Pleistocene and Recent Deposits in the Denver Area Colorado

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A CONTRIBUTION TO GENERAL GEOLOGY

PLEISTOCENE AND RECENT DEPOSITS IN THE DENVER AREA, COLORADO

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ABSTRACT

The stratigraphy of Pleistocene and Recent deposits in the Denver area illustrates the close relationship between physical geology, paleontology, archeology, and soils. The deposits are of three principal ages—pre-Wisconsin, Wisconsin, and Recent.

The pre-Wisconsin deposits include alluvial gravels in the valleys and residual deposits on the uplands. Fossil mammals suggestive of Yarmouth age have been collected from some of these gravels in the valleys. Some high-level gravels on the uplands are evidently still older and may be as old as Pliocene. On these pre-Wisconsin deposits at many places there is a characteristic soil profile consisting of a reddish-brown lime-free clay layer over several feet of caliche. This soil is overlapped by Wisconsin deposits and must have developed before Wisconsin time.

Deposits of Wisconsin age include gravel and alluvium in the valleys and eolian deposits on the uplands. The gravel evidently represents glacial outwash. The windblown deposits on the uplands must have been derived from the valleys, for they thin and become finer in texture eastward (leeward) from the valleys. These Wisconsin deposits have yielded abundant remains of mammoth, camel, and other extinct animals. Archeologically the upper Wisconsin deposits are of Folsom age. In areas nearby Folsom artifacts have been found in these deposits; in the Denver area the upper Wisconsin deposits have yielded split bone and crudely flaked objects probably shaped by humans. The Wisconsin deposits, especially the eolian deposits on the uplands, have a characteristic soil profile consisting of an upper lime-free brown layer a foot or two thick above a 2- or 3-foot layer containing lime carbonate in small soft nodules or anastomosing veinlets. This soil is overlapped by Recent deposits and must have developed during Wisconsin time.

The Recent deposits consist mostly of alluvium but include some reworked eolian sand on the uplands. Vertebrate remains in these deposits are of modern types. Archeologically the Recent deposits include the Woodland and younger cultures; the earliest Recent deposits probably include some of the so-called Yuma cultures. The soil on the Recent deposits consists of an upper brown layer about a foot thick over a 1- or 2-foot layer stained reddish with iron oxide. Some of the early Recent alluvial deposits, which have been subjected to flooding, have a weakly developed but distinct zone of lime carbonate under the brown layer.

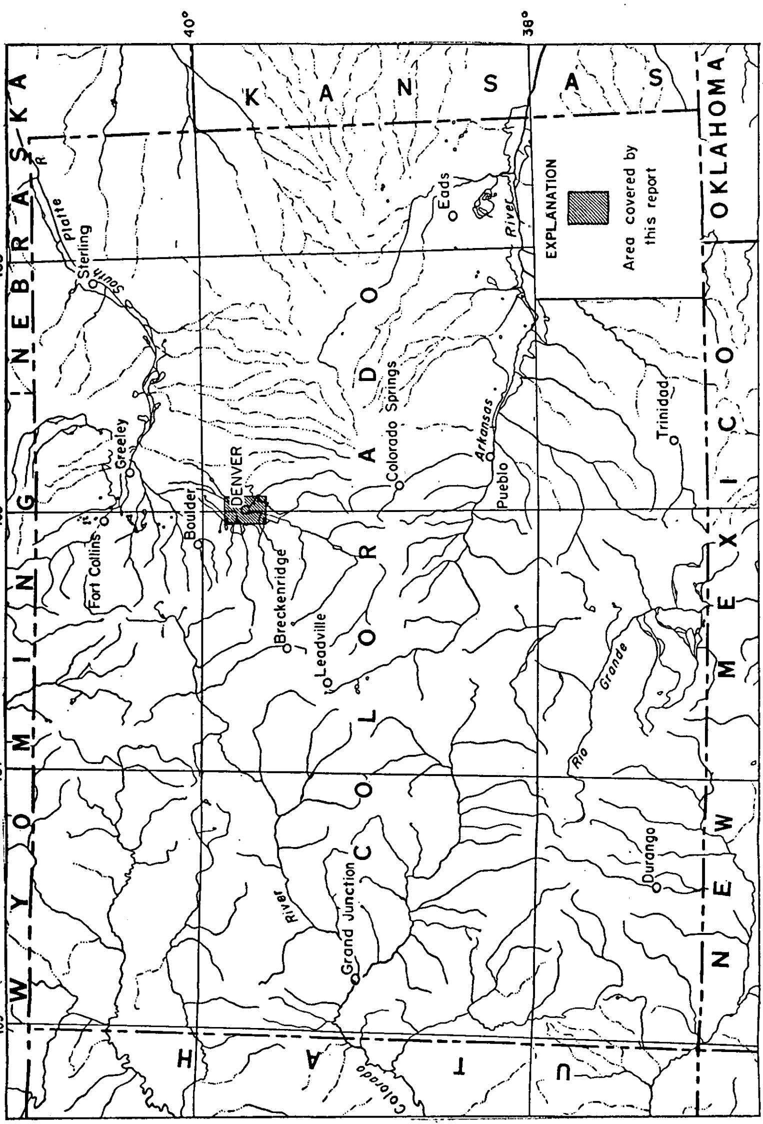

FIGURE 21.—Index map showing location of Denver area.

INTRODUCTION

This report on the Pleistocene and Recent deposits in the Denver area, Colorado (fig. 21), presents the results of studies that have been conducted intermittently since February 1948. Owing to the necessity of limiting the field work to an average of perhaps 1 day a week during the 4-year period 1948–52, it has not been possible to study adequately the problems presented by the deposits. The objective of this report, therefore, has been limited to a description of the stratigraphy of the surficial deposits. The bearing of the stratigraphy on problems of geologic history and processes can only be partly treated at this time.

Determination of the stratigraphy of the deposits has been based upon four kinds of evidence: the physical geology of the deposits, including such features as superposition of beds and changes in facies; the paleontologic record; the archeologic record; and the buried soils which help in distinguishing pre-Wisconsin, Wisconsin, and Recent deposits.

PREVIOUS WORK

Many articles have been written about the geomorphology of the Front Range and adjoining plains, most of them dealing with the history of the erosion surfaces or glaciation. On the other hand, the stratigraphy of the Pleistocene and Recent deposits in Colorado has been generally neglected although similar deposits have been intensively studied in adjoining States, notably in Nebraska and Kansas. At the end of this report is a list of references including those previous studies that describe the Tertiary and pre-Tertiary rocks of the Denver area, those that describe the geomorphology of the Front Range and adjoining High Plains, and a few others that describe the paleontology, archeology, soils, or general stratigraphy of similar deposits in areas nearby.

ACKNOWLEDGEMENTS

In making this study I had the benefit of advice and counsel from many of my colleagues. Mrs. Jean Hough, of the U. S. Geological Survey, was especially helpful in furnishing identifications and interpretations of the bone fragments that were collected. Professor Arnold Withers, of the University of Denver, cooperated in the archeologic phases of the study. G. M. Richmond first called my attention to the fact that the Wisconsin soils could be distinguished from the pre-Wisconsin and Recent ones. My wife, Alice P. Hunt, participated in much of the field work. She assisted with the archeology, searched for vertebrate remains, and it was she who discovered the split bone in the late Wisconsin deposits.

STRATIGRAPHY

BEDROCK

The bedrock on which the surficial deposits rest is the Denver formation of Upper Cretaceous and Paleocene age. At the extreme southwest corner of the area, however, the base of the formation is turned up steeply and the underlying Upper Cretaceous Arapahoe formation is exposed. The Denver formation, composed of conglomerate, sandstone, siltstone, and compact clay, has been estimated to be about 1,500 feet thick (Emmons, Cross, and Eldridge, 1896, p. 172). At least the lower half of the formation is exposed in the area. The sandstone and conglomerate, and presumably the siltstone and clay also, are composed very largely of andesitic debris. Granitic or gneissic debris from the Front Range is uncommon although these materials are rather abundant in the upper half of the formation which is still preserved on Green Mountain, 2½ miles west of the mapped area.

The conglomerate and sandstone facies are mostly west of the South Platte River; they are especially well exposed along the north side of Bear Creek and in the hills along the west edge of the area north of Bear Creek. One outcrop of conglomerate was found east of the South Platte River (at Florida Avenue and University Boulevard), but in most of the east half of the area the Denver formation is composed largely of siltstone and clay.

The conglomerate beds range from a few feet to at least 30 feet thick. They commonly occur as channel deposits that cut several feet into underlying beds and have steep sides disconformable against finer textured beds in which the channel was cut. Pebbles in the conglomerate are mostly less than 2 inches in diameter and are in a matrix of silty sand.

The sandy beds generally are only a few feet thick. The sand ranges in texture from less than 0.5 millimeter to grit and commonly is mixed with silt. Some silt-free beds of sand are crossbedded and streaked with black sand. Shale pellets are common where the sand has a silt matrix.

The siltstone and clay beds are lenticular but less so than the sand or conglomerate. Individual beds range from thin laminae to several inches thick. Beds a half-inch thick commonly are in lenses several feet long.

The Denver formation is much weathered. Many of the pebbles are decomposed and easily broken; some can even be cut with a knife. Outcrops of the permeable beds are stained by iron oxide producing a rich light brown that is quite distinctive from the generally darker brown of the surficial deposits; the siltstone and clay are buff, gray, or green.

In general, the Denver formation is noncalcareous. In places the top few feet are strongly impregnated with lime carbonate, but this is a Pleistocene phenomenon mostly the result of pre-Wisconsin weathering (p. 102).

The eroded surface of the formation only approximately conforms to the present topography. In many places this bedrock surface is rougher than the present topography because depressions have been partly filled with Pleistocene and Recent colluvial, fluvial, and loessial deposits. At some places the present-day streams are incised across hills on the bedrock surface. An example of this is McIntire Wash and the tributaries on each side of it in the S½ sec. 9, T. 4 S., R. 69 W. The tributary valleys immediately north and south of McIntire Wash have at least 10 feet of alluvium filling old valleys in the bedrock surface, but the main stream, McIntire Wash, cuts across a bedrock high and has become incised into the Denver formation.

As would be expected, the best exposures of the Denver formation are along the steep sides of the slopes. Such slopes are incompletely mantled by thin Recent colluvial deposits and have a complex areal pattern of outcrops that are shown only diagrammatically on the map. A few outcrops of the bedrock are found on the upland surfaces but not enough to permit reconstruction of the bedrock surface in detail. It should be noted, however, that on the upland in the southeast part of the area, between Cherry Creek and the South Platte River, the Denver formation is exposed in the west-facing slopes. This part of the upland is overlain with eolian sand and silt which is thick on the eastward, or leeward slopes, but thin or absent on the westward, or windward, slopes.

SURFICIAL DEPOSITS

PLIOCENE OR PLEISTOCENE DEPOSITS

In the west half of the area are numerous isolated hills that are capped by gravel deposited by streams that antedate the present valleys. These gravel-capped hills are the highest ground in the area. No such deposits are found east of the South Platte River; it is presumed, therefore, that the ancient master drainage was northward much as it is today.

The alinement of the row of gravel-capped hills south of Bear Creek suggests that the deposits represent an ancient course of Bear Creek (pl. 4, section *F–F′–F″*). Moreover, west of this area there is another and larger remnant of similar gravel alined with these hills. This line of gravel-capped hills extends westward to within 2½ miles of the mouth of Bear Creek canyon which debouches from the mountains at the town of Morrison 4 miles west of this area.

At the westernmost hill the altitude of the top of the gravel is about 5,770 feet; at the easternmost hill, a mile from the South Platte River, the altitude of the top of the gravel is 5,500 feet. This difference of 270 feet in 5½ miles represents an average gradient of slightly less than 50 feet per mile. The altitudes of the gravel on the other knobs coincide with the general gradient. In the same distance modern Bear Creek has an average gradient of about 35 feet per mile. The gradient on the hilltop gravel deposits projected westward to the town of Morrison intersects the hogback ridge north and south of Bear Creek Canyon several hundred feet below the ridge top. Evidently Bear Creek had already formed its canyon at the present site of the town of Morrison when these high gravels were deposited.

The gravel on the hills is more than 10 feet thick. It is coarse and includes a large quantity of cobbles as much as 6 inches in diameter. The material is largely granitic, gneissic, and quartzitic, and obviously was derived from the Front Range. Some sand and a little silt is included with the gravel, but on the whole the deposits are well sorted. All of them are strongly impregnated with lime carbonate, which forms a coating on most of the pebbles. This caliche is a residual effect of pre-Wisconsin weathering (p. 102).

A 2-foot bed of volcanic ash is interbedded with the gravel on the hill at the northeast corner of sec. 12, T. 5 S., R. 69 W. This ash bed appears massive although it parts along bedding planes that are not at all evident in the outcrop. The ash bed overlies and is overlain by coarse gravel. It covers only a few acres on top of the hill and was not found on the other hills to the east or west.

A spectrographic analysis of a sample of this ash, serial no. 56842, plate no. II–342, analyzed by A. T. Myers, of the U. S. Geological Survey, showed the following:

Si	xx	Ce	.0x−
Al	xx−	Cu	.000x
Fe	x−	Ga	.00x−
Ti	.x−	La	.0x−
Mn	.0x	Nb	.00x+
Ca	.x	Nd	.00x+
Mg	.0x+	Pb	.00x−
Na	x−	Pr	.00x
K	x−	Sr	.0x−
Ba	.x−	Y	.0x−
Be	.000x	Zr	.0x

Looked for, but not found: Ag, As, Au, B, Bi, Cd, Co, Cr. Ge, In, Ir, Hf, Hg, Li, Mo, Ni, Os, P, Pd, Pt, Re, Rh, Ru, Sb, Sc, Sn, Sm, Ta, Th, Tl, Te, U, V, W, and Zn.

A sample of the ash was submitted to the Kansas Geological Survey for comparison with the Tertiary and Pleistocene ash beds that their geologists have studied in Kansas and Nebraska. The samples were examined by Ada Swineford. In a personal communication John C. Frye reports that the Denver area sample is different from the Tertiary ashes they have studied, but that it is very similar to the Pearlette ash, which is regarded as Yarmouth in age.

This suggestion of a Yarmouth age for these high and old gravel deposits, however, conflicts with other evidence which indicates that the present valleys had been cut practically to their present depth by Yarmouth time (p. 98). The ash-bearing gravel is about 200 feet higher than Bear Creek and 250 feet higher than the South Platte River. The gravel very likely represents a former bed of Bear Creek, and because the gravel caps the highest hills in the area this means a topographic reversal with the lowest parts of the an ient landscape, the gravel beds, now forming the highest hills—which is very different from mere valley deepening. If the oldest deposits found in the present valleys are Yarmouth, the high gravels south of Bear Creek must be much older. They could be as old as Pliocene. Until paleontologic evidence is found, the age of these high gravels must remain uncertain.

Gravel deposits also cap the hills at the west edge of the area north of Bear Creek. This gravel, however, includes considerable andesitic debris, and the deposits were probably derived from erosion of the Denver formation on Green Mountain, 2½ miles to the west.

Other high-level gravel deposits, also largely quartzitic, cap the hills north of Clear Creek. These deposits were derived by reworking still more ancient pediment gravels located at the foot of the Front Range northwest of this area. The gravel deposits north of Clear Creek and those at the west edge of the area north of Bear Creek rest on what may be old pediment surfaces. These deposits therefore could be younger than the deposits capping the row of hills south of Bear Creek; they could have been deposited on and graded to the upland surface while the main streams were incising themselves into their present valleys.

An isolated gravel deposit composed largely of quartzitic material caps Ruby Hill overlooking the South Platte River at the center of the south side of sec. 21, T. 4 S., R. 68 W. This is the highest point in that vicinity, 150 feet above the river, and, since the deposit was formed, the upland surface west of the gravel has been eroded 25 feet below the gravel. A similar isolated gravel-capped hill, 170 feet higher than the river, is a mile north of Welby (west side, sec. 25, T. 2 S., R. 68 W.).

PLEISTOCENE DEPOSITS

PRE-WISCONSIN DEPOSITS

ALLUVIAL GRAVEL

Pre-Wisconsin Pleistocene gravel deposits occur in some high terraces and others not so high along the main streams. These deposits date from a time when the South Platte River and its principal tributaries had become incised into their present valleys.

The most expansive deposit caps the 2-mile-square bench lying between Clear Creek and the South Platte River and directly north of Denver. This gravel, about 15 feet thick, rests on the Denver formation and is overlain by a thin mantle of eolian sand. The top of the gravel, which is about 40 feet above the flood plain of the South Platte River, slopes slightly toward the river. The following section was measured in a gravel pit on the east edge of the deposit.

Section of pre-Wisconsin gravel measured in gravel pit at center SW¼ sec. 11, T. 3 S., R. 68 W.

	Feet
Surface.	
Loam, dark brown, or loamy sand, late Pleistocene or early Recent; Recent soil, disturbed. Sharp contact with the layer below	1. 5
Gravel, strongly lime enriched, upper 2 feet in part reddish and clayey or loamy. Gravel has high percentage of crumbly gneiss, granite, and schist; common large size is 5 inches. Lime is uniformly distributed through upper part but occurs in veins and nodules in lower part; the veins become smaller and branch downward. Probably pre-Wisconsin subsoil	4
Gravel, cobble size, like above but with very little lime; some staining by iron and manganese oxide. Includes some lenses of stratified sand that are 10 feet long and 1 to 2 feet thick	11
Base. Denver formation.	

The age of this gravel deposit, which can be traced along each side of Clear Creek upstream to the west edge of the area, is not known. It is much coarser and more weathered than the Wisconsin gravel deposits. Locally its upper surface contains remnants of a pre-Wisconsin soil, and it is overlain by eolian deposits that in part are of Wisconsin age. Assuredly the gravel represents outwash from pre-Wisconsin glaciers in the Front Range; it presumably is as old as Illinoian, and probably is as old as Kansan.

Along the north side of Cherry Creek just southeast of the city and along the south side of Sand Creek northeast of the city are some other exposures of pre-Wisconsin gravel. These deposits were derived from the southeast. Both were deposited as fill in the valleys and each contains two or more buried pre-Wisconsin soils. Fossil vertebrates that suggest a Yarmouth age were found in each of the areas. The following sections are representative of the deposits in the two areas:

Section in gravel pit by Cherry Creek, NE¼SE¼ sec. 17, T. 4 S., R. 67 W.

	Feet
Surface.	
Sand and silt, wind-deposited, brown. Probably Wisconsin or younger. Remains of *Citellus* and related animals abundant elsewhere in this deposit	3
Clay and silt, reddish, strongly impregnated with lime. Probably a remnant of a pre-Wisconsin (Sangamon?) soil developed on an eolian deposit	6
Gravel containing *Equus*	8
Eolian(?) deposit, weathered, consisting of 2 feet of lime-free reddish clay and silt over 2 feet of lime-enriched clay and silt. Probably a remnant of a Yarmouth soil	4
Sand, some fine gravel	10
Base.	

The bone that was collected from the gravel was examined by Jean Hough, of the U. S. Geological Survey, who reported as follows:

The bone is the distal end of the tibia of a small horse. (*Equus* sp.?)

This tibia agrees almost exactly in size and other features with the corresponding bone of specimens of *Equus excelsus* Leidy in the U. S. National Museum collections from Niobrara River, Nebr., but is less completely fossilized. The gravels from which the *E. excelsus* specimens were collected are now dated as middle Pleistocene (Yarmouth). (For details, see Geol. Soc. America Bull., v. 59, p. 566–567, 1948.)

Species of horses cannot be identified by fragments of limb bones, so the determination of the age is merely tentative.

The exposures along Sand Creek are illustrated by the following section:

Section along south bank of Sand Creek, south side of SW¼ sec. 17, T. 3 S., R. 67 W.

	Feet
Surface.	
1. Sand, loamy. Upper foot is dark brown; second foot is light brown; bottom foot is calcareous with lime occurring in anastomosing veinlets. This unit together with the one below is interpreted to be an early or middle Wisconsin eolian deposit	3
2. Sand, bedded, partly grit, probably a fluvially reworked eolian deposit. *Citellus richardsoni* (Sabine) and *Cynomys ludovicianus*	3
Unconformity.	
3. Clay loam, red, much lime in tiny veinlets	1
4. Sand, lime-rich loamy, in beds a few inches thick. Lime is in veins. This unit and the one above are remnants of a pre-Wisconsin, probably Sangamon, soil	6

Section along south bank of Sand Creek, south side of SW¼ sec. 17, T. 3 S., R. 67 W.—Continued

	Feet
5. Sand, fine, brown, horizontally bedded; little lime	1
6. Loam, lime-cemented, massive. *Citellus richardsoni; Cynomys ludovicianus*; low molars of *Equus* cf. *excelsus* Leidy	3
Unconformity.	
Locally a second pre-Wisconsin soil including an upper red-clay layer over a lime-rich layer. The parent material is silt. This is probably a Yarmouth soil.	
7. Gravel, common large size is 0.25 inch in diameter. *Cynomys ludovicianus* and molar of *Symbos* cf. *promptus* Hay	7
8. Gravel, loamy. Top 3 feet grades westward into clean sand	6
Base.	

The fossil vertebrates collected from the section in Sand Creek were examined by Jean Hough who reported as follows:

The rodents *Citellus* (ground squirrel) and *Cynomys* (prairie dog) do not help date the deposits because the same species are found throughout the late Pleistocene and are indistinguishable from modern forms inhabiting the region.

The horse teeth (*Equus* cf. *excelsus* Leidy) and the molar of the musk ox (*Symbos promptus*) do determine these beds as pre-Wisconsin or at the latest very early Wisconsin. Both of these forms are characteristically middle Pleistocene although a later range has been postulated for them.

Also, loose on the surface of unit 6 was found a bone that Doris Cochran, of the U. S. National Museum, identified as "the caudel vertebra of some reptile, possibly a large snapping turtle."

A collection from unit 7 in the Sand Creek section has been identified by C. B. Schultz and Lloyd Tanner, of the University of Nebraska State Museum, as follows: "Lower cheek tooth (incomplete) of horse, *Equus* cf. *excelsus;* compares favorably with examples from the Sappa formation (Yarmouth interglacial) of western Nebraska. Proxima phalanx of a small cervid (deer); not diagnostic."

Another collection was made nearby from a bed equivalent to unit 7 in the section above. The locality is center, south side, SW¼ sec. 17, T. 3 S., R. 67 W. Mrs. Hough reported on this collection as follows:

The collection includes—

Ankle bone (calcaneum) and a broken metapodial of an antilocaprid (antelope) or cervid (deer) probably the latter. It could be *Cervalces,* a primitive deer described by Hay, from Pleistocene deposits (late Aftonian to early Kansan) at Afton, Okla. The bones are very much smaller than the corresponding bones of antelope or deer that inhabit the region today, and they agree well in size and other characters with those of a specimen of *Cervalces roosevelti* Hay in the U. S. Natural Museum collection. The material is insufficient, however, to make a positive identification of the calcaneum as *Cervalces.*

Fragments of horse teeth.

Rabbit bones including a fragment of a scapula, the distal end of a tibia, a vertebra, and a broken radius.

Lower molar of a prairie dog.

The material in the collection is too fragmentary for accurate determination. It would be my opinion that the lagamorph and rodent bones are younger than the horse and cervid remains. The latter could well be Yarmouth.

Underlying the Wisconsin sand and gravel that forms the prominent terrace along the east side of the South Platte River (p. 104) is a cobble gravel at least 15 feet thick that probably is pre-Wisconcin in age. Cobbles 6 inches in diameter are abundant and are composed of granite, quartz, quartzite, gneiss, and some petrified wood. No fossils have been found in this gravel. Interbedded with the gravel are lenses of sand and grit as much as 6 inches thick and a few to several feet long. In a cut at the very north end of the area, at the center of the north line, NE¼ sec. 20, T. 2 S., R. 67W., was observed a reddish clay soil over lime-enriched cobble gravel. The soil is buried by the the Wisconsin deposits and probably is pre-Wisconsin in age. Similar cobble gravel, but lacking the soil, is exposed in the lower part of deep pits at many places under the Wisconsin terrace. The cobble gravel presumably represents a continuous deposit, but there is no means for correlating it with either the fossil-bearing gravels along Cherry Creek and Sand Creek or the gravel capping the bench between Clear Creek and the South Platte River.

Elsewhere in the area the pre-Wisconsin gravel deposits are exposed only on the uplands where they were derived from reworking of earlier upland gravels. At many places the pre-Wisconsin gravels can be traced up tributaries that head toward older gravel deposits; this feature is especially noticeable south of Bear Creek.

The composition of these gravel deposits depends upon their source. South of Bear Creek they resemble the Pliocene or Pleistocene gravel capping the isolated hills there (p. 96). North of Bear Creek the upland gravels are coarse and include a large proportion of granitic and gneissic rocks, similar to the gravel in the upper part of the Denver formation. As a result of later Pleistocene weathering and soil development, all these upland gravels are strongly impregnated with calcium carbonate which coats the pebbles in addition to impregnating the matrix. Many of the gneissic, granitic, and sparsely scattered lava pebbles are decomposed and crumble easily.

Only locally are these deposits more than a very few feet thick. One that is exceptionally thick (15 feet) is at the side of Lakewood Gulch in the SW¼ sec. 1, T. 4 S., R. 69 W.

RESIDUUM

The uplands are blanketed with residual deposits of deeply weathered reworked alluvium, reworked loessial deposits, and lag gravel. These deposits are extensive in the western part of the area, and they underlie much of the younger eolian deposits that blanket most of the eastern part.

Where the upland deposits are gravel, some of them are colluvial many are fluvial, and others are lag gravels from the weathering of older deposits. The gravel is coarser than in the Denver formation—cobbles 6 inches in diameter are common even where the Denver formation is not conglomeratic or contains only small pebbles.

All these deposits have been deeply weathered. A large proportion of the pebbles and cobbles in them are crumbly, and mixed with them is much clay or silt. Many of the deposits are thoroughly impregnated with lime carbonate. These weathered upland deposits (residuum) are the remnants of a deep soil that was formed in pre-Wisconsin time.

In its original state the old soil probably consisted of several feet of reddish clay above a layer 10 feet or more thick composed of weathered parent material strongly impregnated with lime carbonate and other salts leached from the overlying clay. This considerable development of lime from parent materials that contain only moderate amounts of clay and almost no original calcium carbonate attests to severe weathering.

The remnants of the old soil generally include the lime-enriched layer but rarely more than a foot or so of the lower part of the overlying clay. The remnants locally are as deep as 10 feet; augering probably would disclose localities where greater thicknesses are preserved.

The old soil is similar to the other pre-Wisconsin soils in the Rocky Mountain region (Hunt and Sokoloff, 1950). The association of pre-Wisconsin vertebrate fossils with these soils in this area (p. 99), the similarity of the soils to other known pre-Wisconsin soils, and the absence of similar soils on known Wisconsin or younger deposits leave little doubt but that the old soil comprising the residuum in the Denver area also is the remnant of a pre-Wisconsin soil or soils.

There are many similarities between this old soil and the pre-Lake Bonneville soil in Utah. Both have a thick upper layer of clay in which the parent material is so decomposed that it cannot be identified megascopically. Below the clay is weathered parent material strongly impregnated with lime. The lime-enriched zone is several times thicker in Utah than in the Denver area, but this is readily attributable to the abundant limestone in the parent materials of the ancient soil in Utah. In addition, in Utah and in the Denver area, erosion of the old soil gave rise to thick clayey or silty deposits—in Utah these younger deposits are represented by the lacustrine Alpine formation; in the Denver area the erosion products accumulated as Wisconsin alluvium.

The origin of the clay layer is uncertain. Part of the clay was probably derived from the weathering of pre-Wisconsin loessial materials, but part of it also was probably derived from the decomposition of hard rocks, either as bedrock or residual gravel, that were underlying the loess. The similarity of the clay through the Rocky Mountain region, regardless of great variations in the composition of the underlying parent materials, suggests a loessial origin.

The origin of the lime zone also involves uncertainties. At many places this lime zone assuredly is largely, if not entirely, the product of soil processes, but even at some of these places the overlying leached layer is thin and the quantity of lime in the lime zone seems to be excessive to have been derived from this thin leached layer. This could easily be attributed to erosion of the surface layers, but leaves unanswered how thick must the leached layer have been to develop the lime zone.

The silt and clay content of the clay horizon of the pre-Wisconsin soil in the Denver area generally exceeds 50 percent and locally is as high as 70 percent.

In the Louisville quadrangle, immediately northwest of the Denver area, Malde (1954) found that illite is the dominant clay mineral in pre-Wisconsin soil in that area. Illite probably is the dominant clay mineral in these soils rather generally in the Rocky Mountain region. The samples that have been reported as containing much montmorillonite in addition to illite (Hunt and Sokoloff, 1950, p. 111–113) very possibly represent samples of pre-Wisconsin clay containing admixed Wisconsin loess or volcanic ash.

Some of the clay contains sand coarser than 20 mesh screen, and a considerable proportion of these sand grains are subangular and deeply pitted.

The pH value of the leached clay generally is around 7.0; the pH of the lime-enriched layer almost invariably is above 7.5. One cannot be certain, however, to what extent the pH values in the soil have been changed as a result of alterations during the successions of climate that have prevailed since the soil developed.

Where the lime-enriched zone is stony or gravelly, the lime coats the pebbles and thoroughly impregnates and whitens the interstitial silt and clay. Where the lime zone is silty or clayey, the whole layer generally is uniformly impregnated by lime in veins that become thinner and divide into branches downward.

At the time the old soil was formed, the topographic surface of the uplands had more relief than does the present surface. The old soil today is preserved on the divides between the alluviated flats. The lower part of the old soil, the lime-enriched zone, is generally found along the crests of the divides; the upper part of the soil, the lime-free clay, is generally found only on the lower slopes along the flanks of the divides. The clay has been washed off the crests of the divides to add to the alluvial fill in the depressions. The local relief on the

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uplands today probably is at least 20 feet less than was the relief at the time the old soil was formed.

The residuum is the parent material for certain of the Larimer soils and part of the Fort Collins clay (p. 126).

With the exception of one possible occurrence recorded by the Denver Museum of Natural History, no fossils have been found in the residuum. The specimen consists of a fragmentary mammoth pelvic bone that was found on the west side of Ruby Hill at the edge of a small gully 1,000 feet south of West Florida Street, 750 feet east of the South Platte River, and about halfway up the west wall of the river valley. The bone was found in a clayey colluvial layer about 1 foot thick overlying the Denver formation and overlain by Piney Creek alluvium (p. 114). The fossil is older than the Piney Creek alluvium, but it could be Wisconsin in age and therefore younger than the residuum on the uplands.

WISCONSIN DEPOSITS

GRAVEL FILL

The most extensive gravel fill in the area forms the half-mile-wide Broadway terrace which lies along the east side of the South Platte River valley and 40 feet higher than the river. The fill also underlies the flood plains of the South Platte River, Bear Creek, and Clear Creek; a fill correlated with this one has been mapped in Cherry Creek. (See pl. 4.)

On the Broadway terrace the deposit is 12 to 15 feet thick. It overlies 3 feet of sand which may be a fluvially reworked eolian sand of Wisconsin age (p. 109); this sand overlies a cobble gravel which may be of pre-Wisconsin age (p. 101). On the river side of the terrace the base of the Wisconsin gravel fill apparently cuts downward unconformably across the underlying beds and is at least 15 feet below river level at the gravel pits excavated in the flood plain. Originally, therefore, this fill was at least 55 feet thick.

The fill is composed of rather clean gravel and sand. Most of the pebbles in the upper part are less than 1 inch in diameter, but a few are 2 to 3 inches. Along Clear Creek the lower part of the fill contains thick beds of cobble gravel. The gravels include about 60 percent pink granite, 20 percent quartz or quartzite, 10 percent gneiss, and 10 percent miscellaneous rock types. The gravel is well stratified; the beds are lenticular and considerably crossbedded. In the north part of the area about 10 feet below the top of the fill, the gravel contains a 1- or 2-foot contorted layer of silt.

The gravel fill evidently is outwash from the Wisconsin glaciers in the Front Range. The upper part, capping the Broadway terrace, undoubtedly is late Wisconsin in age.

The gravel along Clear Creek and Bear Creek is similar in texture and composition. For a few miles above the mouth of each of these valleys, however, the upper part of the fill has been removed without leaving terrace remnants (p. 132).

The gravel fill along Cherry Creek that is correlated with this fill also has similar texture and bedding but contains materials derived from the Paleocene and Tertiary formations in its headwaters.

The soil on the late Wisconsin gravel deposits consists of 1½ feet of brown silt-cemented gravel at the surface underlain by 1½ feet of gravel that is stained with iron and manganese oxides. The weakly developed profiles of Gilcrest soils are formed on these gravelly parent materials (p. 125).

Many bones of extinct animals, such as mammoth and camel, have been collected from this fill, mostly from the gravel pits along the Broadway terrace. A considerable number of such occurrences have been recorded by the Denver Museum of Natural History. Harvey Markman furnished the following list of mammoth, horse, and camel remains that have been collected from the gravel deposits along the main streams. Most of these almost certainly were collected from the Wisconsin gravel fill, but a few may have been collected from the older deposits that underlie it.

Pleistocene vertebrate remains from Wisconsin gravel fill in the Denver area

[List furnished by Harvey Markman, from records in Denver Museum of Natural History]

Denver Museum no.	Specimen	Locality
457	*Elephas* (*Mammonteus*) *primigenius* (molar tooth).	Alameda St. railroad underpass at Sante Fe Blvd.
464, 465, 466, 467	*Equus* (2 teeth), mammoth (2 tusks and part of femur), associated.	Gravel pit, 52d and York Sts.
473	Mammoth (molar tooth)	West Second and Kalamath Sts.
743	Mammoth (lower molar)	South Broadway and Kentucky Ave., 12 feet below surface.
761	Mammoth (tusk)	48th and Gilpin Sts.
776, 799, 800, 801, 1197	Mammoth (2 molars, piece of tusk, 1 molar reported from depth of 30 feet); *Equus* (tooth, associated with mammoth tusk and a molar).	Sand Pit of Arvid Olson, Louisiana and South Huron Sts., near Overland Park.
1150	Mammoth (molar tooth)	315 Clayton St.
1467	Mammoth (molar tooth and part of a tusk).	J. W. Brannan Sand and Gravel Co., 4818 Clayton St.
1472	Mammoth (molar tooth)	Cherry Creek at intersection of Cherry St.
1475	Mammoth (molar tooth, *see also* 1634).	Gravel pit, 52d and Columbine Sts.
1476	Mammoth (molar tooth)	Denver Country Club.
1477	Mammoth (molar tooth)	Derby (probably from one of the gravel pits on the Broadway terrace about one-half mile west of Derby).

Pleistocene vertebrate remains from Wisconsin gravel fill in the Denver area—Con.

Denver Museum no.	Specimen	Locality
1481	*Equus* (2 molars)	Gravel pit, 4800 Brighton Blvd.
1605	Mammoth, and probably camel (bone fragments, badly damaged, discarded).	Overland Pressed Brick Co., 1701 South Lipan St.
1634	Mammoth (molar tooth and about 5 feet of tusk, *see also* 1475).	Gravel pit, 52d and Columbine Sts.
1644	Mammoth (2 upper molars)	Mountain States Gravel Co., 5200 Filmore St.
1645	Mammoth (2 molars)	South Platte River west of Englewood. (Probably from gravel pit opposite mouth of Bear Creek.)
1652	Mammoth (large femur)	Gravel pit at West Exposition and Mariposa Sts.
[1]	Camel (cannon bone)	Sand pit on Cherry Creek Dr. near Monaco St.

[1] No number.

A bone from the gravel pit at the southeast corner, sec. 30, T. 2 S., R. 67 W., was identified by Mrs. Hough as "cannon bone of camelid, probably *Camelops* sp." Bison teeth from these same beds were identified as follows by C. B. Schultz and Lloyd Tanner, of the University of Nebraska Museum: "Fragments of lower incisor of *Bison;* not diagnostic."

A bone fragment from the gravel pit on the west side of the road at the center, sec. 31, T. 2 S., R. 67 W., was judged by Mrs. Hough to be a mammoth bone because of its highly porous texture. Also collected here was a bone that she identified as "the head of the humerus of an artiodactyl."

Other bone fragments collected from the Wisconsin gravel fill along the South Platte River valley seem to have been split or otherwise shaped by man (p. 120). One specimen (L–1–20) from the southeast corner, sec. 30, T. 2 S., R. 67 W., is particularly well shaped (fig. 22) and resembles the split bone fragments associated with Folsom points at the Lindenmeier site in northern Colorado. Specimen L–1–23 (fig. 22) is apparently split mammoth bone. A few chipped stones that may be crudely shaped artifacts were found with these split bone fragments. Continued search of this gravel fill will probably yield indisputable artifacts, presumably of Folsom man who was living on the High Plains before the mammoth and camel became extinct.

The lack of strong soil development on these fill deposits, the occurrence of Pleistocene mammals in them, their association with what are believed to be artifacts, and the probability that the gravel represents glacial outwash combine to indicate a late Wisconsin age for the upper part of the fill. The lower part of the fill, which underlies the bed of the South Platte River, may be early Wisconsin in age.

It is of interest to compare the longitudinal profile of the surface of the Broadway terrace with that of the bed of the South Platte River and its tributaries. Plate 5, which illustrates these profiles, shows that the terrace is highest above the river immediately downstream from the mouths of the principal tributaries. Below the mouths of Cherry Creek and Clear Creek the terrace is 50 feet higher than the river, but in the vicinity of Fort Lupton, in the middle of a stretch where the river is not joined by any major tributaries, the terrace is only 15 feet higher than the river. Farther downstream, where the river is joined by Saint Vrain Creek and the Big Thompson River, the terrace rises again to 50 feet above the river. It would seem that the river was unable to distribute evenly the load delivered to it by its larger tributaries. It is possible, of course, that the variation in height of the terrace is because the river has cut more deeply into the fill at the confluence of its major tributaries, but this is unlikely because of the smooth profile of the present bed of the river.

ALLUVIUM

Along the lower part of Weir Gulch and Lakewood Gulch at the west edge of the South Platte River valley is an alluvial deposit composed largely of clay and silt and evidently derived from the erosion of the deep clayey pre-Wisconsin soils that mantled the uplands adjoining the headwaters of the gulches. The alluvium contains more silt and clay (about 50 percent) and much less sand or gravel than the later alluvial deposits, and it is not so thinly bedded. The whole deposit is moderately calcareous. Locally the upper 2 or 3 feet of the alluvium is strongly mottled with lime carbonate, in a manner and to a degree characteristic of the lime zone in the Wisconsin soil in this area (p. 102).

Several collections of vertebrate fossils collected from the alluvium indicate a Pleistocene age but are not otherwise diagnostic.

Five of the collections were examined by C. L. Gazin, in the U. S. National Museum, who reported as follows:

A bone collected at Eighth Avenue and Federal Boulevard "appears to be the incomplete extremity of two fused limb bones, possibly the proximal end of a fused radius and ulna of a camelid."

A collection in Lakewood Gulch, 800 feet east of Sheridan Boulevard, includes "lower jaws, three cervical vertebrae, the radius and ulna of a bison, species of which cannot be determined."

A collection from Weir Gulch between Eighth Avenue and Alameda Boulevard includes "sternal rib portion and toe bone of bison and a cuboid of a camel."

A collection from Weir Gulch at Third Avenue and Federal Boulevard includes "lower jaw and rib fragments of bison."

A collection from Weir Gulch, 800 feet south of Alameda Boulevard, includes "skull and rib fragments of bison and the distal end of the humerus belonging to *Antilocapra*. Neither the bison nor the antelope material can be distinguished from the Recent forms of the region."

A collection from Weir Gulch, 500 feet south of Alameda Boulevard, was examined by Jean Hough, who reports as follows:

Bison: Fragments of vertebrae bearing zygapophyses for articulation with ribs; 1 complete cervical vertebra with high neural spine; 1 complete dorsal vertebra with low neural spine; frgaments of ribs; part of a radius.

The bison is large. Exact specific identification is not possible from these bones, but I think it could be safely referred to a late Pleistocene species, possibly, *B. occidentalis*.

Professor Arnold Withers, Department of Anthropology, University of Denver, collected a specimen from the alluvium at 26th Avenue and Zuni Streets. Mrs. Hough reports that "the bone, judging from the porous structure, probably is part of a mastodon or mammoth limb bone." This bone is wedge shaped (fig. 23, K–4–9) and resembles the split bone fragments that were collected from the gravel fill of the Broadway terrace.

The evidence as to the age of this alluvium is conflicting. The soil resembles the soil developed on the Wisconsin eolian deposits (p. 109) and suggests that the deposit is early Wisconsin (Iowan or Tazewell) in age. However, the same fossil mammals have been found in this alluvium as in the gravel of the Broadway terrace, and one of the bones seems to have been split in the same way as several that were found in the terrace. Moreover, the top of the alluvial fill is about the same height as that of the terrace. It seems likely, therefore, that the alluvium should be correlated with the fill of the terrace and that it is late rather than early Wisconsin in age.

EOLIAN DEPOSITS

Eolian deposits extend eastward across the uplands from each of the main valleys. These deposits are sandy near the valleys, which evidently provided the sources, but eastward they become finer textured, sandy silt or silt. Locally the sand facies is more than 15 feet thick, but the silt facies commonly is less than 6 feet thick. Where these deposits are known to be less than 2 feet thick, they have not been mapped. Where the deposits are largely sand, they have been considerably reworked during late Pleistocene or early Recent time. Because of this reworking, the sand facies of the Wisconsin eolian deposits is rarely exposed and does not appear on the map (pl. 3); it underlies the late Pleistocene or early Recent eolian sand. The latter, however, is omitted in most of the cross sections on plate 4 which are intended to show the probable stratigraphic relationship between the gravel on the upper part of the Broadway terrace and the

Wisconsin eolian deposits which underlie that gravel and extend eastward onto the uplands.

Most of the Wisconsin eolian sand or silt is massive, but a rude stratification can be seen in some places. The sand facies commonly contains less than 20 percent of material finer than 100 mesh screen; 20 percent is coarser than 20 mesh; 60 percent is finer than 20 mesh and coarser than 100 mesh screen. In the sandy silt facies 40 percent is finer than 100 mesh.

Weathering of the silt facies has developed some clay which, according to tests by the Bureau of Reclamation, is chiefly montmorillonite. This weathering of the silt has developed a rather distinctive soil profile that apparently was formed in Wisconsin time because the profile is the same whether it is buried by late Wisconsin deposits or is at the surface. (See p. 127; fig. 25). The upper foot of soil is brown and is darker than the underlying layers apparently because of admixed organic material. It is clayey and lime free. Beneath this is a light-buff zone, generally 1 to 2 feet thick, enriched in lime carbonate in the form of nodules 0.01 to 0.25 inch in diameter. The individual nodules generally are separated by an inch or so of relatively lime-free silt. The lime zone commonly has a distinct prismatic structure. Beneath it is structureless silt of darker buff than the lime zone.

In the sand facies or where the silt facies is underlain by gravel, the lime may occur in veinlets as well as in nodules. The underlying permeable layers are reddened with iron oxide and locally streaked black with manganese oxide.

The eastward thinning of the eolian deposits and the eastward diminution in grain size indicate that the winds were from the west. Moreover, the winds seem to have been from the southwest because the sand facies occurs along the northeast side of Cherry Creek and Sand Creek. The silt facies is thickest on the eastern or lee sides of the ridges and is thin or absent on many of the west-facing slopes. The later reworking of the sand seems to have been by northwesterly winds because north of Sand Creek the dunal topography has a decided northwest grain.

Wisconsin eolian silt is the parent material for the Fort Collins clay loam (p. 126).

Underlying the late Wisconsin gravel fill that forms the Broadway terrace and overlying the buried pre-Wisconsin cobble gravel is a bed of sand, in part gritty or pebbly, and 1 to 3 feet thick. This sand is well stratified. It contains abundant bones that have been identified by Mrs. Hough as *Citellus richardsoni* (Sabine), a ground squirrel, and *Cynomys ludovicianus*, a prairie dog. The bones are isolated from one another; no articulated bones were found. Nor were any burrow holes found. The sand is interpreted as having been originally an eolian deposit that formed across the terrace on the pre-Wisconsin cobble gravel but was reworked by the river when that old terrace was overlapped by the late Wisconsin gravel fill. I correlate the sand with the Wisconsin eolian deposits on the uplands to the east (pl. 4) and suspect that it is early Wisconsin in age.

The silt facies on the uplands to the east also contains abundant bones that Mrs. Hough has reported upon as follows:

Citellus richardsoni (Sabine).

Citellus sp., lower jaw: This is a very small species of ground squirrel. The mandible is unusually slender, and the teeth slant in a way unlike that of the known species inhabiting the region. It is not *Citellus richardsoni* (Sabine).

Cynomys ludovicianus: Femur, vertebrae and other fragmentary bones, probably intrusive.

Metapodial of a geomyid rodent. This specimen is unusual in being considerably larger than any of the species of geomyids living in Colorado today. In fact, the only Recent genus I could find that was at all closely similar was *Heterogeomys* and that genus is found only in Mexico. The specimen is identical with similar bones in the U. S. National Museum collected from early Pleistocene deposits in San Pedro Valley, Ariz.

At 34th Avenue and Locust Street: Part of the phalanx (toe bone) of a bovid, either a cow or bison. It could be Pleistocene or Recent.

East of this area, in road cut at center east side, sec. 30, T. 3 S., R. 66 W.: Distal end of cervical vertebra of an artiodactyle, possibly an elk. These bones are not diagnostic enough for specific identification and so cannot be dated more exactly then Pleistocene to Recent.

A bone collected from Wisconsin eolian sand near the Cherry Creek dam southeast of this area, in SE¼ sec. 36, T. 4 S., R. 67 W., was identified by Mrs. Hough as "proximal end of metapodial of a bovid, either a cow or small bison, with parts of shaft of bone, probably from the same animal." The top of the eolian deposit from which this collection was taken is marked by an unconformity along which were found camel bone and split bone. (See fig. 23, L–1–25; p. 112.) An upper jaw bone from the same place was identified by G. E. Lewis, of the U. S. Geological Survey, as American badger, *Taxidea taxus*.

Just west of the mapped area, at 2000 South Dayton St., on the north side of Cherry Creek, a well was dug through the late Pleistocene or Recent eolian sand (p. 112) into the Wisconsin eolian sand. Teeth collected in this Wisconsin eolian sand were identified by Mrs. Hough as *Equus* and described as follows:

Equus sp. (cf. Rancho la Brea-McKittrick horse.) Third and fourth upper premolars. Late Pleistocene, i. e., post-Sangamon. These teeth agree well in size, rectangularity of the crown, and degree of flattening of the protocone, etc., with the large horse from the tar pits at Rancho la Brea. This horse was formerly referred to *E. occidentalis*. Recently D. E. Savage (1951, Late Cenozoic vertebrates of the San Francisco Bay region: Calif. Univ. Pub. v. 28, no. 10, p. 239–253) has shown this horse to be a caballine rather than a plesippine species and hence distinct from *E. occidentalis*. He considers it also a different species from *E. caballus* but does not name the species.

At 32d and Leyden Streets, a mile west of the Denver airport, Wisconsin eolian sand is overlain by Pleistocene or Recent eolian sand. Three collections (UNSM field nos. 32–50, 33–50, 34–50) from this locality were identified as follows by C. B. Schultz and Lloyd Tanner, of the University of Nebraska State Museum:

32–50. Incisor and associated incisor of a small rodent; compare favorably with examples of *Thomomys* (Western Pocket Gopher); undoubtedly from Recent rodent burrow.

33–50. Right ramus of *Citellus* (ground squirrel); compares favorably with examples of *Citellus tridecemlineatus*, the Recent "Thirteen-striped Ground Squirrel"; probably from Recent rodent burrow in loess deposits.

34–50. Left ramus of *Citellus* (ground squirrel) associated with snake vertebrae; not complete enough to be diagnostic, but ramus noticeably larger than specimen 33–50 and specifically different; ramus and snake vertebrae appeared to be in place in the "lower loess" deposits at this locality; middle to late Wisconsin(?).

Other vertebrate remains, evidently from these upland eolian deposits, are recorded in the Denver Museum of Natural History. Mr. Harvey Markman furnished the following list.

List of Pleistocene vertebrate remains from Wisconsin (?) eolian deposits in the Denver area

[List furnished by Mr. Harvey Markman, from records in Denver Museum of Natural History]

Denver Museum no.	Specimen	Locality
(1)	Camel (cannon bone and carpals)	1300 Adams St.
1459	Camel (sacrum and 10 vertebrae, all damaged).	620 Clermont St.
1589	Camel (4 cervical vertebrae and fragments of other bones).	From excavation for basement at South High School.
1598	Camel (4 cervical vertebrae and a few fragments of other bones). Large, probably *Camelops*.	From sewer excavation at 2583 South Pennsylvania St.
1606	Mammoth (badly damaged skull of a young individual; fragment of ribs, vertebrae, and teeth).	South part of Denver Municipal Airport.
(2)	Camel, large, probably *Camelops* (fragments of cannon bone and foot).	Do.

1 No number.
2 Not cataloged.

These eolian deposits probably are early Wisconsin in age because (1) they contain a Pleistocene fauna; (2) they are believed to correlate with the sand that underlies the gravel of late Wisconsin age capping the Broadway terrace; and (3) the soil profiles on these eolian deposits are much less developed than the pre-Wisconsin soil profiles and are much better developed than the Recent soil profiles.

LATE PLEISTOCENE OR EARLY RECENT DEPOSITS

EOLIAN SAND

The late Pleistocene or Recent eolian sand along the east sides of the valleys (pl. 3) must have been derived by reworking the sand facies of the Wisconsin eolian deposits. Little or no eolian sand was transported from the riverbed to the uplands after the Broadway terrace was built. The supply of sand was cut off as soon as the South Platte River began cutting into the terrace, for the terrace lies east of the river, but it is practically without any covering of eolian deposits, which were derived from the valleys only while they were being aggraded.

In the northeastern part of the area are relicts of dunal ridges, some of them as high as 15 feet. They are largely free of stones; but in the intervening swales, where deflation has occurred, stones are not uncommon. The dunal ridges are alined northwest as if built by winds from the northwest, in contrast to the Wisconsin eolian deposits which seem to have been deposited by southwesterly winds (p. 109).

These relict dunes are the parent material for Greeley sandy soils (p. 125). They have a brown surface layer about 1 foot thick underlain by a somewhat more reddish layer, also about 1 foot thick, evidently stained by iron oxide. Profiles of this sort are typical of prehistoric Recent deposits in this area.

Archeologic records at the University of Denver record two triangular end scrapers from a sand pit between the airport and Sand Creek. The sand evidently is part of the late Pleistocene or early Recent eolian sand; the scrapers were found 6 feet below the surface. A bison tooth was reported from a higher level in the sand.

Except for some rodentlike remains, I found no fossils in these deposits in this area. A few miles to the southeast, however, in some excavations near the Cherry Creek dam, in SE¼ sec. 36, T. 4 S., R. 67 W., several bones were collected from the unconformity at the base of these beds. They were examined by Jean Hough, who has identified the following:

- Camel metapodial.
- Two skulls of prairie dog *Cynomys ludovicianus*.
- Lower jaw of ground squirrel, *Citellus richardsoni*.
- Toe bone and proximal end of the metapodial of a bovid, either cow or bison.
- Cannon bone (metapoidal) of antelope.

Associated with these remains were some pieces of split bone (fig. 23, L–1–25) that may have been shaped by man.

Several of the bones and particularly the split bone are partly fossilized, and this suggests that they are very old. These paleontologic data together with the evidence provided by the soils, by the stability of the dunes, and by the absence of eolian deposits on the Broadway terrace indicate that these deposits are early Recent or very late Pleistocene in age.

The late Pleistocene or early Recent eolian sand is the parent material for some of the sandy Greeley and Weld soils (p. 125).

RECENT DEPOSITS

In the Denver area can be distinguished two alluvial deposits that are Recent in age yet antedate the present flood plains. The older, which in this report is named the Piney Creek alluvium, is the thickest and most extensive of the deposits. The younger alluvium and the alluvium forming the present-day flood plains are shown together on the geologic map. Included with the Recent deposits are the pre-Piney Creek alluvial and gravel deposits capping the cut terraces along the South Platte River below the level of the Broadway terrace. Thin colluvial deposits mantle steep slopes in the area; these are incompletely shown on the map.

ALLUVIUM AND GRAVEL ON ROCK-CUT TERRACES

A terrace that has been cut into the gravel of the Broadway terrace extends for a mile north from the mouth of Sand Creek. This terrace was eroded about 10 feet below the top of the Broadway terrace and is mantled by a couple of feet of alluvium. The overlap of the alluvium against the inner edge of the terrace was observed in the gravel pit in SW¼SW¼ sec. 31, T. 2 S., R. 67 W. A similar alluvium-mantled terrace has been cut in the gravel immediately south of the mouth of Sand Creek.

Two feet of similar alluvium (not shown on the map) immediately overlies the Wisconsin gravel fill of the Broadway terrace at the gravel pit at the north edge of the area, center north side, NE¼ sec. 20, T. 2 S., R. 67 W. A bone collected from this alluvium was identified by Mrs. Hough as a canid tibia. She states:

> The characters are intermediate between those of *Canis rufus* (red wolf) and *Canis latrams* (coyote). The head is much larger and the shaft much thicker than that of the coyote. In these respects it resembles the red wolf, but the bone is much shorter than the tibia of the modern species. It is probably early Recent rather than younger.

The alluvium from which this collection was taken caps the Broadway terrace and is 40 feet higher than the South Platte River. The alluvium was deposited later than the Wisconsin gravel fill on which it rests, but it must have been deposited before the South Platte River had incised itself into the gravel fill. This alluvium must be older than the Piney Creek alluvium (p. 114) and probably represents a very temporary flood plain of the South Platte River at a stage immediately following deposition of the Wisconsin gravel fill.

Small gravel deposits overlie rock-cut terraces along the west side of the South Platte River valley and at heights as much as 40 feet higher than the river. The terraces are cut on the Denver formation. The deposits include a large proportion of cobbles of which about a third are granitic, a third are quartzitic, and a third are metamorphic, sedimentary, and andesitic. The finer gravels are rather similar to the late-Wisconsin gravel fill forming the Broadway terrace, but the proportion of cobbles is larger and they include a larger proportion of quartzitic material.

Most of the deposits are less than 10 feet thick, and many are less than 5 feet thick. They are younger than the late-Wisconsin gravel fill because they have not been buried by it. Probably they were deposited during the period of valley cutting that so largely flushed the Wisconsin gravel fill from the valley. The occurrence of these gravel-covered rock-cut terraces along the west side of the South Platte River valley and the absence of any remnants of the Broadway terrace along that side indicate that the river cut laterally into its west wall while eroding the gravel fill.

PINEY CREEK ALLUVIUM

The Piney Creek alluvium is hereby proposed as a new term for deposits along Piney Creek, an eastern tributary to Cherry Creek, in the NW¼NW¼ sec. 25, T. 5 S., R. 66 W., where about 7 feet of the alluvium is exposed. On top of it is an archeologic site which Arnold Withers, of the University of Denver, has identified as representing the Woodland Culture (p. 120). The alluvium itself at the type locality and at many other places has yielded abundant bison bones but has not yielded bones of unequivocal Pleistocene forms (p. 118). Charcoal, hearths, and stone artifacts (fig. 24) have been found in the alluvium.

Charcoal, associated with fragments of grinding stones, was collected from a hearth 18 inches below the top of the Piney Creek alluvium in the NW¼NW¼ sec. 25, T. 2 S., R. 68 W. A radiocarbon analysis of the charcoal, by J. Lawrence Kulp, of Columbia University, indicates an age of 1150±150 B. P. (A. D. 800±150). Presumably the specimen is older than this because of the impossibility of removing contaminating organic matter other than the noncarbonized obvious rootlets. The radiocarbon determination, together with the occurrence of Woodland artifacts on top of the alluvium at the type locality, indicates that the alluvium was deposited no later than 800 A. D., and it may well have been deposited considerably before the Christian Era. The Piney Creek alluvium evidently is a Recent deposit and probably is approximately equivalent to the alluvial Tsegi formation in northeastern Arizona and to the Calamity formation in west Texas (Hunt, 1953).

Stratification in the Piney Creek alluvium rises toward the mouths of the tributaries, and the composition of the sediments varies according to the kind of sediment furnished by the tributaries. Thus, the alluvium brought into Bear Creek from the south contains a great many pebbles and cobbles from the old gravel deposits to the south, but on the north side of Bear Creek the alluvial deposits are finer textured and the pebbles in them are derived from conglomerate in the Denver formation.

Along the lower 3 miles of Weir Gulch the Wisconsin alluvium was dissected by an arroyo, which later was partly filled by Piney Creek alluvium. Near the South Platte River the surface of this Piney Creek alluvium is 6 feet lower than the Wisconsin alluvium and is graded to the present flood plain of the river, whereas the Wisconsin alluvium is at the level of the Broadway terrace, 50 feet above the river (pl. 4, section *D–D′*). Three miles up Weir Gulch the two alluvial surfaces are 3 feet apart. Still farther upstream, west of Sheridan Boulevard, the two deposits were not distinguished; it is presumed that the older alluvium there is buried beneath the Piney Creek alluvium.

The Piney Creek alluvium along Cherry Creek is graded to the present flood plain of the South Platte River, but upstream it rises onto the Wisconsin gravel fill that is correlative with the Broadway terrace. (See pl. 4, sections *D–D′*, *E–E′*, and *G–G′*). At the east edge of the area the alluvium is on top of the Wisconsin gravel fill.

The Piney Creek alluvium is well stratified; individual beds commonly are several inches thick. The material is largely silt but contains many thin layers of silty sand and some gravel. A few pebbles or cobbles occur in the alluvium. Locally, especially in the deep and narrow valleys like Lakewood Gulch, the alluvium includes layers of coarse cobbly gravel in a silt matrix. Layers of clean sand are uncommon.

Many of the depressions occupied by the alluvium west of the South Platte River are broad shallow swales. Many also are strangely wide as compared to their length, and their surfaces commonly are only a few feet lower than the interflat divides. In places they are intricately interconnected, locally they are hanging valleys. They are indeed anomalous physiographic features, and I can offer no reasonable explanation for them.

The depth of alluvium in the middle of the broad swales is not known; so it is not possible to reconstruct the original form of the valleys in which the alluvium was deposited. The general areal pattern of the alluvial flats is dendritic, and the swales assuredly were originally the result of stream erosion. One cannot be certain, however, to what extent they were modified by wind erosion or deposition, or to what extent the alluvium and the alluvial flats have undergone deflation.

The ponds in the western part of the area are artificial, but the low gradients on the alluvial flats together with the impermeability of the ground provided many natural sites for the reservoirs.

The Piney Creek alluvium along the main valleys was derived locally and was deposited on the valley floors by the tributaries rising on the adjoining uplands. The main streams could only level off the deposits transported there by the tributaries. Fans at the mouths of the tributaries forced the main streams against the farther side of the valley. This accounts for the irregular surface on the flood plain of Bear Creek and parts of the South Platte River valley. The alluvium was deposited after these main streams had become incised into the Wisconsin gravel fill.

The Piney Creek alluvium comprises the parent material for Laurel clay and clay loam (p. 125).

Several collections of bones have been taken from the Piney Creek alluvium. Two of these were examined by C. L. Gazin, of the U. S. National Museum, who reported as follows:

1. Sanderson Gulch, 0.5 mile west of Federal Boulevard: "Lower jaw of the prairie dog, *Cynomys ludovicianus*."
2. Weir Gulch, 500 feet north of Alameda Boulevard: "Fused metatarsals, incomplete tibia, and rib portions of bison."

A bison jaw collected from the Piney Creek alluvium in Weir Gulch, 500 feet northeast of Eighth Avenue and Federal Boulevard, was described by Mrs. Hough as follows:

Lower jaw, probably *Bison* (*Bison*) *occidentalis*.

Species of bison cannot be separated by tooth structure alone, especially if the teeth are worn. In fact, unless a complete dental series is present, it is very difficult to determine the difference between *Bos taurus* (cow), *B. gunniens* (yak), and *Bison*. Size is therefore the only criterion.

The specimen is unusually large. The alveolar length of the teeth present, M^{1-3}, is 112 mm, well beyond the maximum given by M. F. Skinner (1947, Am. Mus. Nat. History Bull., v. 89, art. 3, p. 162) for the Recent plains bison, *Bison* (*bison*) *bison*. The presumption is therefore that the specimen is *B. occidentalis*, a late Pleistocene species, precursor to the modern form.

There still remains doubt, however, whether *Bison occidentalis* survived into the Recent because this jawbone could have been reworked from the extensive Wisconsin alluvium that flanks the Piney Creek alluvium at this locality and upstream from it.

The bones collected from the alluvium at the type locality were identified by Mrs. Hough as "*Bison* sp.; radius and part of the articular surface of the scapula." Other vertebrate remains collected from the Piney Creek alluvium in adjoining areas have been identified by Mrs. Hough as belonging to bison.

The paleontologic evidence indicates that Piney Creek alluvium is Recent; the archeologic and radiocarbon evidence indicate that it is before A. D. 800.

PROTOHISTORIC AND HISTORIC ALLUVIUM

Protohistoric and historic alluvium have been mapped only along the flood plains of the South Platte River, Bear Creek, Clear Creek, Sand Creek, and Cherry Creek. The alluvium can be traced up many of the tributary streams, but these deposits are not of mappable extent in those areas. Also, on many of the upland flats, especially west of the South Platte River, thin young alluvial deposits overlie the Piney Creek alluvium, but these younger deposits are not shown on the map.

These young alluvial deposits are much coarser in texture than either the Piney Creek or Wisconsin alluviums. As determined by field tests made with a hydrometer, one sample of the alluvium contains only 20 percent of silt and clay and another, 30 percent. Gravel layers and sand beds are common; the gravel commonly includes cobbles. The sand is crossbedded and streaked with thin layers of black sand.

The flood plain of the South Platte River consists of a very few feet of dark humus-rich sandy silt overlying granitic gravel. This gravel is part of the Wisconsin gravel fill although the upper part has been reworked. The sandy silt of the flood plain commonly is less than 2 feet thick, but locally it occurs in channels that extend several feet into the underlying gravel. The flood plain deposits along the other streams resemble those along the South Platte River.

These young alluvial deposits are the parent materials for most of the Cass soils and for the Laurel sandy soils (p. 124).

COLLUVIUM

Recent colluvial deposits mantle steep slopes throughout the area. These deposits generally are on bedrock and are thin. Like the alluvium they are rather uniformly, though not conspicuously, calcareous, and the uppermost few inches are leached of lime. The deposits represent the materials that are now or recently have been moving down the steep slopes by creep and sheet wash. They are so thin and scattered that no attempt is made to show all bedrock outcrops in the colluvial areas.

PALEONTOLOGY

The Pleistocene and Recent deposits in the Denver area have yielded abundant mammal and other bones, and this paleontologic record has been invaluable in working out the stratigraphy of the deposits. More than 100 collections were made during the field work, and the records of 32 additional collections have been furnished by the Denver Museum of Natural History. The localities where collections have been made are shown on plate 3.

Most of the identifications have been made by Mrs. Jean Hough, of the U. S. Geological Survey. Several were made by C. L. Gazin and one by Doris Cochran, of the U. S. National Museum. The record of collections in the Denver Museum of Natural History was furnished by Harvey Markman, of the Museum staff.

Practically all the collections are composed of single bones, and a large proportion of them are fragmentary. Only two assemblages of many bones, suggesting fairly complete skeletal remains, were found, both of bison in Recent deposits. Neither of these was excavated.

The stratigraphic occurrences of the 20 species of vertebrate animals that have been found in the Pleistocene and Recent deposits in the Denver area are shown in the following list.

Occurrences of Pleistocene and Recent vertebrate remains in the Denver area

[Known occurrences shown by X; possible occurrences shown by ?]

	Pre-Wisconsin		Wisconsin			Late Pleistocene or Recent	Recent			
	Alluvial gravel	Residuum	Gravel fill	Alluvium	Eolian deposits	Eolian sand	Aluvium and cobble gravel on rock-cut terraces	Piney Creek alluvium	Protohistoric and historic alluvium	Colluvium
Elephas primigenius (mammoth)	X	?	?	?	?					
Mammoth (or mastodont)	?	X	X	X	X					
Camelops sp. (camel)	X	?	X	X	X	?				
Symbos cf. *promptus* (musk ox)	X	?								
Equus cf. *excelsus* (horse)	X	?								
E. sp. (horse)			X	?	X					
Bison cf. *occidentalis*			?	?	?	?	?	[1] ?		
B. cf. *bison*							?	X	X	?
Antilocapra sp. (antelope)			?	X	?	?	?	X	X	?
Cervis sp. (elk)			?	?	X	?	?	?	?	?
Adocoileus sp. (deer)			?	?	?	?	?	X	X	?
Cervalces cf. *roosevelti* (moose)	X	?								
Canis cf. *rufus* (red wolf)						?	X	?		
Lepus sp. (rabbit)			?	?	?	?	?	?	?	?
Citellus richardsoni (ground squirrel)		X	X	X	X	X	?	?	?	?
C. sp. (not *richardsoni*)				?	X	?				
Cynomys ludovicianus (prairie dog)		X	X	X	X	X	?	?	?	?
Heterogeomys? sp. (prairie dog)				?	X	?				
Snapping turtle	?	?								
Taxidea taxus (American badger)			?	?	?	X	?	?	?	?

[1] See p. 116.

Although this list is incomplete and not all the identifications are specific, it agrees generally with the more complete record obtained in Nebraska (Schultz, Lueninghoener, and Frankforter, 1951, table 1). The record indicates a change in fauna in this area coincident with the break in the physical geology that, in this report, is accepted as the boundary between Pleistocene and Recent deposits.

Of the 19 species represented in the collections, 1 (*Bison* cf. *bison*) has not been found in this region in deposits older than Recent. Several, including mammoth, camel, and horse, have not been found in deposits younger than Wisconsin.

More adequate data on the paleontologic change from the Pleistocene to the Recent are provided by the paleontologic record that has been assembled in Nebraska. Schultz and Frankforter (Schultz, Lueninghoener, and Frankforter, 1951, table 1) list 115 mammals from Pleistocene and Recent deposits in Nebraska; of these, 84 are shown as Pleistocene and do not occur in the Recent. Thirty-eight species are recorded from Wisconsin deposits in Nebraska; of these, 17 have not been found in the Recent. Twenty-three species have been found in late Wisconsin deposits; of these, 4 (*Bison antiquus*, *B. occidentalis*, *Parelephas columbi*, and *Castoroides sp.*) have not been found in the Recent. Of 31 Recent species, 1 (*B. bison*) appears for the first time in the Recent; and 22 of the others, although of the same genus, are not necessarily the same species as in the Wisconsin and older deposits.

The collections also provide some information about the ecology of the Denver area in late Wisconsin time. Of the 22 collections of mammoth 18 were in flood-plain deposits, whereas 7 of the 11 collections of camel were from eolian deposits on the uplands. Evidently the mammoths preferred the valley bottoms whereas the camels ranged across the uplands as well as in the valleys.

In addition to the vertebrate remains a few mollusks were found in the Denver area, but no systematic collections were made. A fairly large mollusk fauna, apparently of late Wisconsin age, although perhaps early Recent, has been found as far west as Yuma County in eastern Colorado (Gebhard, 1949, p. 134). The mollusks in Yuma County were in a marl and reportedly associated with mammoth remains and with Folsom and Yuma artifacts. But the marl lies in a deflation hollow and may be younger than the mammoth remains and artifacts that it contains. Byron Leonard, of the University of Kansas, identified 19 mollusks in the fauna. According to him, 2 of the species indicate wetter environment than that prevailing in Yuma County today, and, if the correlation is correct, they help in reconstructing the conditions that must have prevailed in the Denver area during Wisconsin time. One of the species *Lymnea stagnalis* requires permanent water, as it cannot aestivate in mud during drought. Consequently the lakes causing the marl cannot have been ephemeral. The other significant species is *Menetus exacuous*, which is a woodland snail living near water, and hence suggests that Yuma County was thinly forested—at least around the lakes (Gebhard, 1949, p. 135). At the time the marl was deposited in Yuma County comparably moist conditions must have prevailed in the Denver area.

ARCHEOLOGY

The prehistoric cultures that have been recognized in the central plains, including the Piedmont and High Plains of Colorado, range in age from late Pleistocene to historic time. Archeology therefore is a valuable supplement to paleontology in deciphering the stratigraphy of Pleistocene and Recent deposits. The archeologic horizons as related to the stratigraphy of the Denver area as follows:

Archeologic horizons as related to geologic stratigraphy in the Denver area

Age	Archeologic horizon	Formation or event in Denver area
Recent.	Dismal River.	Arroyo cutting and development of modern flood plains.
	Upper Republican (about A. D. 1400).	Alluviation.
		Arroyo cutting.
	Woodland (about A. D. 1000).	
		Deposition of Piney Creek alluvium.
		Dissection of Broadway terrace.
Late Pleistocene or early Recent.	Yuma (?).	Deposition of eolian sand.
Pleistocene (late Wisconsin).	Folsom.	Deposition of late Wisconsin gravel fill and alluvium.

Although in the Denver area no unequivocal artifacts have been found in the late Pleistocene deposits, these deposits have yielded 30 pieces of bone believed to have been split artificially. Some of these pieces of split bone are illustrated in figures 22 and 23. Pieces of chert having irregular flake scars along their edges occur in the same beds with the split bone. There are five principal reasons for believing that the split bone records human occupation.

1. The split bone is highly restricted stratigraphically. All 30 pieces were found in the top 15 feet of the Wisconsin gravel in the Broadway terrace or at the unconformity at the base of the late

Pleistocene or early Recent eolian sand on the uplands. (See pl. 3.) If the bones were split by carnivorous animals, one would expect to find similarly split pieces at other stratigraphic horizons.

2. Two pieces of split bone (K–8–43 and K–12–3, fig. 23) that were found at younger stratigraphic horizons were associated with unquestionable artifacts.

3. It is known that this area was occupied by a hunting people (Folsom) at the time the late Wisconsin gravel and alluvium were being deposited. At Dent, Colo., 40 miles north of this area, in terrace deposits that are equivalent to the Broadway terrace, Folsom points have been found associated with the articulated remains of mammoth (Bryan and Ray, 1940, p. 48; Wormington, 1949, p. 38).

4. Many of the specimens appear to have been cut as well as split, for the fracture is oblique both to the surface and to the axis of the bone. The fractures do not show signs of gnawing.

5. The split bone occurs most commonly in association with other bones representing several species, as if the locality were near a midden.

Folsom remains probably should be sought in the alluvium or gravel fill that was deposited during the late Wisconsin, or at the unconformity at the base of the late Pleistocene or early Recent eolian sand that mantles the uplands immediately east of the principal valleys.

The age of the so-called Yuma points is not well established either archeologically or geologically. Most archeologists seem inclined to regard them as somewhat younger than Folsom, largely on the basis of typology, and it is a fact that they have never been found with mammoth (Wormington, 1949, p. 61) except for the reported and doubtful occurrence in Yuma County (p. 119). Various kinds of Yuma points have been found at many places in eastern Colorado on, or in, the late Pleistocene or early Recent eolian sand and in deflation hollows nearby. It is suspected that the so-called Yuma points are contemporaneous with the sand, but in the absence of stratigraphic evidence this is merely a guess.

The Denver area was occupied by man while the Piney Creek alluvium was being deposited. Charcoal, stone artifacts (fig. 24) and hearths have been found in this alluvium at many places. At the type locality of the alluvium, along Piney Creek southeast of this area, Arnold Withers, of the University of Denver, found a Woodland site on top of the alluvium. Charcoal from a hearth in the upper part of the alluvium in the north part of the Denver area gave a radiocarbon date of A. D. 800. The true age probably is older than this. (See p. 114.)

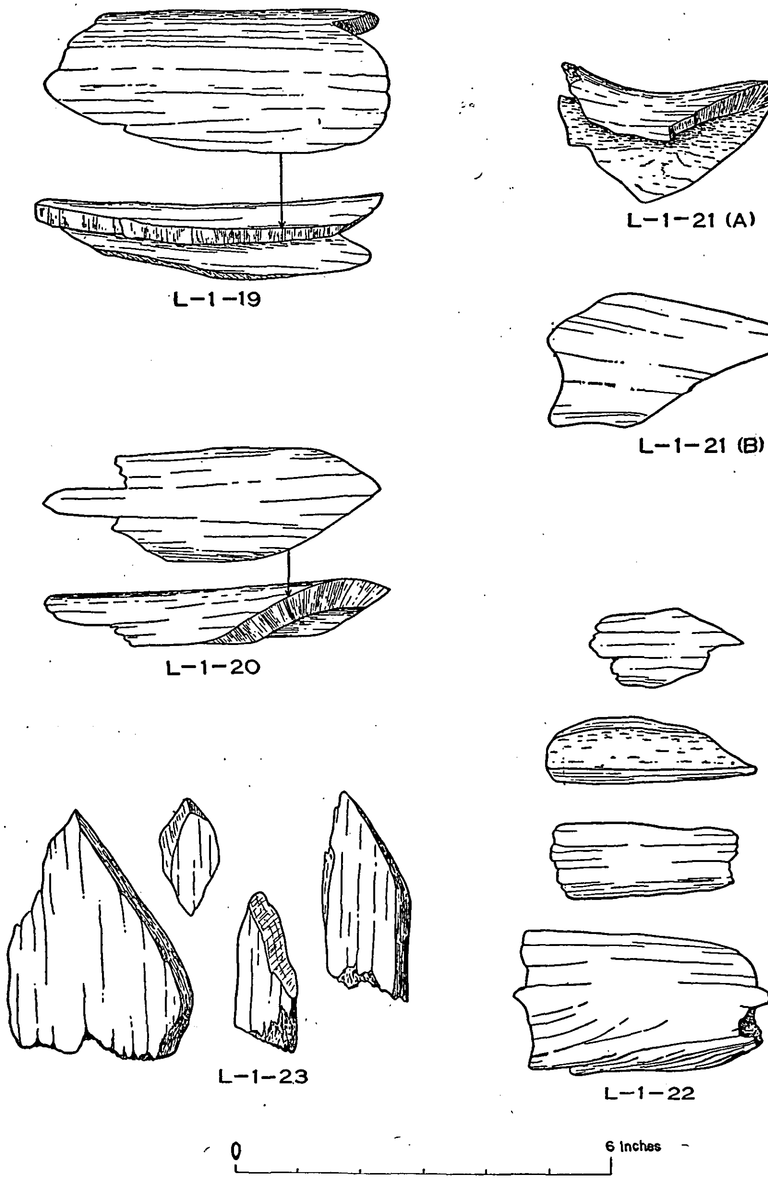

FIGURE 22.—Split bone from late Wisconsin deposits in the Denver area. Numbers refer to University of Denver catalog numbers.

L-1-19: from unconformity at base of late Pleistocene or early Recent eolian sand. SE¼NE¼ sec. 20, T. 3 S., R. 67 W.

L-1-20: from 10 feet below top of late Wisconsin gravel, SE¼SE¼ sec. 30, T. 2 S., R. 67 W.

L-1-21 (A) and (B): from late Wisconsin gravel, SW¼ sec. 13, T. 3 S., R. 68 W.

L-1-22: from late Wisconsin gravel, 1 piece loose, other pieces 15 inches below top. SW¼SW¼ sec. 31, T. 2 S., R 67 W.

L-1-23: from 12 feet below top of late Wisconsin gravel. These bones are very porous and are judged to be mammoth bone. NE¼SW¼ sec. 31, T. 25 S., R. 67 W.

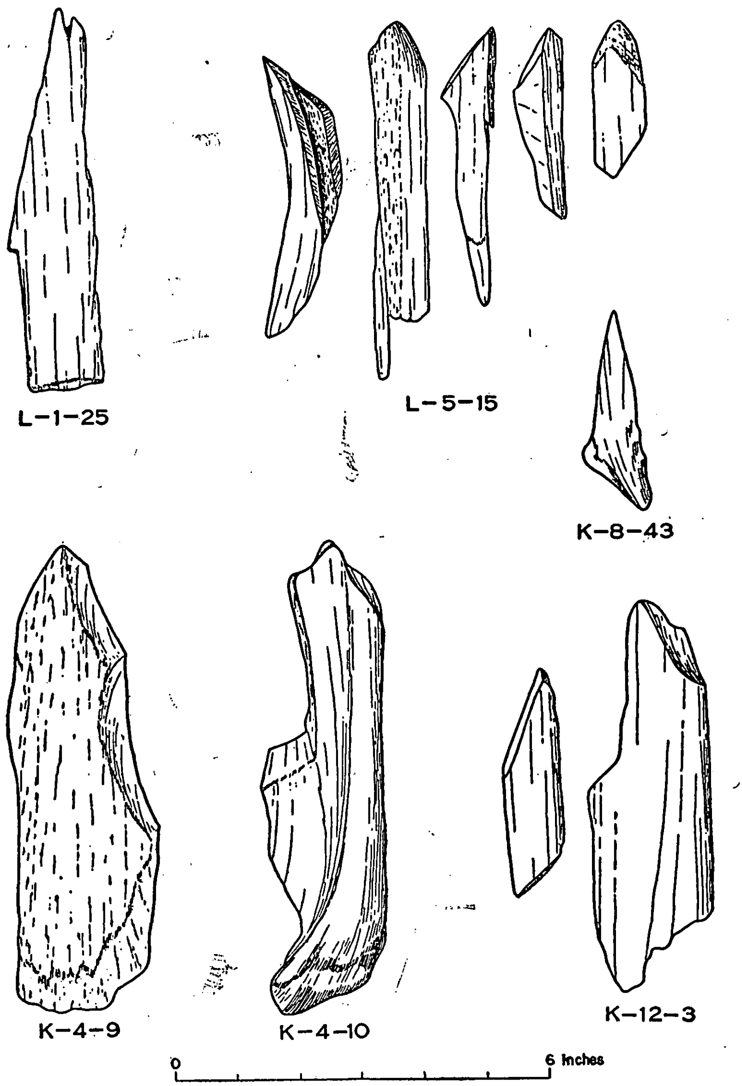

FIGURE 23.—Split bone from late Wisconsin and Recent deposits in Denver area. Numbers refer to University of Denver catalog numbers.

L-1-25: loose on surface, 4 feet below top of late Wisconsin gravel. North side NE¼, T. 2 S., R. 67 W.

L-5-15: from unconformity at base of late Pleistocene or early Recent eolian sand; associated with camel bone. SE¼ sec. 36, T. 4 S., R. 67 W.

K-4-9: from 2 feet below top of late Wisconsin alluvium at 26th and Zuni Sts. in Denver. This bone is very porous and is judged to be mammoth bone.

K-4-10: from 7 feet below top of late Wisconsin gravel in Clear Creek. 1,200 feet east of center of sec. 8, T. 3 S., R. 68 W.

K-8-43: from alluvium (probably Piney Creek) in Weir Gulch 500 feet south of Alameda Blvd., in Denver. Associated with articulated bison bones, antelope, and charcoal.

K-12-3: from alluvium (probably Piney Creek). Associated with metate and flaked stone objects. Sec. 11, T. 7 S., R. 69 W.

Natural size

FIGURE 24.—Projectile points having equilateral triangle blade and stem are believed to be typical of the occupations contemporaneous with the Piney Creek alluvium (early Woodland culture?) in the Denver area. This specimen from Piney Creek alluvium in Rock Creek, 8 feet below surface in SW¼NW¼ sec. 23, T. 1 S., R. 69 W., collected by M. R. Mudge.

The correlation of the Upper Republican and Dismal River archeologic horizons with the geologic formations or events in the Denver area, which is indicated in the table on p., 120 is wholly conjectural. The Upper Republican and Dismal River sites that are near Denver and that have been brought to my attention are on the uplands. It has not been possible as yet to relate these sites to the geologic events that have occurred in the last 900 years.

SOILS

The kinds of soil that will be developed in a given area are dependent very largely on the Pleistocene and Recent deposits and on the Pleistocene and Recent climatic history of that area. The soils in the north half of the Denver area have been mapped (Harper, Acott, and Frahm, 1932; it is possible therefore to examine in some detail the close relationships between the soils and the geology.

The soils that have been recognized in the area correlate with the geologic formations and history as follows:

Correlation between the geology and some of the soil types in the Denver area

Soil types and description (from Harper, Acott, and Frahm, 1932, p. 9, 10)	Parent material and geologic history of the soils
Laurel fine sand and very fine sandy loam. Light-colored soils of the first bottoms, developed over recently deposited material; stratified; sand noncalcareous, sandy loam mildly calcareous and micaceous.	*Protohistoric or historic alluvium.* On modern flood plains (about A. D. 1600 or later).
Cass loam and fine sandy loam. Nearly black, dark-brown, or dark reddish-brown surface soils; very slightly lighter brown subsoils, in many places, heavy. Waterworn gravel, fine sand, and finely divided mica are distributed throughout the surface soils and subsoils; essentially noncalcareous. Underlain by a gravelly layer.	*Protohistoric alluvium.* In the major valleys only (about A. D. 1400). These soils have been subject to flooding.

Correlation between the geology and some of the soil types in the Denver area—Con.

Soil types and description (from Harper, Acott, and Frahm, 1932, p. 9, 10)	Parent material and geologic history of the soils
Laurel clay and clay loam. Gray-brown clay to depth of 10 inches (in the clay-loam type this layer contains more fine sand). Below this layer to depth of 6 feet or more is a gray slightly compact layer; in most places mildly calcareous at all depths.	*Piney Creek alluvium.* Older than A. D. 1000; probably deposited about the beginning of the Christian Era. After this alluvium was deposited it was subject to flooding; but this condition ended when streams became incised into the alluvium soon after A. D. 1000.
Greeley loamy fine sand. To depth of 15 inches grayish-brown, noncalcareous mellow fine sand; contains many plant roots, slightly dark staining caused by accumulations of humus. Between depths of 15 to 30 inches rich-brown noncalcareous loam or heavy loam, high content of fine sand; firm, slightly cemented, tendency towards massive prismatic structure; commonly mildly calcareous. A few lime-carbonate nodules at depths of 4 to 6 feet. *Greeley fine sandy loam.* Similar in profile to loamy fine sand, but each horizon is sandy loam or loam.	*Late Pleistocene or early Recent eolian sand.* The parent material dates from the late Pleistocene or early Recent. The climatic changes since then include 2 relatively moist and 2 relatively dry periods. The history of these soils is further complicated because their upper few inches must have been repeatedly reworked by wind action during the dry periods.
Weld fine sandy loam. The 2½-inch surface layer is light fine sandy loam matted with grass roots; dark brown, noncalcareous, slightly laminated. Between depths of 2½ to 10 inches is light-brown noncalcareous firm but friable fine sandy loam or loam. Between depths of 10 to 18 inches is rich-brown noncalcareous slightly columnar clay loam or clay. Below 18 inches is olive-brown friable or loose fine sandy loam or loamy fine sand, moderately or highly calcareous.	The top 18 inches or so has had the same parent material and history as the Greeley loamy fine sand and fine sandy loam. At about 18 inches from the top is an unconformity below which are eolian deposits of Wisconsin age. Part of the weathering in this subsoil therefore dates from late Pleistocene time. Locally this same condition may be found in the Greeley soils.
Gilcrest gravelly sandy loam and gravelly loam. Developed on the terraces of the large stream valleys; the surface soils are slightly laminated, sandy, and more or less mixed with gravel; in many places the heavier subsoil is prismatic and has a well-defined layer of lime accumulation. The deep subsoil is gravel.	The deep subsoil is the Wisconsin gravel fill that forms the Broadway terrace. The surface soils comprise the alluvial layer capping that gravel and are early Recent in age. These soils were subject to flooding immediately following deposition of the Broadway terrace, but this condition ended when the South Platte River became incised into the gravel fill at the beginning of the Recent. The climatic changes since then include the dry period at the beginning of the Recent and subsequently 2 relatively moist and 2 relatively dry periods.

Correlation between the geology and some of the soil types in the Denver area—Con.

Soil types and description (from Harper, Acott, and Frahm, 1932, p. 9, 10)	Parent material and geologic history of the soils
Fort Collins clay loam. The 8-inch surface layer is slightly laminated grayish-brown mellow fine sandy loam. At average depth of 8 inches, color changes to brown, dark brown, or reddish brown; texture changes to clay; and structure becomes decidedly prismatic. The upper 22 inches has been leached of lime and carbonate but contains an accumulation of decomposed organic residue. Between 22 and 38 inches is grayish-brown calcareous clay with prismatic structure. Between 38 and 54 inches lime content is high, between 54 and 96 inches it is slightly less. The lime occurs principally in streaks and pockets.	*Wisconsin eolian deposits.* If these deposits date from early Wisconsin their climatic history includes the periglacial climates of the later substages of the Wisconsin, the mild interstadials of the Wisconsin, and the Recent climates. At various stages in this history the upper layers in some places were eroded and at others a few inches of younger sediment were added.
Fort Collins clay. Heavier texture than Fort Collins clay loam but otherwise similar.	The upper layers of this soil represent a fine grain facies of Wisconsin eolian deposits that have become admixed with the upper part of a pre-Wisconsin soil. The deeply weathered subsoil is pre-Wisconsin in age.
Fort Collins loam. The surface soil is gritty loam and contains both well-rounded and angular sand. The lower part of the surface soil is lighter in texture than that of the Fort Collins clay loam. The columnar clay layer beneath contains a few more angular fragments than the clay loam.	This soil has the same parent material and history as the Fort Collins clay but in addition has had some late Pleistocene or early Recent eolian sand added to its upper layers.
Larimer gravelly clay loam. Developed from old weathered materials. Top 8 inches dark-brown noncalcareous clay loam containing a few pebbles. Between 8 and 15 inches is reddish-brown noncalcareous clay having a vertical breakage. Below 15 or 20 inches is grayish-brown highly calcareous clay loam. Between 3 and 6 feet is horizon of still higher lime content. Below this is weathered parent materials of various kinds.	This soil dates from pre-Wisconsin time. Its climatic history includes the mild climate of the Sangamon stage, the alternating periglacial and mild interstadial climates of the Wisconsin, and the Recent climates. At various stages in this history the upper layers in some places were eroded and at others a few inches of younger sediment were added.

This summary correlation between the soils and geology of the Denver area highlights the fact that the geologically older soils have the more fully developed profiles. The soils on the Piney Creek alluvium and younger deposits have developed practically no profile except for the accumulation of some organic matter in the surface layers. Soils on the late Pleistocene or early Recent deposits have a darker and generally thicker organic-rich surface layer; below this is a layer with prismatic structure, and there has been some redistribution of soluble salts. Soils on the Wisconsin deposits have very well developed profiles, and soils on the still older pre-Wisconsin deposits have still better developed profiles.

This sort of correlation suggests that differences in profile development are the result of differences in the duration of the weathering process. But this conclusion fails to consider another equally pertinent fact; that is, the profiles of the ancient soils are just as well developed where they are buried by younger deposits as where they have remained at the surface. (See fig. 25.) Except for the fact that the top few feet of the buried soils were eroded before burial,

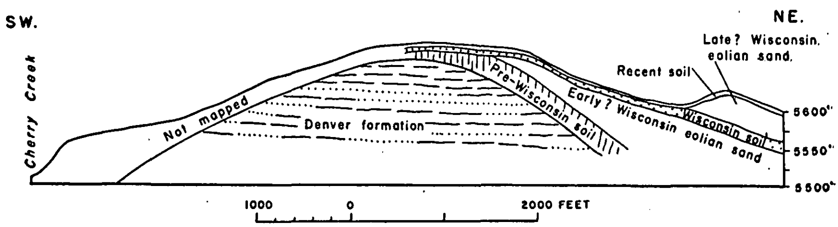

FIGURE 25.—Diagrammatic section along canal northeast of Cherry Creek in sec. 36, T. 4 S., R. 67 W., and adjoining sections. Wisconsin eolian deposits offlap the northeast (lee) side of the hill composed of Denver formation. A pre-Wisconsin soil on the Denver formation is buried by early(?) Wisconsin eolian sand. A Wisconsin soil on this sand in turn is buried by late(?) Wisconsin eolian sand. At the northeast end of the canal a Recent soil has developed on the late(?) Wisconsin eolian sand. Toward the southwest this Recent soil is superimposed on the Wisconsin soil. On top of the highest hill this combination has been superimposed on the pre-Wisconsin soil. Split bone and a camel metapodial were collected from the late(?) Wisconsin eolian sand.

these soils are as fully developed where they are buried as where they have remained at the surface. The buried pre-Wisconsin soil is more fully developed than the buried Wisconsin soil, and the buried Wisconsin soil is more fully developed than the Recent soil. To attribute these differences to differences in duration of weathering, it must be assumed that the periods of soil development have become progressively briefer since Sangamon time. This, of course, may be true, but so far the stratigraphic record has provided no evidence to show whether the periods of weathering were brief or long. It does evidence a succession of climatic changes that must have repeatedly affected the kind and rate of the soil-forming processes.

The mere antiquity, as such, of ancient soils therefore has no bearing on the intensity and depth of their weathering. Before soils can be used for interpreting the length of time required for their development, it is necessary to know what the climates and other factors that control rate of weathering were like when the soils were formed.

Correlating the geology and soils also suggests that the soil structures, such as the laminations in the surface layer and the prismatic structure of the underlying layer, may be Recent features. These structures occur in several of the soils that are Recent and (or) late Pleistocene in age. They also occur in the Wisconsin soils (Fort Collins clay loam) and locally in the pre-Wisconsin soils. These structures however were not found in the Pleistocene soils where they are deeply buried by younger Pleistocene or Recent deposits. It seems likely that these soil structures are comparatively young features and are the result of Recent weathering. Where they occur in more ancient soils, they probably have been superimposed on profiles that were already well developed.

Harper, Acott, and Frahm recognized that some of the soils in this area, notably the Larimer soils (1932, p. 12), involved the superposition of a weathering profile on already weathered parent materials. They also noted that certain other soils included an upper layer of sand that had been blown onto the surface of the older soil (1932, p. 16). The problem of superimposed profiles of different ages is worth elaborating because superimposed profiles are the rule rather than the exception in areas like this where the surficial deposits differ considerably in age.

Except as a soil that formed under an ancient climate became buried and stayed buried beneath younger deposits, that soil would itself become the parent material of a younger soil. Such parent material may be either the *A* or *B* horizon of the older soil, depending chiefly on the depth to which the older soil was eroded before the younger one developed.

In the Denver area, soils of three different ages have been distinguished—pre-Wisconsin, Wisconsin, and Recent. In the simplest case, illustrated by the right end of figure 25, the older soils have

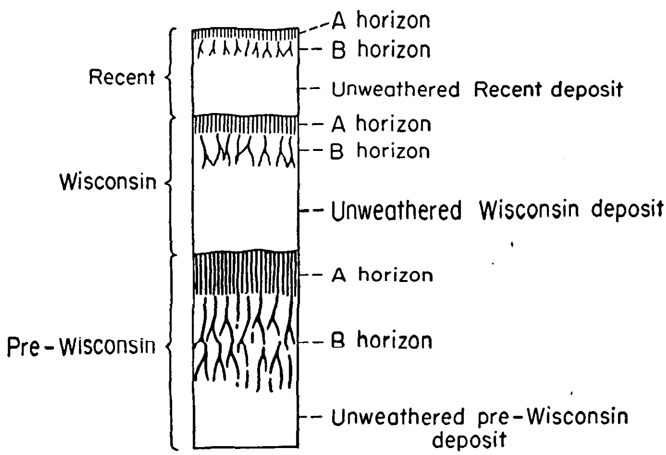

FIGURE 26.—Diagrammatic stratigraphic section illustrating relationship between pre-Wisconsin, Wisconsin, and Recent soils, where the older soils are buried under younger deposits. In this example each of the 3 soils developed from materials that were unweathered when those soils began to form.

been buried; they occur one above the other and are separated by unweathered Wisconsin and Recent deposits.

However, where the deposits thin out, as illustrated at the center of figure 25, the younger profiles become superimposed upon the remnants of the older ones. Clearly, the parent material of a Recent soil may have been any one of a great many possible combinations of older materials. Nine combinations that are common in the Denver area are as follows:

1. The parent material of a Recent soil may be unweathered (fig. 26). Found mostly on the Recent alluvial deposits or on the late Wisconsin or Recent eolian deposits. Soil examples: Some of the Cass, Laurel, and Greeley soils.

2 and 3. The parent material may be either the *A* or *B* horizon of a Wisconsin soil that developed on material that was unweathered when that Wisconsin soil began to form (fig. 27). Found mostly in the areas blanketed by thick eolian deposits of early or middle Wisconsin age. Soil example: Fort Collins clay loam.

4 and 5. The parent material may be either the *A* or *B* horizon of a Wisconsin soil that developed on the *A* horizon of a pre-Wisconsin soil (fig. 28). Found mostly in the areas blanketed by thin eolian deposits of early or middle Wisconsin age. Soil example: Fort Collins clay.

6 and 7. The parent material may be either the *A* or *B* horizon of a Wisconsin soil that developed on the *B* horizon of a pre-Wisconsin soil (fig. 29). Occurrence similar to preceding combination. Soil example: Larimer gravelly clay loam (in part).

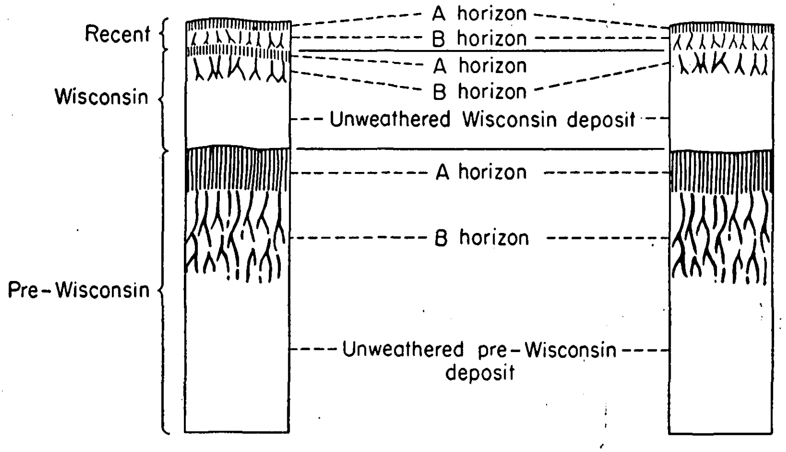

FIGURE 27.—Diagrammatic stratigraphic sections illustrating a Recent soil developed on the *A* horizon (left section) or the *B* horizon (right section) of a Wisconsin soil. In this example the pre-Wisconsin soil remained buried under Wisconsin deposits.

8 and 9. The parent material may be either the *A* or *B* horizon of a pre-Wisconsin soil (fig. 30). Found mostly in the areas blanketed by residuum. Soil example: Larimer clay loam (in part); Fort Collins clay (in part).

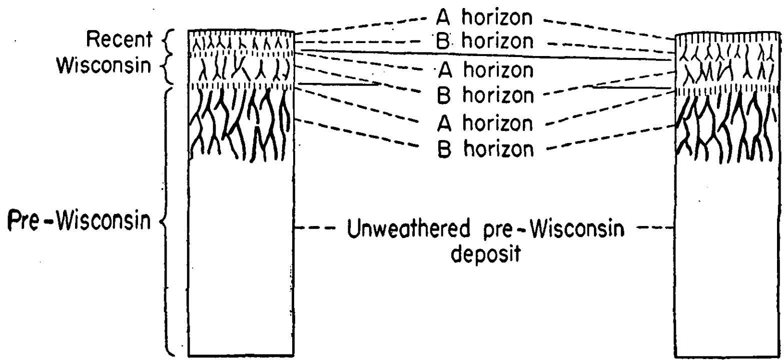

FIGURE 28.—Diagrammatic stratigraphic sections illustrating a Recent soil developed on the *A* horizon (left section) or *B* horizon (right section) of a Wisconsin soil that developed on the A horizon of a pre-Wisconsin soil.

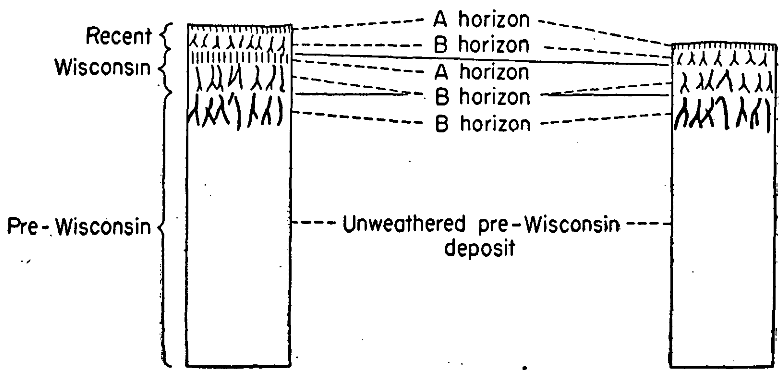

FIGURE 29.—Diagrammatic stratigraphic sections illustrating a Recent soil developed on the *A* horizon (left section) or *B* horizon (right section) of a Wisconsin soil that developed on the *B* horizon of a pre-Wisconsin soil.

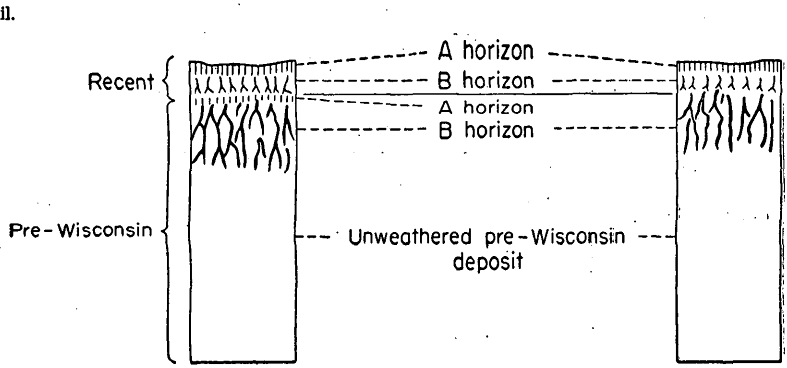

FIGURE 30.—Diagrammatic stratigraphic sections illustrating a Recent soil developed on the *A* horizon (left section) or *B* horizon (right section) of a pre-Wisconsin soil. In these examples, erosion has removed the layers that weathered during Wisconsin time.

Superimposed soil profiles of different ages sometimes can be recognized by discontinuities in the profile, such as abrupt changes in texture, abrupt reversals or other abrupt change in pH or color, or by the repitition of lime-free material beneath a lime-enriched layer. However the real proof that a soil consists of two or more superimposed profiles depends upon tracing the weathered layers laterally to where the older soils "peal off" from the base of the younger ones so that they become separated by unweathered deposits, as illustrated on the right side of figure 25.

PLEISTOCENE AND RECENT HISTORY

Evidence from both paleontology and soil studies indicate that by Yarmouth time, not only was the present drainage system well established, but the main valleys already were essentially as deep as they are today. The 30 feet or more of gravel that was deposited in the valleys during this or other pre-Wisconsin stages forms terraces along Clear Creek, Bear Creek, Cherry Creek, and Sand Creek. Before the beginning of Wisconsin time a terrace had been built along the east side of the South Platte River (pl. 6, *A*), 25 to 30 feet higher than the present river.

The present drainage system, including the northward course of the South Platte River, must have been developed before the beginning of Pleistocene time. Late Pliocene or early Pleistocene gravel deposits capping the row of knobs south of Bear Creek represent an ancient course of Bear Creek 250 feet higher than valley fill of Yarmouth age, and a couple of hundred feet lower than the Orodell berm, which has been inferred to be late Pliocene in age (Van Tuyl and Lovering, 1935, p. 1336). The eastward projection of this ancestral course of Bear Creek is lower than the uplands east of the South Platte River; therefore the old drainage must have turned northward pretty much as it does today.

Along the west edge of the area and north of Clear Creek are many other gravel-capped knobs and mesas, some of them as high as the knobs south of Bear Creek. But all of these are located along second-order drainage lines and consequently, despite their elevation above the present drainage, some of them may be considerably younger than the ancestral course of Bear Creek.

It is worth noting that all these gravel-capped knobs and mesas, rising above the general surface of the upland, are located west of the South Platte River.

At the beginning of Wisconsin time the uplands in the Denver area had become deeply weathered and were covered by residuum (pl. 6, *A*). The South Platte River had cut at least 50 feet lower than the top of the gravel terrace of pre-Wisconsin age, and at least 20 feet lower than its present bed. During Wisconsin time the valleys again became aggraded, and by the end of Wisconsin time (pl. 6, *C*) the Broadway terrace was built 40 to 50 feet higher than the bed of the South Platte River, and about 15 feet higher than the pre-Wisconsin gravel terrace, which became buried.

The valley bottoms must have been broad desolate flats while they were being aggraded because they were the source of large quantities of sand and silt blown eastward out of the valleys onto the uplands. There were at least two stages of eolian deposition—the first occurred in the early part of Wisconsin time (pl. 6, *B*); the second occurred in late Wisconsin time after gravel fill had formed the Broadway terrace (pl. 6, *C*). The supply of eolian sand and silt was cut off as soon as the South Platte River began cutting into the gravel fill of the Broadway terrace (p. 112). But, although no new sand was added to the sand hills, the dunes probably continued active for some time after the river had become incised into the Broadway terrace.

For some unexplained reason the Recent downcutting of South Platte River was exclusively along the west side of the Wisconsin gravel fill, leaving the Broadway terrace intact as a continuous feature along the east side of the river, not only across the Denver area (pl. 6, *D*) but for many miles downstream. The record of Recent downcutting is preserved in a series of cut terraces. Some high ones, mantled by alluvium, have been cut in the western edge of the Broadway terrace. Others, mantled by cobble gravel, have been cut at several different levels in the Denver formation along the west wall of the valley. This downcutting was completed before the Piney Creek alluvium was deposited.

As a result of this downcutting by the South Platte River, its principal tributaries in the Denver area, especially Clear Creek and Cherry Creek, had the lower parts of their courses steepened. Only these steepened lower courses of the tributaries became incised into the gravel fill of Wisconsin age. For example, Cherry Creek has cut little if at all into the Wisconsin fill upstream from a point about a mile east of Colorado Boulevard, although it is cut deeply into the fill downstream from there. Clear Creek has not cut into the Wisconsin fill upstream from Arvada; below there it has cut deeply into the fill. The contrast between these two stretches of Clear Creek is illustrated by the difference in the valley bottom topography upstream and downstream from Arvada. Upstream the bottom is flat; downstream it is broadly V-shaped.

There are no remnants whatsoever of the Broadway terrace along the lower part of Bear Creek or Clear Creek. Gravel like that in the Broadway terrace underlies the beds of both streams, but there are no terrace remnants. It is difficult to account for such complete removal of the gravel that must have filled these valleys to the level of the Broadway terrace.

Mammoth and camel were in the Denver area while the Broadway terrace was being formed. They survived until the terrace was complete, but their remains are not found in younger deposits. Presumably they became exterminated during the period of downcutting that followed deposition of the terrace. The fossil remains occurring in the younger, Recent deposits are entirely modern in form.

In Recent time, probably two to four thousand years ago, there ensued a period of alluviation, recorded by the Piney Creek alluvium. Unlike the gravel fill of Wisconsin age, which has a flat surface transverse to the valleys, the Piney Creek alluvium has a surface that rises towards the valley sides, especially towards the mouths of tributaries. In the major valleys, the Piney Creek alluvium consists of a series of broad, low, coalescing, alluvial fans. Therefore, the Piney Creek alluvium must have come from the lateral tributaries and sidehills, a stream regimen very different from the one that deposited the Wisconsin fills.

Deposition of the Piney Creek alluvium ended about the beginning of the Christian Era. During the last thousand years, there occurred a period of arroyo cutting, a second period of alluviation, and finally, in protohistoric or historic time, another period of arroyo cutting that developed the present stream beds.

Prehistoric man, presumably Folsom, was in the Denver area in late Wisconsin time, while the Broadway terrace was being formed. During the period when the South Platte River was cutting into the terrace, the area was probably occupied by the peoples who made the so-called Yuma points. Another lithic, pre-pottery culture was in the area while the Piney Creek alluvium was being deposited, and this was succeeded by sedentary or semisedentary potterymaking cultures. In protohistoric or historic times these were replaced by the nomadic tribes who were occupying the Great Plains when the United States expanded westward.

SELECTED BIBLIOGRAPHY

Antevs, E., 1937, Climate and early man in North America, *in* MacCurdy, G. G., ed., Early man, p. 125–132: Phila. and New York, J. B. Lippincott Co.

Atwood, W. W., and Atwood, W. W., Jr., 1938, Working hypothesis for the physiographic history of the Rocky Mountain region: Geol. Soc. America Bull., v., 49 p. 957–980.

Bailey, A. M., 1943, Colorado Museum of Natural History, a pictorial book of the Museum Exhibits: Colo. Mus. Nat. History Pop. Ser. 1, 3d revised ed., 96 p.

Barbour, E. H., and Schultz, C. B., 1937, Pleistocene and post-glacial mammals of Nebraska, *in* MacCurdy, G. G., ed., Early man, p. 185–192: Phila. and New York, J. B. Lippincott Co.

Behre, C. H., Jr., 1933, Physiographic history of the upper Arkansas and Eagle Rivers, Colo.: Jour. Geology, v., 41, p. 785–814.

Behre, C. H., Jr., and others, 1941, The geologic history of South Park, Colo.: New York Acad. Sci. Trans., 2d ser., v. 4, no. 1, p. 1–4.

Berthoud, E. L., 1872, Tusk of an elephant or mastodon found in Colorado: Am. Jour. Sci., 3d ser., v. 3, p. 302.

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

Bryan, Kirk, 1937, Geology of the Folsom deposits in New Mexico and Colorado: *in* MacCurdy, G. G., ed., Early man., p. 139–152: Phila. and New York, J. B. Lippincott Co.

——— 1950, Geological interpretation of the (Ventana Cave) deposits, *in* Haury, E. W., The stratigraphy and archeology of Ventana Cave, Ariz., p. 75–125: Ariz. Univ. and N. Mex. Univ. Press.

Bryan, Kirk, and Ray, L. L., 1940, Geologic antiquity of the Lindenmeier site in Colorado: Smithsonian Misc. Coll., v. 99, no. 2, Pub. 3554, 76 p.

Campbell, M. R., 1922, Guidebook of the western United States, Part E, the Denver & Rio Grande Western Route: U. S. Geol. Survey Bull. 707.

Cannon, G. L., Jr., 1890, The Quarternary of the Denver Basin: Colo. Sci. Soc. Proc., v. 3, p. 48–70.

——— 1893, The geology of Denver and vicinity: Colo. Sci. Soc. Proc., v. 4, p. 235–270.

Capps, S. R., Jr., 1909, Pleistocene geology of the Leadville quadrangle, Colorado: U. S. Geol. Survey Bull. 386.

Colbert, E. H., 1937, The Pleistocene mammals of North America and their relations to Eurasian forms, *in* MacCurdy, G. G. ed., Early man, p. 137–184: Phila. and New York, J. B. Lippincott Co.

Condra, G. E., Reed, E. C., and Gordon, E. D., revised by Condra, G. E., and Reed, E. C., Correlation of the Pleistocene deposits of Nebraska: Nebr. Geol. Survey Bull. 15A, 1950.

Dane, C. H., and Pierce, W. G., 1936, Dawson and Laramie formations in southeastern part of Denver Basin, Colo.: Am. Assoc. Petroleum Geologists Bull., v. 20, p. 1308–1328.

Davis, W. M., 1911, The Colorado Front Range, a study in physiographic presentation: Assoc. Am. Geographers Annals, v. 1, p. 21–84.

Dodds, G. S., 1908, Geology and physiography of the mesas near Boulder, Colo.: Colo. Univ. Studies, v. 6, p. 11–19.

Ehnbom, L., 1916, Geological sections in the vicinity of Golden [Colo.]: Colo. School Mines Quart., v. 11, no. 3, p. 11–15.

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

Emrich, C. T., 1909, Mastodon bones [from Golden, Colo.]: Colo. School Mines Bull., v. 5, no. 1, p. 36–37.

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

Frye, J. C., 1945, Problems of Pleistocene stratigraphy in central and western Kansas: Jour. Geology, v. 53, no. 2, p. 73–93.

Frye, J. C., and Leonard, A. B., 1951, Stratigraphy of the late Pleistocene loesses of Kansas: Jour. Geology, v. 59, p. 287–305.

Frye, J. C., Swineford, Ada, and Leonard, A. B., 1948, Correlation of Pleistocene deposits of the central Great Plains with the glacial section: Jour. Geology, v. 56, p. 501–525.

Fuller, M. B., 1923, The physiographic development of the Big Thompson River valley in Colorado: Jour. Geology, v. 31, p. 126–137.

——— 1925, The bearing of some remarkable potholes on the early Pleistocene glaciation of the Front Range, Colo.: Jour. Geology, v. 33, p. 224–235.

Gebhard, P. H., 1949, An archeological survey of the blowouts of Yuma County, Colo.: Am. Antiquity, v. 15, p. 132–143.

Green, T. H., 1939, Outline [of the geology] of the Boulder region: Compass, v. 19, p. 121–124.

Harper, W. G., Acott, Lloyd, and Frahm, Elmer, 1932, Soil survey of the Brighton area, Colorado: U. S. Bur. Chemistry and Soils, ser. 1932, no. 1 [1935].

Heaton, R. L., 1940, Geological aspects of the Colorado-Big Thompson project: Mines Mag., v. 30, no. 5, p. 257–264; no. 6, p. 305–312.

Henderson, C. W., and others, 1933, Colorado: 16th Internat. Geol. Cong., United States, Guidebook 19, Excursion C–1, 146 p.

Henderson, Junius, 1950, Extinct glaciers of Colorado: Colo. Univ. Studies., v. 3, p. 39–44.

Hunt, C. B., 1953, Pleistocene-Recent boundary in the Rocky Mountain region: U. S. Geol. Survey Bull. 996–A.

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

Hurst, C. T., 1943, A Folsom site in a mountain valley of Colorado: Am. Antiquity, v. 8, p. 291–295.

Ives, R. L., 1938, Glacial geology of the Monarch Valley, Grand County, Colo.: Geol. Soc. America Bull., v. 49, p. 1045–1066.

——— 1940, Rock glaciers in the Colorado Front Range: Geol. Soc. America Bull., v. 51, p. 1271–1294.

——— 1942, Early human occupation of the Colorado headwaters region, an archeological reconnaissance: Geog. Rev. v. 32, p. 448–462.

——— 1946, Glacial bastions in northern Colorado: Jour. Geology, v. 54, p. 391–397.

Johnson, J. H., 1925, Bibliography of the geology of the Denver Basin of Colorado: Colo. School Mines, Circ. Inf.

——— 1930, The geology of the Golden area, Colorado [2d ed., revised]: Colo. School Mines Quart., v. 25, no. 3, 33 p.

——— 1931, The paleontology of the Denver quadrangle, Colorado: Colo. Sci. Soc. Proc., v. 12, no. 11, p. 355–378.

——— 1934, Introduction to the geology of the Golden area, Colorado: Colo. School Mines Quart., v. 29, no. 4, 36 p.

Johnson, W. D., 1901, The High Plains and their utilization: U. S. Geol. Survey 21st Ann. Rept., pt. 4, p. 601–741.

——— 1902, The High Plains and their utilization [conclusion of paper] U. S. Geol. Survey 22d Ann. Rept., pt. 4, p. 631–699.

Jones, W. D., and Quam, L. O., 1944, Glacial land forms in Rocky Mountain National Park, Colo.: Jour. Geology, v. 52, p. 217–234.

Lee, W. T., 1900, The origin of the debris-covered mesas of Boulder, Colo.: Jour. Geology, v. 8, p. 504–511.

——— 1917, The geologic story of the Rocky Mountain National Park, Colo.: U. S. Natl. Park Service.

——— 1923, Peneplains of the Front Range and Rocky Mountain National Park, Colo.: U. S. Geol. Survey Bull. 730–A, p. 1–17, 1922.

LeRoy, L. W., 1946, Stratigraphy of the Golden-Morrison area, Jefferson County, Colo.: Colo. School Mines Quart., v. 41, no. 2, 115 p.

Little, H. P., 1925, Erosional cycles in the Front Range of Colorado and their correlation: Geol. Soc. America Bull., v. 36, p. 495–512.

Lovering, T. S., 1929, Geologic history of the Front Range, Colo.: Colo. Sci. Soc. Proc., v. 12, no. 4, p. 59–111.

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

Lugn, A. L., 1935, The Pleistocene geology of Nebraska: Nebr. Geol. Survey Bull. 10, 2d ser.

Malde, H. E., 1954, Surficial geology of the Louisville quadrangle, Colorado: U. S. Geol. Survey Bull. 996–E [in press].

Mather, K. F., Gilluly, James, and Lusk, R. G., 1927, Geology and oil and gas prospects of northeastern Colorado: U. S. Geol. Survey Bull., 796–B, p. 65–124.

Patterson, R., 1938, Glacial effects in the Rocky Mountain region west of Denver: Compass, v. 18, no. 4, p. 204–207.

Petersen, W. A., 1942, Glacial features in Rocky Mountain National Park: Compass, v. 23, no. 1, p. 31–39.

Powers, W. E., 1935, Physiographic history of the upper Arkansas River valleys and the Royal Gorge, Colo.: Jour. Geology, v. 43, p. 184–199.

Ray, L. L., 1940 Glacial chronology of the southern Rocky Mountains: Geol. Soc. America Bull. v. 51, p. 1901–1905.

Renaud, E. B., 1931, Prehistoric flaked points from Colorado and neighboring districts: Colo. Mus. Nat. History Proc., v. 10, no. 2.

——— 1932, Yuma and Folsom artifacts [new material]: Colo. Mus. Nat. History Proc., v. 11, no. 2, p. 5–18.

Richardson, G. B., 1915, Description of the Castle Rock quadrangle, Colorado: U. S. Geol. Survey Geol. Atlas, folio 198.

Roberts, F. H. H., Jr., 1935, A Folsom complex—Preliminary report on investigations at the Lindenmeier site in northern Colorado: Smithosnian Misc. Coll., v. 94, no. 4.

——— 1936, Additional information on the Folsom complex; report on the second season's investigations at the Lindenmeier site in northern Colorado: Smithsnonian Misc. Coll., v. 95, no. 10.

——— 1937, The Folsom problem in American archeology, *in* MacCrudy, G. G. ed., Early man, p. 153–162: Phila. and New York, J. B. Lippincott Co.

——— 1946, Prehistoric peoples of Colorado: Colo. Mag., v. 23, no. 4, p. 145–156; no. 5, p. 215–230.

Rockwell, A. P. 1872, Discovery of the tusk of an elephant in Colorado: Am. Jour. Sci., 3d ser., v. 3, p. 373–374.

Schneider, Hyrum, 1913, Physiography of Golden [Colorado] and vicinity and its relation to the geologic structure: Colo. School Mines Quart. v. 8, no. 3, p. 3–10.

Schoew, W. H., 1928, Evidence of stream piracy on the Dakota hogback between Golden and Morrison, Colo.: Kans. Acad. Sci. Trans. v. 31, p. 112–114.

Schultz, C. B., Lueninghoener, G. C., and Frankforter, W. D., 1951, A graphic resume of the Pleistocene of Nebraska, with notes on the fossil mammalian remains: Univ. Nebr. State Mus. Bull., July 1951.

Singewald, Q. D., 1950, Gold placers and their geologic environment in northwestern Park County, Colo.: U. S. Geol. Survey Bull. 955–D.

Strong, W. D., 1935, An introduction to Nebraska archeology: Smithsonian Misc. Coll., v. 93, no. 10.

Sweet, A. T., Brown, L. A., and Haines, W. E., 1929, Soil survey of the Greeley area, Colorado: U. S. Bur. Chemistry and Soils, ser. 1929. no. 5 [1932].

Sweet, A. T., and Dodson, C. H., 1930, Soil survey of the Longmont area, Colorado: U. S. Bur. Chemistry and Soils, ser. 1930, no. 29 [1935].

Sweet, A. T., and Spencer, J. N., 1927, Soil survey of the Fort Collins area, Colorado: U. S. Bur. Chemistry and Soils, ser. 1927, no. 27 [1931].

Van Tuyl, F. M., and Coke, J. M., 1932, The late Tertiary physiographic history of the High Plains of Colorado and New Mexico: Colo. Sci. Soc. Proc., v. 13, no. 1, p. 19–25.

Van Tuyl, F. M., and Lovering, T. S., 1935, Physiographic development of the Front Range: Geol. Soc. America Bull., v. 46, p. 1291–1349, 1935; discussion by J. L. Rich, and authors' reply p. 2046–2054, 1936.

Van Tuyl, F. M., and others, 1938, Guide to the geology of the Golden area: Colo. School Mines Quart., v. 33, no. 3.

Varnes, H. D., and Larrabee, D. M., 1946, Preliminary map showing sand and gravel deposits of Colorado: U. S. Geol. Survey Missouri River Basin Study no. 2.

Wahlstrom, E. E., 1947, Cenozoic physiographic history of the Front Range, Colo.: Geol. Soc. America Bull., v. 58, p. 551–572.

Wegemann, C. H., 1944, A guide to the geology of Rocky Mountain National Park [Colo.]: 32 p., Washington Natl. Park Service.

Wooster, L. C., 1920, Glacial moraines in the vicinity of Estes Park, Colo.: Kans. Acad. Sci. Trans., v. 29, p. 91–94.

Wormington, H. M., 1949, Ancient man in North America: Denver Mus. Nat. History, Pop. Ser. no. 4, 3d ed. revised, 198 p.

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