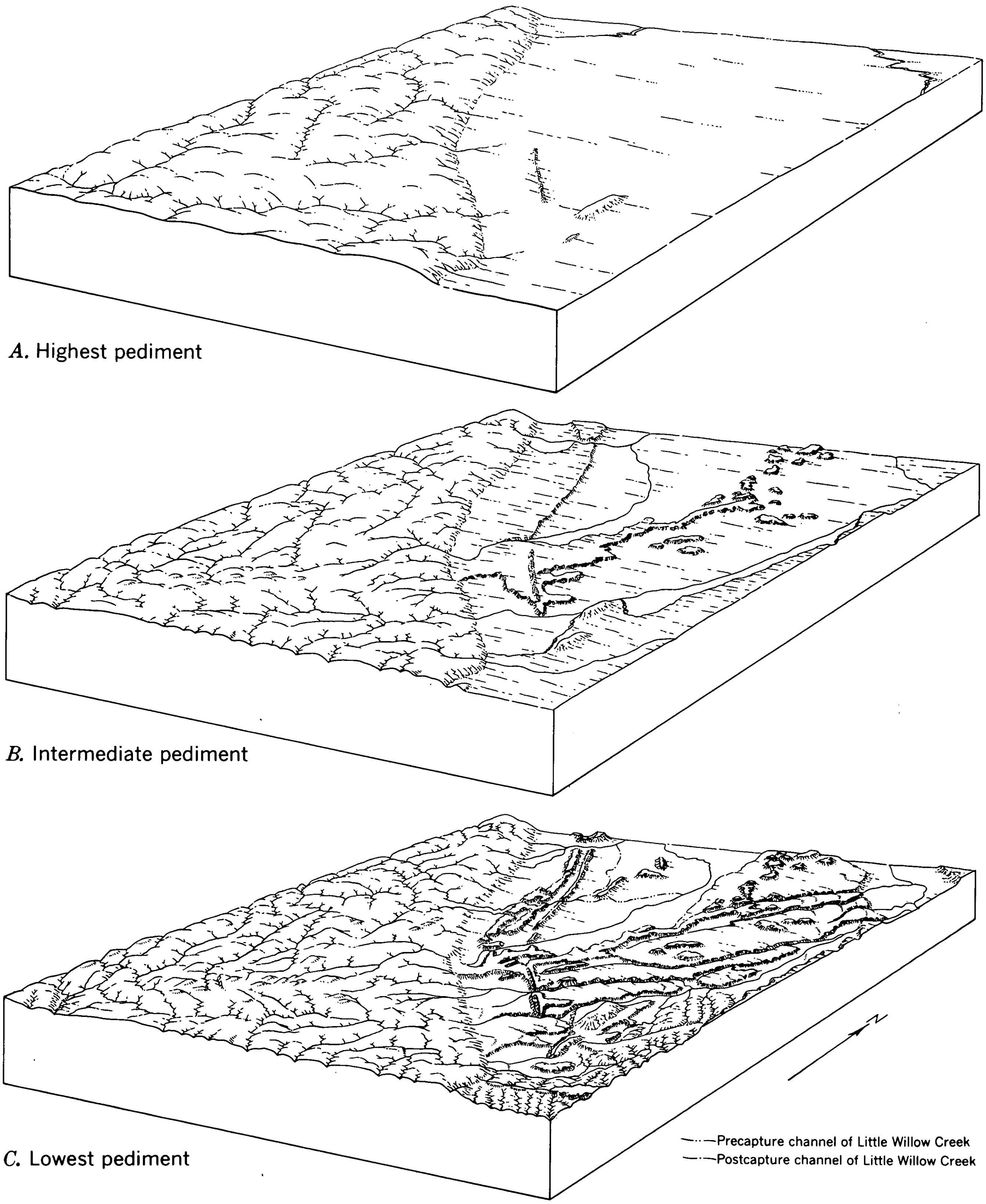

FIGURE 21.—Generalized block diagrams of the Kassler quadrangle showing evolution of the pediments (*A*, highest; *B* intermediate; *C*, lowest) and a minor drainage change of Little Willow Creek.

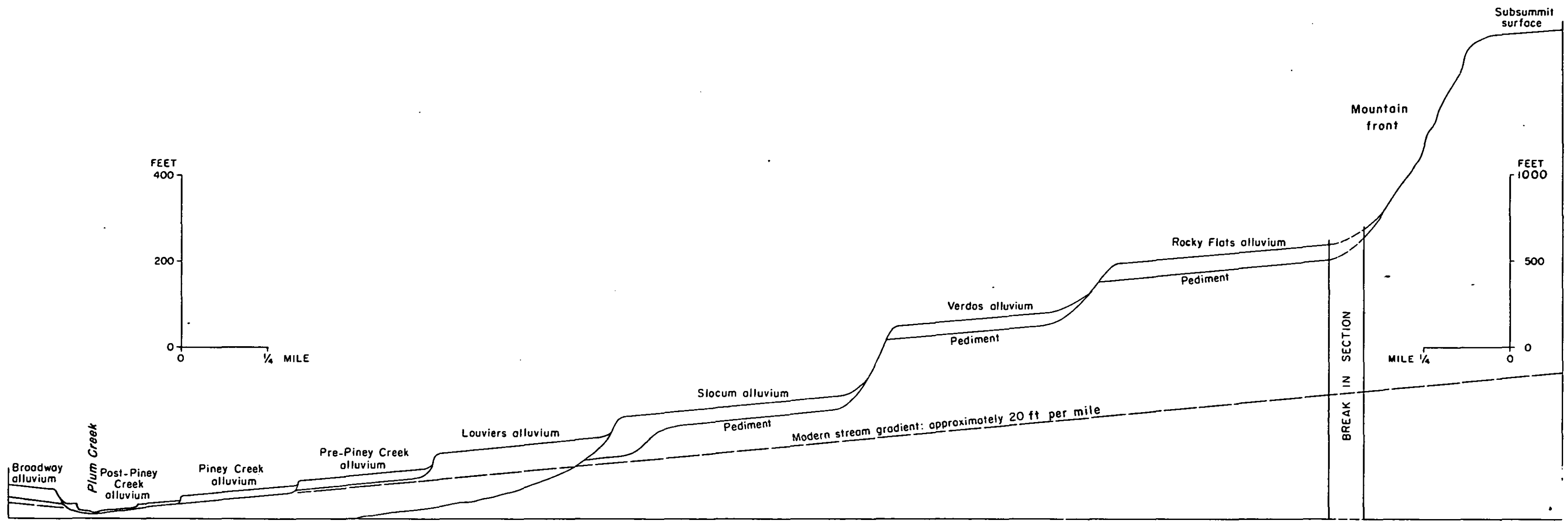

FIGURE 22.—Diagrammatic east-west cross section showing topographic relations of the deposits to the surfaces.

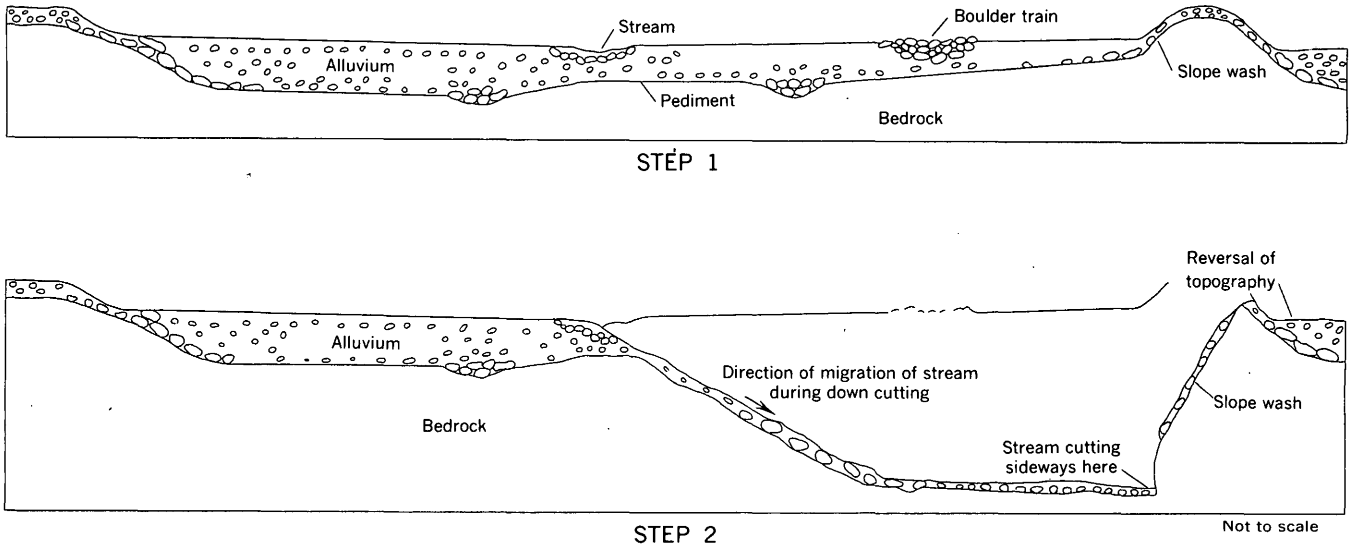

FIGURE 23.—Cross sections showing cutting of pediments by a stream flowing perpendicular to the mountain front. In step 1 the stream is at grade. The boulders were concentrated by slope wash near bedrock prominences, and by the stream during flash floods. In step 2 a new geomorphic cycle is in progress. The stream has cut downward and is now cutting sideward into bedrock. The old alluvial deposit of a stream off the right end of step 2 is now perched on a divide as a result of a reversal of topography. If sideward cutting were to continue toward the right and the divide were breached, a drainage diversion would take place between the two streams.

South Platte River, are now controlled by local base levels, such as bedrock obstructions, that will remain until master base level has stabilized for a length of time sufficient for these obstructions to be reduced to grade line. During cutting of the highest pediment—the most widespread and most nearly perfect Pleistocene pediment—many streams in the area, even some mountain streams, attained profiles of equilibrium. Not since that time has this condition again been so nearly attained. The youngest pediments were the smallest in extent, although they now are more extensive owing to erosion of the older pediment (see fig. 24). The Verdos and Slocum pediments show many signs that they were of local extent (see fig. 23); each covered a little less area than the preceding one, and small reversals of topography are easy to find in both pediments. As each cycle of pedimentation ended short of completion and with geographically restricted pediments (fig. 21), the streams were entrenched in an alluvium-filled channel near the top of a pediment. Later, during the process of alluviation, this channel was filled and the pediment covered. At the start of the next geomorphic cycle, streams were flowing on a thick blanket of alluvium (fig. 23), which they had to erode before a new cycle of pedimentation was started.

Streams that cut new pediments across old ones meet greater obstacles than those that cut pediments on irregular soft bedrock. A stream that starts to cut down into a pediment must first move coarse gravel until it reaches bedrock. After the stream has cut down through the gravel and has reached soft bedrock, which can be cut easier than the coarse gravel can be moved,

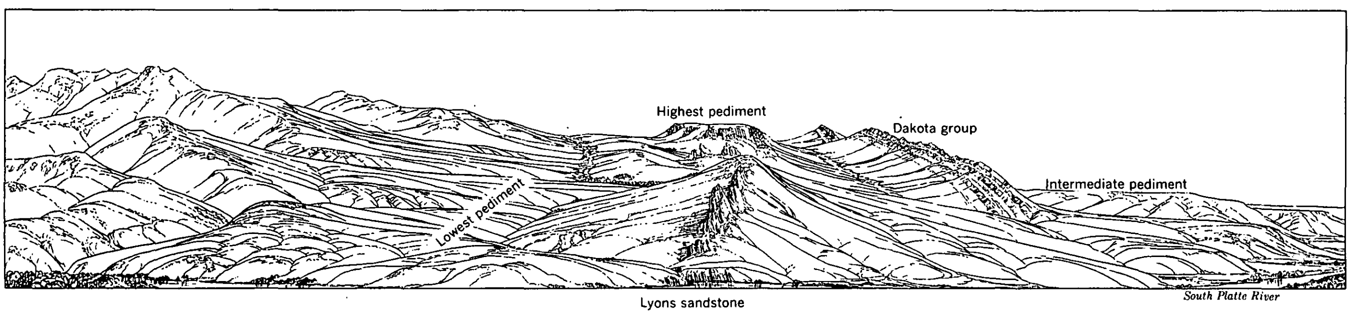

FIGURE 24.—View northward into the Littleton quadrangle across the South Platte River at Kassler showing relation of pediments to each other and to ridges of bedrock. After W. H. Holmes (*in* Hayden, 1873, section III, opposite p. 31).

it cuts downward and sideways through the soft bedrock until it reaches the grade imposed by new local base level (fig. 23). The point at which the stream first reaches grade probably is the site of accumulation of boulders, which later are preserved as a boulder train on or near the surface of the pediment. The stream continues to carry some gravel, because as it erodes bedrock the pediment-gravel cover is undercut and falls into the stream. After reaching grade, the stream cuts laterally into soft rock of the adjoining pediment slopes. The completeness of cutting of the pediment is dependent on the amount of time that the master stream remains at the same base level, on the power of the stream, and on the character of the rock that is being cut.

A stream at grade erodes coarse gravel and soft bedrock easier than it cuts hard bedrock. The places bordered by hard bedrock constrict the stream, whereas the places bordered by soft bedrock are planed. It requires a much longer time to cut a pediment on resistant sedimentary or crystalline rocks than to cut one on soft shale. In the Kassler quadrangle, the Dakota sandstone is so resistant that the smaller streams have not been able to cut downward through it to reach grade, although the same streams have cut small surfaces on the soft Niobrara and Pierre formations.

TERRACES

Terraces are well developed along most streams, but the most complete sets are along the South Platte River and Plum Creek. Along Plum Creek (fig. 22 and pl. 1) the fill terrace of Slocum alluvium lies 70 to 80 feet above the creek, the fill terrace of Louviers alluvium lies 40 to 60 feet above the creek, the fill terrace of Broadway alluvium lies 30 feet above the creek, the fill terrace of Piney Creek alluvium lies 15 to 20 feet above the creek, and the two fill terraces of post-Piney Creek alluvium lie 12 and 3 feet above the creek (fig. 16). The fill terrace of pre-Piney Creek alluvium lies 25 feet above stream level of Indian Creek and Rainbow Creek.

Along the smaller streams the alluvium is generally piled up to form a single terrace, one fill on top of another; locally, however, as many as three terraces, each composed of one of the latest three alluvial fills, may be seen. Figure 25 shows the arrangement of the alluvial fills and the sequence of cutting and deposition along two small streams, Sterling Gulch and Lehigh Gulch (pl. 1).

The streams that deposited the terraces gradually became steeper between Wisconsin and Recent times. The evidence for this conclusion is shown in figure 26 where, along the small arroyos, older deposits lie beneath younger deposits; along the large streams older deposits lie in the highest terrace, younger deposits in the lowest terrace. The steepening of gradient came about because not enough time was available to allow the cutting of arroyos to the heads of all the streams during each cycle of downward cutting. If time or other circumstances had been favorable, then terraces would border every stream from mouth to head.

VALLEYS

The valleys were cut between Pliocene and present times. Measurement of the heights of pediments and terraces above streams both in the quadrangle and in nearby areas gives accurate evidence of the times and depths of valley cutting. Configuration of bedrock floors of the valleys is irregular (fig. 25). Major valley cutting took place before late Wisconsin time; since then streams have merely reworked older deposits. Incipient arroyos along the smaller ephemeral streams are postulated to have formed because the valleys were so steep that their modern vegetative cover did not prevent erosion during torrential storms.

In the literature on Front Range regional geomorphology, the term canyon-cutting cycle is used repeatedly. Opinion is not unanimous on the age of the canyon-cutting cycle and very little information is available in early reports on the depth of cutting during each increment of erosion. A so-called canyon-cutting cycle was dated by Lee (1922, p. 16–17) as starting in late Pliocene or early Pleistocene time, after the Rocky Mountain surface was cut, and continuing to the present. Bryan and Ray (1940, p. 24) confined the canyon-cutting cycle to post-Timnath pediment (post-Illinoian?) and Wisconsin time, that is, the time between formation of the pediments and formation of the terraces. Lee's usage seems most sensible because he has included in late Pliocene to present time all valley cutting after the formation of the Rocky Mountain surface. In Illinoian to Wisconsin time less than one-twentieth of the valley cutting took place. It seems inappropriate that such an insignificant amount of cutting be given such an all-inclusive name as canyon-cutting cycle.

In the Kassler quadrangle, valley cutting took place intermittently between Pliocene and early Wisconsin time. Measurement of the heights of the Pleistocene pediments above stream level along the mountain front provides good evidence of the range of time during which increments of the valleys were cut. Cutting started with the dissection of the Rocky Mountain surface, which is about 8,000 feet above sea level and about 2,000 feet above modern streams in this area. The principal episode involved about 1,650 feet of cutting between the Rocky Mountain surface and the highest

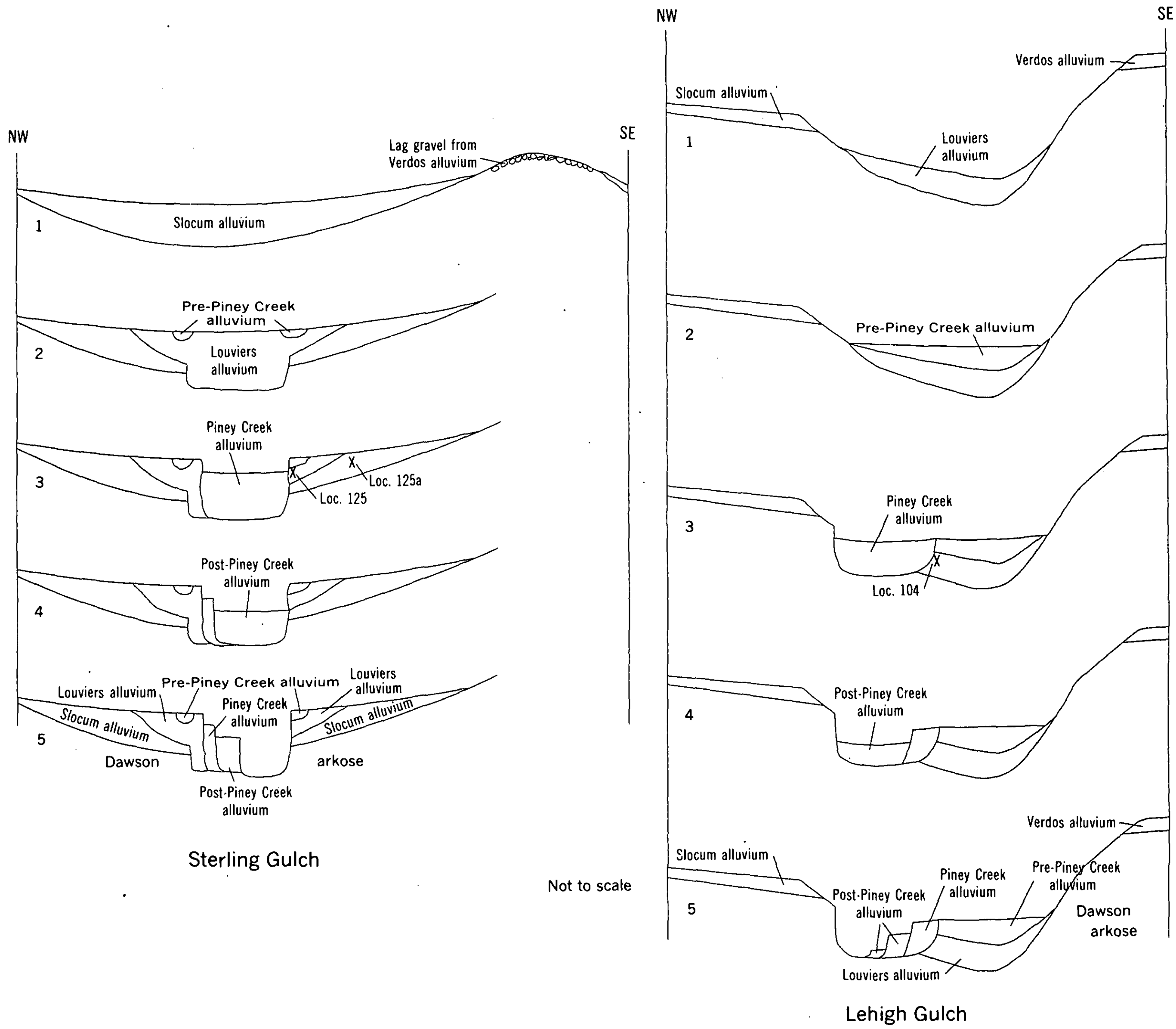

FIGURE 25.—Diagrammatic cross sections showing stages in formation of valley-fill sequence along Sterling Gulch, SE¼ sec. 30, T. 6 S., R. 68 W., and along Lehigh Gulch, NW¼ sec. 16, T. 7 S., R. 68 W., showing reversal of topography.

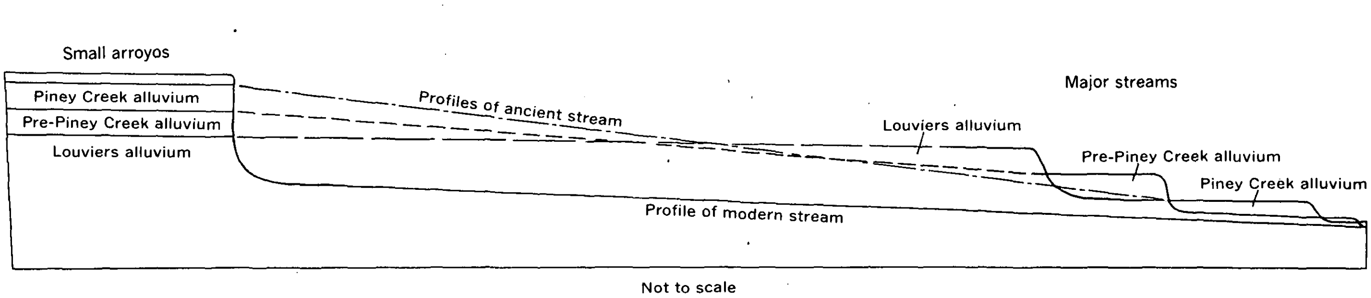

FIGURE 26.—Cross section showing relation of alluvial terraces along major streams to buried alluvium along small arroyos.

pediment. Streams cut valleys 100 feet deep between the highest pediment and intermediate pediment and 150 feet deep between the intermediate pediment and the lowest pediment. Between cutting of the lowest pediment and early Wisconsin time, the streams cut about 130 to 160 feet, or 30 to 60 feet below modern stream levels; then Louviers alluvium partly filled these channels.

Although the streams that cut the deep early Wisconsin channels are presumed to have cut into bedrock, the bases of the channels are not exposed and the shape and content of the channels are not well known. Operators of gravel pits along the South Platte River and Clear Creek report that the configuration of bedrock is quite irregular; in a few areas, depths range from less than 10 feet to as much as 60 feet within a quarter of a mile. Generally, though, gravel ranges from 25 to 35 feet in thickness. An auger hole on the west side of Plum Creek in the SE¼NE¼ sec. 4, T. 7 S., R. 68 W., indicates that the alluvium on which Plum Creek flows may exceed 65 feet in thickness.

No major valley cutting has taken place since early Wisconsin time. After early Wisconsin time, stream erosion before each alluviation became progressively less so that the sediments of each cycle of alluviation have been only slightly disturbed by the following cycle of erosion. For instance, the Wisconsin deposits in the channel bottom of the South Platte River probably have not been disturbed since they were deposited. As Bryan and Ray (1940, p. 24) said, a new series of changes in stream gradients took place, in which, between periods of incision, aggradation rather than planation was characteristic.

Cutting in late Wisconsin and Recent times involved the erosion or reworking of earlier deposits, with only minor cutting into bedrock in the headwaters of streams. Throughout Quaternary time, therefore, both the amounts of cutting and the deposits became smaller.

The discovery that each deposit is progressively smaller than the preceding one introduces the possibility that a vigorous episode of erosion such as that of early Wisconsin time could wipe out all trace of Wisconsin and Recent alluvial deposits. Such a catastrophe may have erased the record of the minor events of the earlier alluvial stages. The apparent over-simplicity of the geomorphic history of pre-Wisconsin time compared to the Wisconsin and Recent history may be due to a castastrophe that eliminated the deposits of all but the major events.

Depth of downcutting in the mountains since pre-Wisconsin time and since mid-Wisconsin time was determined along Bear Creek between Idledale and Kittredge (fig. 1) 11 miles northwest of the Kassler quadrangle. In a roadcut on State Route 74 on the west side of Sawmill Gulch at Idledale, a soil of pre-Wisconsin age is exposed about 50 feet above Bear Creek. About a mile farther west, a road cut in the SW¼SW¼ sec. 29, T. 3 S., R. 70 W., which also displays a pre-Wisconsin soil, lies about 80 feet above Bear Creek and yielded the following mollusks:

Collection J–1:
Vallonia cyclophorella Ancey
cf. *Succinea avara* Say
Pupoides hordaceus (Gabb)

Pupoides hordaceus is characteristic of the molluscan fauna in the Slocum alluvium of the Kassler quadrangle; therefore, the Bear Creek collection J–1 probably is of Illinoian or Sangamon age.

Depth of cutting since mid-Wisconsin time can be seen at the west end of Kittredge in the SE¼SW¼ sec. 35, T. 4 S., R. 71 W., where Louviers alluvium is exposed in a road cut about 30 feet above Bear Creek. The alluvium yielded a typical suite of mollusks and vertebrate fossils:

Collection J–2:
Mollusks:
Vallonia cyclophorella Ancey
V. gracilicosta Reinhardt
Vertebrates (U.S. G.S. vertebrate collection D46):
Bison sp.
Equus sp.

It is apparent that Bear Creek too has cut only about 80 feet to stream level since Illinoian time and about 30 feet since Wisconsin time.

The depth of valley cutting discussed above may be used to show the ages of steepening of gradients at certain elevations along the mountain valleys in the Kassler quadrangle. Abrupt changes in gradient that are related to the pediment beneath the Rocky Flats alluvium can be seen in Mill Gulch in the center of sec. 15, T. 7 S., R. 69 W. (pl. 1), in Bear Creek in the NE¼ sec. 4, T. 8 S., R. 69 W., in Indian Creek in the NW¼ sec. 6, T. 8 S., R. 68 W., and below the gentle reach along several other streams where Piney Creek alluvium is mapped. The abrupt changes in gradient related to the highest pediment range in altitude from 6,750 to 7,000 feet above sea level.

Abrupt steepening of gradients that are related to the pediment beneath the Slocum alluvium was found along many tributaries of the South Platte River. For instance, waterfalls were seen in the NE¼SW¼ sec. 9, T. 7 S., R. 69 W. (pl. 1), with 20 feet of fall and in the NE¼SE¼SW¼ sec. 33, T. 6 S., R. 69 W., with 50 feet of fall, and sharp breaks in stream gradient were seen in other tributaries at elevations of 50 to 80 feet above the South Platte River. These nickpoints are the result of post-Illinoian cutting. The small tributaries that have a gentle gradient 50 to 80 feet above modern stream level of the South Platte River were graded to the stream that was cutting the Slocum pediment. Later headward cutting has eroded stream channels only 100 or 200 feet up the tributaries from the South Platte River where most of these streams fall over waterfalls or steep cascades.

INCIPIENT ARROYOS

Small crescent-shaped scarps that become discontinuous arroyos are common at the heads of broad grassed upland valleys that are filled with silty alluvium. The scarps are spaced about every 100 feet and few are more than 2 feet high or 10 feet wide. Figure 27 shows a profile of a typical valley containing the scarps. From scarp to scarp the following features are shown: a plunge pool below each sod-covered scarp, a low-gradient segment of valley that is convex toward the sky, and a high-gradient segment that is concave. Incipient arroyos form in silty or clayey alluvium only as a result of certain conditions. Many of the small upland valleys are too steep, apparently, for torrential rains to flow smoothly. Turbulent flow prevails, especially where a spotty or nonexistent grass cover allows rapid runoff. Any irregularity, such as a tuft of grass or a joint crack in dry clayey alluvium, gradually will be deepened and widened to a scarp and plunge pool. Once the plunge pool and scarp are created, the water either flows over a sod-covered lip or cuts down through the soft A horizon of the soil upstream from the scarp and flows over the scarp on a lip created by the clayey B horizon. As alluvium is removed from the plunge pool, it is deposited in a fan deposit a few yards downstream (fig. 27). The slope of this segment of stream valley including the plunge pool and fan is less than the slope of the former valley floor. Across this low-gradient fan the middle of the channel is higher than the sides. This shape causes the stream to be spread out and to be inefficient as an erosive agent until it drops its load, passes beyond the fan, and returns to a channel where it again proceeds through the same cycle downstream.

The incipient arroyos are lengthened by stream erosion, by undercutting of columns of alluvium, and by tunneling. Arroyos that have long scoop-shaped, gradually deepening channels at their heads are being lengthened by stream erosion. Arroyos that are box draws with walls 5 to 25 feet high are lengthened by undercutting of the columns by water that falls into the plunge pool and by weakening of the base of the columns by constant saturation. Some arroyos are lengthened by water that enters and tunnels through wide columnar joints many feet upstream from the arroyo head. As the tunnel is enlarged, support is removed from the roof, which subsequently caves and thus a new segment of arroyo is created. The incipient arroyos finally merge and form the steep-walled arroyos that are typical of a semiarid country.

CAUSE OF ARROYO CUTTING

The problem of arroyo cutting that besets the ranchers of the area is not entirely of their own making. As shown on table 1, several cycles of arroyo cutting are recorded in prehistoric time, and the major cycles of valley cutting antedate even the coming of man to North America (table 1). Overgrazing and the practice of burning over pastureland in historic time, which resulted in the deforestation of the mountain slopes, certainly allowed the torrential downpours, which are typical of a semiarid climate, to run off more quickly with more erosive power. Fire in prehistoric time,

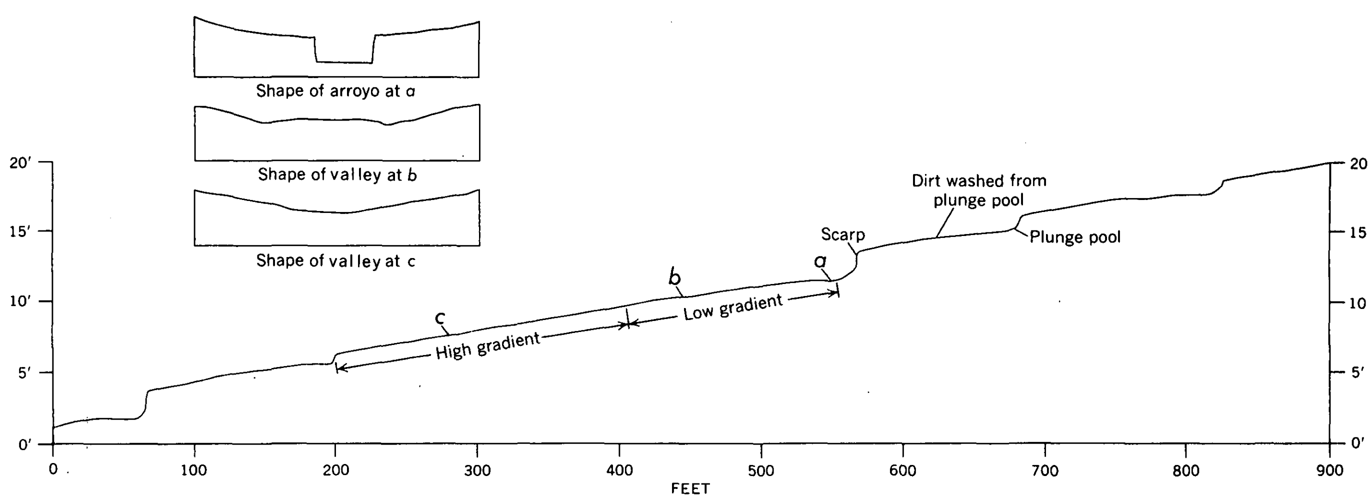

FIGURE 27.—Profile showing scarps of incipient arroyos developed in the head of a small valley. Based on measurements in the N½NW¼ sec. 34, T. 5 S., R. 69 W., Littleton quadrangle, Colorado.

shown by charcoal in the pre-Piney Creek alluvium, also may have contributed to the erosive ability of the ancient streams, but the primary cause of arroyo cutting is considered to be climatic change; fires and overgrazing merely served to accelerate the erosion that was inevitable.

STREAM CAPTURES

Stream captures are common in this area, chiefly because the gradients of many streams are so steep. The stream that does the capturing generally has a shorter reach and a steeper gradient to base level than the stream that is captured. Little Willow Creek is the result of such a stream capture (fig. 21). In the early stage of cutting of the Slocum pediment, Little Willow Creek flowed eastward from a gap in the hogback of the Dakota group and entered Willow Creek somewhere between sec. 7, T. 7 S., R. 68 W., and sec. 12, T. 7 S., R. 69 W. A small stream, flowing generally in the course of the modern Little Willow Creek, cut headward to the south and captured Little Willow Creek where it issued from the gap in the Dakota hogback. Little Willow Creek then completed the cutting of the Slocum pediment northward and deposited alluvium on it. Because base level (the South Platte River) was closer along the course of Little Willow Creek than along Willow Creek and because downcutting continued after the capture, the remnants of Slocum alluvium deposited before the capture are higher than the Slocum alluvium deposited after the capture. Bedrock at the side of the channel is only 11 feet deep in a hole augered on the south side of the road in the SE¼ sec. 12, T. 7 S., R. 69 W., but bedrock in the channel (fig. 9) is buried under more than 35 feet of alluvium. High hills of Verdos alluvium lie north of the channel.

Another stream capture took place in early Wisconsin time when the stream in Lehigh Gulch flowed northward around the west side of a ridge of Verdos alluvium that straddles the line between secs. 9 and 16, T. 7 S., R 68 W. (pl. 1). In later Wisconsin time a minor headward-cutting tributary of Indian Creek captured the stream in Lehigh Gulch south of the section line and diverted it eastward into Indian Creek; this action left a knob of Verdos alluvium which is now surrounded by pre-Piney Creek alluvium. Farther upstream at locality 104 pre-Piney Creek alluvium was deposited, and the stream moved westward across the alluvium and cut a new channel. The flank of the old early Wisconsin channel is preserved in the stream cut shown on figure 25. In addition to these stream changes, another capture is imminent. The neck between the two streams west of locality 104 is less than 50 feet wide and probably will be breached in a few years; it recently was narrowed by about 15 feet in a single flash flood.

EFFECT OF WEATHERING AND HYDROTHERMAL ALTERATION ON GEOMORPHIC DEVELOPMENT

Pleistocene weathering has a direct bearing on the width and depth of valley cutting. Weathering softened the rocks, particularly the crystalline rocks, and made erosion easier, but its effect was minor compared to the effect of the much older hydrothermal alteration, which greatly facilitated the erosion of valleys. The depth of weathering can be measured in tens of feet, but hydrothermal alteration can be measured in hundreds of feet.

Weathering had less effect than faults on both the amount and the position of valley cutting. In valleys cut into weathered crystalline rocks, weathering had not softened the rocks enough for the mountain streams to keep pace with downcutting of the plains streams. Where the valleys were cut along faults, however, as along Stevens and Mill Gulches, hydrothermal alteration had already softened the rocks sufficiently that valleys were easily eroded. In effect, along the valleys that are located along faults, the streams could easily cut downward, even without the weathering part of the geomorphic cycle.

Erodability varies with different kinds of hydrothermal alteration. Silicified, hydrothermally altered fault gouge is not as susceptible to erosion as unsilicified fault gouge. Where rocks were only weathered, erosion was slow and ineffective; where they were first altered and silicified and then weathered, erosion was even slower; but where they were altered only and not silicified, erosion was fast, and, at least along these segments where the streams follow such faults, they could reach grade as quickly as some plains streams.

Rocks in the quadrangle were weathered several times; the principal times from oldest to youngest were:

1. Pennsylvanian
2. Middle Pliocene (post-Ogallala) to Nebraskan (Rocky Flats)
3. Aftonian(?)
4. Yarmouth(?)
5. Sangamon(?)

Pennsylvanian weathering is discussed with the Fountain formation in Professional Paper 421–B.

Weathering during middle Pliocene to Nebraskan time took place on the Rocky Mountain surface, about 2,000 feet above modern streams. This surface is underlain primarily by foliated and unfoliated granitic rocks. Several factors contributed to a local deep weathered zone. Coarse grain size and foliated internal structure of some rocks allowed the weathering solutions to enter; faults crushed the rock along zones several hundred feet wide; closely spaced joints which contained water were riven by frost.

Aftonian(?) weathering took place at or above the level of Rocky Flats alluvium. The best exposures of crystalline rock weathered in Aftonian(?) time are in the SE¼ sec. 25, T. 7 S., R. 69 W.

Yarmouth(?) weathering, which affected rocks at or above the level of Verdos alluvium, is apparent under the Yarmouth soil, where bedrock was weathered to a depth of several feet.

Sangamon(?) weathering took place 80 to 100 feet above modern streams. The best example is in the NE¼ sec. 33, T. 6 S., R. 69 W. No marked weathering has affected the crystalline rocks since Sangamon time.

CORRELATION

The surficial deposits can be correlated with other deposits in the Denver Basin and in neighboring States on the basis of fossils, soils, and radiocarbon age, and by tracing the landforms. The soil correlations require the assumption that Quaternary climate was regional, that the soils are a response to climate, and that the climatic fluctuations of the Quaternary were concurrent in the Great Plains and in the Rocky Mountains. If these assumptions are correct, then correlation of soils should be quite reliable.

Table 5 shows the correlation of the surficial deposits of the Kassler quadrangle with those of the Louisville quadrangle (Malde, 1955), of the Denver area (Hunt, 1954), and of Nebraska (Schultz and others, 1951). The deposits in which fossil bone was identified and radiocarbon was analyzed are more abundant in the Nebraska section, primarily because the deposits in Nebraska are finer grained.

GEOLOGIC HISTORY

The earliest event that affected the geomorphic development of the region was the uplift of the Rocky Mountains and the arching of their sedimentary cover in Late Cretaceous and Paleocene time. The Tertiary geomorphic events are poorly documented, but their history is reconstructed as follows: In Eocene time either no sediments were deposited or they were deposited and then removed. In early Oligocene time streams cut a broad surface across the Precambrian rocks and deposited the Castle Rock conglomerate (a correlative of the lower part of the White River group) which has since been eroded from the Kassler quadrangle. In Miocene time either no sediments were deposited or they were deposited and removed. In Pliocene time, the Rocky Mountain surface was cut by streams flowing across the Precambrian and later rocks, and the Ogallala formation was deposited by the streams.

The record of Quaternary events in the geomorphic development is much better documented. The most impressive events are canyon cutting and pedimentation. Canyon cutting started in late Pliocene time. At five times in the Quaternary—because of a change in climate—streams cut downward. After each of the first three times of downcutting, the streams attained a profile of equilibrium and then cut sidewise to form pedi-

TABLE 5.—*Correlation of Quaternary deposits of Colorado and Nebraska areas with deposits of the Kassler quadrangle*

Age	Kassler, Colo. (this report)	Louisville, Colo. (Malde, 1955)	Denver, Colo. (Hunt, 1954)	Nebraska (Schultz and others, 1951)
Recent				Soil Z'.[1]
	Loess and eolian sand [2]			Silt and loess.[1]
	Post-Piney Creek alluvium [1,2]	Post-Piney Creek alluvium	Flood-plain alluvium [1]	
	Late Recent soil [3]	Recent soil	Recent soil	Soil Z.[1]
	Piney Creek alluvium [1]	Piney Creek alluvium and colluvium.	Piney Creek alluvium [1]	Cochrane silt and loess.[1,2]
	Early Recent soil [3]			Soil Y.[1]
	Eolian sand		Eolian sand [1]	
	Pre-Piney Creek alluvium [1,2]			
Wisconsin				T2A fill.
	Broadway alluvium	Gravel fill and alluvial fill	Gravel fill [1] and alluvium along Lakewood and Wier Gulches.[1]	{Soil YY Bignell soil.[1,2] T2B fill.}
	Wisconsin soil [3]	Wisconsin soil	Wisconsin soil	Soil X Brady soil.[1]
	Younger loess [1]	Eolian silt and sand	Eolian deposits [1]	Silt and loess.
				Soil W.
	Louviers alluvium [1,2]	Cobble gravel	Alluvial gravel [1]	Todd Valley formation.
Pre-Wisconsin	Sangamon(?) soil [3]	Pre-Wisconsin soil	Pre-Wisconsin soil	Sangamon soil.[1]
	Older loess			Loveland formation.[1]
		Undifferentiated upland deposits	Residuum	
	Slocum alluvium [1]			Crete formation.[1]
	Yarmouth(?) soil [3]			Yarmouth soil.
	Verdos alluvium	Upland gravel	Gravel on hilltops west of South Platte River.	Sappa formation.[1]
	Silt and volcanic ash			Pearlette ash.
				Grand Island formation.[1]
				Red Cloud formation.[1]
	Aftonian(?) soil [3]			Aftonian soil.
	Rocky Flats alluvium	Gravel on Rocky Flats		Fullerton formation.[1]
				Holdredge formation.

[1] Fossil bone reported.
[2] C_{14} samples analyzed.
[3] Age term.

ments. Three major stages of pedimentation, the first of Nebraskan or Aftonian age, the second of Kansan or Yarmouth age, the third of Illinoian or Sangamon age, indicate that sideward cutting by streams dominated at least three times in the pre-Wisconsin stages.

In Nebraskan or Aftonian time the pediment beneath the Rocky Flats alluvium was cut about 1,600 feet below the Rocky Mountain surface and the Rocky Flats alluvium was deposited on it. Plum Creek, along the east side of the Kassler quadrangle, was developed as a northward-flowing stream between pediments sloping toward it from the east and from the Front Range. The pediment beneath the Rocky Flats alluvium is the most extensive of the Pleistocene pediments and is the only Pleistocene pediment that was cut on Precambrian rocks. An Aftonian(?) soil was developed on the Rocky Flats alluvium and on all exposed rocks. In Kansan or Yarmouth time the pediment beneath the Verdos alluvium was cut 100 feet below the highest pediment. The Verdos alluvium was deposited on the pediment and in the valleys of the South Platte River, Plum Creek, Indian Creek and Willow Creek. During the deposition of the Verdos alluvium coarse volcanic ash, probably from a volcano to the west, fell over all the middle Great Plains. The ash was interbedded with the lower part of the Verdos alluvium. A Yarmouth(?) soil was developed on the Verdos alluvium. Rainbow Creek, Jarre Creek, and Lehigh Gulch were merely low swales on the surface of the Verdos alluvium.

In Illinoian time the Verdos alluvium was dissected, the pediment beneath the Slocum alluvium was cut 150 feet below the Verdos alluvium, and the Slocum alluvium deposited in Illinoian or Sangamon time in a climate that was warmer than now. A fill terrace of the Slocum alluvium was deposited along the South Platte River and Plum Creek. Little Willow Creek was formed by capture of one of the tributaries of Willow Creek. The older loess was blown out of the South Platte River valley onto the Slocum alluvium. A Sangamon(?) soil was developed on the Slocum alluvium and on the older loess.

From Wisconsin to the present time the cutting of canyons was completed, and streams repeatedly reworked large loads of outwash from the mountain glaciers. Five fill terraces of regional extent were produced by alluviation in Wisconsin to Recent time. Base level was not stable long enough in Wisconsin time to allow widespread pedimentation.

In early Wisconsin time streams dissected the Slocum alluvium and broad channels were cut into it along Plum Creek and the South Platte River, possibly deeper than they have since been cut; arroyos were cut along the smaller streams. At this time the modern drainage system was formed. Coarse-grained Louviers alluvium was deposited in a broad terrace along the two main streams, and fine-grained alluvium was deposited in narrow channels along the small streams. The great amount of cutting caused most of the colluvium to be deposited at this same time. The climate was favorable for animals; bones of camel, mammoth, horse, deer, and bison and shells of mollusks are abundant at many places.

The younger loess was blown from the outwash along the South Platte River and locally from the Pierre shale up onto the bluffs along the southeast side of the river. The Wisconsin soil was developed on the early Wisconsin deposits and on dissected pre-Wisconsin deposits. Bog clay was deposited in three depressions near Roxborough Park School after the loess was blown across the drainage outlets. In late Wisconsin time the Broadway alluvium was deposited along the South Platte River and Plum Creek. It was entrenched slightly into Louviers alluvium and then spread out as a strath on the Louviers. In early Recent time arroyos were cut locally into Louviers alluvium, and pre-Piney Creek alluvium filled the arroyos. The earliest known evidence of man in the Kassler quadrangle is in this alluvium. Where no arroyos were cut, an early Recent alluvium was deposited on the strath of the Louviers alluvium. No early Recent alluvium was found along Plum Creek or the South Platte River although it may lie at the base of the Piney Creek alluvium. Eolian sand was blown from the pre-Piney Creek alluvium onto the divides south of the streams, and the loess probably was reworked at this time. Early Recent soil was developed on the pre-Piney Creek alluvium, on the eolian sand, and on the Broadway alluvium.

In late Recent time, arroyos were cut along every stream in the area and the Piney Creek alluvium was deposited. Late Recent soil was developed on the Piney Creek alluvium. Arroyos again were cut and then filled with post-Piney Creek alluvium about 1,400 to 1,500 years ago. Eolian sand and loess were deposited shortly after this cycle of alluviation, about 1,300 to 900 years ago. The modern arroyos were cut about A.D. 1900 and flood-plain alluvium is still being reworked.

ECONOMIC GEOLOGY

Gravel from the surficial deposits in the northeast half of the quadrangle is used for construction material. The major uses of the gravel are for road metal on secondary roads and as aggregate for concrete. Large boulders are locally used as riprap in stock ponds.

Prospects listed in this report should be proved by subsequent drilling, or test pitting, and the materials should be subjected to laboratory tests before acceptance for specific uses.

AGGREGATE FOR CONCRETE

Aggregate is defined as inert material which, when bound together into a conglomerated mass by a matrix, forms concrete, mastic, mortar, or plaster (American Society for Testing Materials, 1946). Aggregate for concrete is classified as fine and mixed. The distinction is based on the percentage of material retained on a No. 4 sieve. The part of a sample retained on that sieve is designated as the coarse fraction. The material is classified as a mixed aggregate if the coarse fraction is 5 percent or more by weight of the sample, and as a fine aggregate if the coarse fraction is less than 5 percent. The grading of almost any aggregate material may be changed by crushing and screening until it conforms to required specifications.

Aggregate for concrete consists of sand and gravel-size fragments of hard durable minerals or rocks. The constituent particles are free from adherent coatings that would interfere with the bonding of cement with the particles. Potential sources of aggregate and some constituents that may make the materials unsuitable for aggregate, such as wash material passing the No. 200 sieve) and humus (disclosed in the colorimetric test) are shown in table 6.

The materials reported are accessible from all-weather roads and are exposed at the surface or have an unconsolidated overburden sufficiently thin to permit economic development. The test characteristics or the descriptions of the materials may indicate that some are not suitable for use in concrete; however, the same material may be acceptable for other uses, such as aggregate for bituminous construction or for cover material.

The stratigraphic units that are actual or potential sources of aggregate for concrete are Louviers, Broadway, and reworked Louviers and Broadway alluvium (designated on table 6 as post-Piney Creek alluvium). All the older alluvium is too deeply weathered to be acceptable. The best source of aggregate from the standpoint of quality and quantity is in the flood plain of the South Platte River underneath the Piney Creek and post-Piney Creek alluvium.

The performance record of the Platte River aggregate is good. The Los Angeles abrasion loss runs from 35 percent in the deeper parts of the alluvium to nearly 45 percent in the shallower parts. This loss is high, but acceptable to most users. When crushed, the alluvium generally is deficient in material retained on a No. 50 sieve, but this defect is overcome by putting the crusher dust back in the aggregate. Small lumps of clay from the Piney Creek or post-Piney Creek alluvium contaminate the aggregate somewhat; the larger lumps are picked out by hand, as are sticks and bones.

ROAD METAL

Road metal is defined as material that may be applied to a road to improve the performance characteristics of that road.

Surficial materials are used for road metal in the northeastern part of the quadrangle. Sand and gravel are available in the Rocky Flats, Verdos, Slocum, Louviers, Broadway, and post-Piney Creek alluviums. The Rocky Flats, Verdos, and Slocum alluviums are deeply weathered, but weathered material has the advantage of containing clayey binder material that will make a hard-packed surface and decrease dusting on the road. Table 6 shows the results of tests on materials that have been used or are available for use in construction of roads and other engineering structures.

TABLE 6.—*Summary of materials tests*

[Tests by U.S. Bureau of Public Roads materials laboratory]

Geologic unit	Location			Estimated quantity of material (cubic yards)	Average thickness (feet)	Accessibility	Sieve analysis, percent retained on—								Percent passed No. 200 (wash)	Laboratory test data		Colorimetric test for organic matter
	Section	T. S.	R. W.				1 inch	¾ inch	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100		Sodium sulfate soundness (percent loss)	Los Angeles abrasion (percent loss)	
Post-Piney Creek alluvium.	NW¼NW¼ 36	6	69	Unknown		Good	0	0	1	1	17	41	24	13	1			Light straw.
Louviers alluvium.	NE¼SW¼ 34	6	69	Unlimited	20	do	0	1	21	5	7	43	9	9	2			Dark straw.
	NE¼SE¼ 33	6	68	do	15+	do	3	0	19	17	17	28	6	7	2			Light straw.
Slocum alluvium.	SE¼SW¼ 29	6	68	do	55	do	0	1	25	23	21	14	3	10	1	4.9	46	Do.
Verdos alluvium.	NW¼SW¼ 12	6	69	50,000+	10+	do	9	1	6	14	15	31	7	8	2			Do.
	NW¼NW¼ 21	7	68	50,000+	15	Fair	0	0	12	3	25	28	14	9	5			Do.

RIPRAP

Riprap is defined as any material that will protect earthen fills from erosion. The material for this use must be relatively sound and free from impurities, cracks, and other structural defects that would cause it to disintegrate through erosion, slaking, or freeze-and-thaw. Blocks of riprap should have approximately rectangular faces, 7 inches or more in width.

Large stones are common in the Rocky Flats and Verdos alluvium and have been used for facing on spillways, stock ponds, and erosion check dams. Their roundness makes them hard to set and somewhat unstable.

FOSSIL LOCALITIES

Localities of fossils from the surficial deposits of the Kassler quadrangle are listed, by number, below. The fossils were collected during the fieldwork on which this report is based. Many collections are from outcrops that are too small to map. The arrangement of the list is stratigraphic, from oldest to youngest. Collections were made by Scott in 1953, except where otherwise noted.

Locality (pl. 1)	USGS fossil vertebrate collection (Denver)	USGS Cenozoic mollusk collection (Denver)	Locality description
			Verdos alluvium
91	----	D405	NW¼NW¼ sec. 21, T. 7 S., R. 68 W.
			Slocum alluvium
92	D59	D412	SW¼NW¼ sec. 36, T. 6 S., R. 69 W., from silty alluvium.
93	----	D411	SW¼NW¼ sec. 35, T. 6 S., R. 69 W., from calcareous, reddish-brown, pebbly alluvium.
94	----	D418	SE¼NE¼ sec. 12, T. 7 S., R. 69 W., from pebbly, calcareous alluvium. Scott, D. W. Taylor, and C. C. Cameron, 1954.
95	----	D438	SW¼NE¼SE¼ sec. 4, T. 7 S., R. 68 W., from sandy alluvium under Louviers alluvium at Louviers dump. Scott, Taylor, and Cameron, 1954.
96	D65	-----	NE¼SE¼ sec. 30, T. 6 S., R. 68 W.. from silty alluvium.
97	----	D401	NE¼SW¼ sec. 26, T. 6 S., R. 69 W., from calcareous cobbly alluvium overlying Pierre shale in cut bank of South Platte River.
125a	D54	-----	NE¼SE¼ sec. 30, T. 6 S., R. 68 W.; from silty alluvium.
			Louviers alluvium
100a	D68	D400	SW¼NW¼SW¼ sec. 35, T. 6 S., R. 69 W., from humic gley soil on sandy black alluvium.
			Louviers alluvium—Continued
100b	----	D398	Same location, but from C_{ca} horizon of soil on reddish-brown limy alluvium on west side of arroyo. Scott, Taylor, and Cameron, 1954.
100c	----	D399	Same location, but from C_{ca} horizon of soil on brown sandy alluvium overlying collection D400 on east side of arroyo.
100d	----	D433	Same location, but from humic alluvium 4 feet below A horizon of soil and 50 feet south of collection D400. Scott and Cameron, 1954.
100e	----	D434	Same location, but from top of C_{ca} horizon of soil on alluvium on west side of gully across from collection D400. Scott and Cameron, 1954.
125	D54	-----	SE¼SW¼SE¼ sec. 30, T. 6 S., R. 68 W., and NE¼SE¼ sec. 30, T. 6 S., R. 68 W., from silty alluvium.
101a	----	D415	NE¼SE¼ sec. 30, T. 6 S., R. 68 W., from silty alluvium.
101b	----	D423	Same location, but from calcareous silty alluvium.
102a	D64	D436	NW¼NE¼ sec. 36, T. 6 S., R. 69 W., from calcareous pebbly silt above pebbly clay at ancient spring site. Scott, Taylor, and Cameron, 1954.
102b	----	D432	Same location, but from silty alluvium in main gully at ancient spring site.
102c	----	D437	Same location, but from calcareous silt in gully at southeast corner of ancient spring site about 50 feet east of collection D436. Underlies younger loess. Scott, Taylor, and Cameron, 1954.
103	D63	D421	SW¼NE¼ sec. 5, T. 7 S., R. 68 W., from silty alluvium.
104	D60	D407	NE¼SW¼NW¼ sec. 16, T. 7 S., R. 68 W., from C_{ca} horizon of soil on Louviers alluvium.
105a 105b	D58 D52	----- -----	NW¼SE¼ sec. 4, T. 7 S., R. 68 W., from silt and clayey iron-stained pebble layer in alluvium.
106	D56	D416	SE¼NE¼ sec. 36, T. 6 S., R. 69 W., from silty alluvium.
107	D53	-----	NW¼SW¼ sec. 4, T. 7 S., R. 68 W., from silty alluvium.
108	D51	-----	NW¼NW¼ sec. 4, T. 7 S., R. 68 W., from silty alluvium.
109	D48	-----	NW¼SE¼ sec. 4, T. 7 S., R. 68 W., from sandy alluvium.
110	D172	-----	SE¼SE¼ sec. 19, T. 7 S., R. 68 W., from pebbly alluvium. J. H. Smith, 1956.
111	----	D410	NE¼SE¼ sec. 4, T. 7 S., R. 68 W., from sandy alluvium.
112	----	D424	SW¼SE¼ sec. 36, T. 6 S., R. 69 W., from silty alluvium.
113	----	D403	SE¼SE¼ sec. 17, T. 7 S., R. 68 W., from silty alluvium.
114	----	D406	SE¼SE¼ sec. 5, T. 7 S., R. 68 W., from silty alluvium.

Locality (pl. 1)	*USGS fossil vertebrate collection (Denver)*	*USGS Cenozoic mollusk collection (Denver)*	*Locality description*
			Louviers alluvium—Continued
115	----	D408	NE¼NE¼ sec. 20, T. 7 S., R. 68 W., from silty alluvium.
116	----	D417	SE¼SE¼ sec. 30, T. 6 S., R. 68 W., from silty alluvium.
117	----	D419	NE¼SW¼ sec. 36, T. 6 S., R. 69 W., from sandy calcareous alluvium.
118	----	D422	SW¼SE¼ sec. 29, T. 6 S., R. 68 W., from silty alluvium.
119	----	D425	SE¼NW¼ sec. 8, T. 7 S., R. 68 W.. from silty alluvium.
120	----	D426	SW¼SW¼ sec. 31, T. 6 S., R. 68 W., from silty alluvium.
121	----	D427	NW¼SW¼ sec. 4, T. 7 S., R. 68 W., from silty alluvium.
122	----	D428	NW¼NW¼ sec. 29, T. 7 S., R. 68 W., from silty alluvium.
123	----	D430	SE¼SE¼ sec. 17, T. 7 S., R. 68 W., from silty alluvium up side draw south of main gully.
124	----	D431	NE¼SE¼ sec. 34, T. 6 S., R. 69 W., from sandy micaceous alluvium.
			Younger loess
98a	D50	D420	NW¼NE¼ sec. 36, T. 6 S., R. 69 W., from small gully at southeast corner of ancient spring site.
98b	D50	D429	Same location, but from pit east of main gully at ancient spring site.
99	D61	D413	SW¼NW¼ sec. 36, T. 6 S., R. 69 W.
			Pre-Piney Creek alluvium
126	D43	D404	SE¼SE¼ sec. 11, T. 7 S., R. 69 W., from reddish-brown calcareous stony colluvium.
127	----	D402	NE¼SW¼ sec. 36, T. 6 S., R. 69 W., from yellowish-brown silty alluvium.
128	----	D439	NE¼NW¼NE¼ sec. 29, T. 7 S., R. 68 W., from sandy alluvium.
			Eolian sand
129	----	D414	SW¼SE¼ sec. 20, T. 7 S., R. 68 W.
			Piney Creek alluvium
130	----	D435	SW¼NW¼SW¼ sec. 35, T. 6 S., R. 69 W., from alluvium on west side of gully across from collection D400. Scott and Cameron, 1954.
131	----	D440	NW¼NE¼ sec. 36, T. 6 S., R. 69 W., from alluvium at ancient spring site.
132	{D41, D36}	-----	SW¼NW¼ sec. 20, T. 7 S., R. 68 W.
133	{D40, D33}	-----	SE¼SW¼ sec. 7, T. 7 S., R. 68 W.
134	D37	-----	NW¼NW¼ sec. 12, T. 7 S., R. 69 W.
135	D35	-----	NW¼SW¼ sec. 31, T. 6 S., R. 68 W.
136	D34	-----	NE¼SW¼ sec. 36, T. 6 S., R. 69 W.
138	----	D409	NE¼NE¼ sec. 5, T. 7 S., R. 68 W.
140	----	D451	NW¼SW¼ sec. 20, T. 7 S., R. 68 W
			Post-Piney Creek alluvium
137	D39	-----	SE¼SE¼ sec. 11, T. 7 S., R. 69 W.
139	D42	-----	NW¼NE¼ sec. 36, T. 6 S., R. 69 W., from post-Piney Creek colluvium.

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