Pre-Wisconsin Soil in the Rocky Mountain Region a Progress Report

GEOLOGICAL SURVEY PROFESSIONAL PAPER 221-G

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By CHARLES B. HUNT *and* V. P. SOKOLOFF

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A study of ancient soils in the Lake Bonneville and Denver Basins

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By Charles B. Hunt and V. P. Sokoloff

ABSTRACT

An ancient soil (paleosol) dated, from its stratigraphic relations, as pre-Wisconsin in the Lake Bonneville and Denver Basins, consists of a few feet of red-brown leached clay overlying several feet of lime-enriched weathered parent material. The soil has been found on many kinds of parent material, in many topographic positions, and at altitudes ranging from 5,000 to more than 8,500 feet. Like the rather similar gumbotils in the Middle West the paleosol in the Rocky Mountain region is useful for distinguishing late Pleistocene and Recent features from earlier ones. Further study of paleosols offers promise of furnishing much additional information about soil genesis problems and providing increasingly refined means for distinguishing between Pleistocene features of different age.

INTRODUCTION

An ancient soil, hereafter referred to as paleosol, has been dated, from its stratigraphic relations, as pre-Wisconsin in the Lake Bonneville and Denver Basins. It has been identified tentatively in other parts of the West. This paleosol offers promise of becoming an important means of distinguishing early Pleistocene features from late ones in those parts of the Rocky Mountain region that are remote from known Pleistocene glacial or lacustrine deposits.

The paleosol was first recognized in 1947 in Utah Valley, Utah, during a survey and restudy of the Lake Bonneville Basin that has been started by the United States Geological Survey. More recently the paleosol has been recognized and considerable areas of it mapped in the Denver Basin, Colo.

In developing the evidence that is presented herein and in the preparation of this report we have had the valuable assistance of numerous soil scientists in the Division of Soil Survey, United States Department of Agriculture. James Thorp, Ray C. Roberts, and C. C. Nikiforoff were especially helpful. Thorp and Roberts, accompanied by other members of the Soil Survey and soil scientists of the Utah State Agricultural School, visited the senior author in Utah Valley in 1947 and examined some of the paleosol localities in that area.

In 1946, before the paleosol was recognized, the senior author, who was then mapping Utah Valley, was visited by Dr. Geoffrey B. Bodman of the Division of Soil Survey, University of California. It was very largely through Dr. Bodman's guidance and encouragement during the early phases of the field work that the paleosol was first recognized.

Special acknowledgment is due also to Charles S. Denny of the Geological Survey for his thoughtful and critical review of the manuscript.

If this report contains a contribution to geology and soil science, perhaps its greatest value will be to encourage more complete and more widespread cooperation between soil scientists and geologists. The kind of problem that is under consideration is only a sample of many that require the attention of both.

PALEOPEDOLOGY

GENERAL BACKGROUND

Paleopedology, the study of ancient soils, was begun in the second half of the last century, chiefly in Russia and particularly in the Ukraine, where numerous buried soil profiles are interbedded with loess deposits of different age. Ruprecht (1866) appears to have been one of the first to recognize the existence of paleosol, its bearing on the problems of pedogenesis, and the problem of pedologic and chronologic age of buried soils.

Many American geologists have recognized the weathered zones between the sheets of glacial drift in the middle western States, but Kay and Pearce (1920) seem to have been the first to study the weathered zones as profiles of old soils.

A partial bibliography of papers that contain descriptions of or references to paleosols is given at the end of this report.

Stratigraphically identifiable paleosols, common as they are, particularly in the formerly glaciated areas, constitute but a small proportion of the total. Actually, considerable parts of the soils and soil materials in the regolith are probably paleosols in the sense that they represent effects of ancient rather than modern environments on the parent rock. The cumulative effects represented are so complex, however, as to make it impossible, in the present state of our knowledge, to separate the successions of environments on the sole basis of the end product. Only simple cases can be recognized and interpreted.

SOIL AGE

Age of soil, that is, of the soil profile, can be considered under two categories—chronologic or absolute age and pedologic age. The two are quite different.

Chronologic or absolute age involves the length of time during which a soil may have been forming and the geologic or historic date of the event. In this paper we are concerned primarily with the geologic age of the paleosol.

The concept of pedologic age, which deals with the relative maturity of the soil profile, needs a great deal more study in order to be useful in problems pertaining to chronologic age.

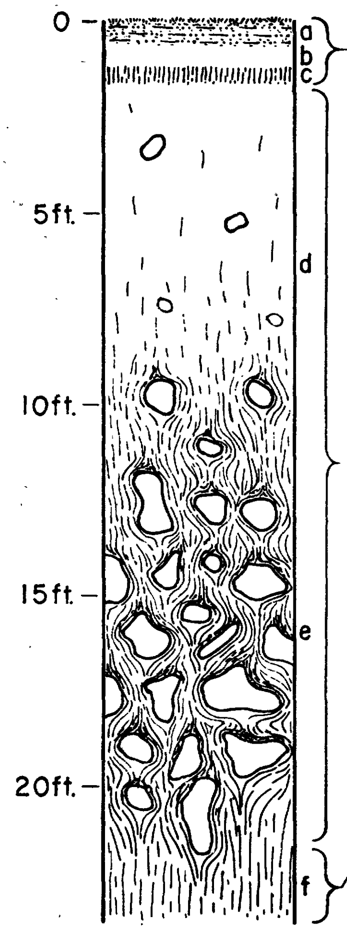
Following Mohr (1944), pedologic age may be thought of as consisting of a zero-time stage, an immature stage, and a mature stage. To these perhaps could be added a fourth or senile stage.

Zero-time stage is the parent-material stage. There is no differentiation of the soil horizons, no soil structure, and no appreciable clay mineral development. This stage is easily recognized in materials like recent volcanic ash or recently exposed rock. However, if the parent material happens to be one of the layers of paleosol, recognition of the zero-time stage, or even of some of the later stages, is by no means an easy matter.

Tamm (1920) and a number of other investigators, including Mohr, are of the opinion that this initial stage of soil formation is relatively brief. Whenever soils have been dated with the aid, for example, of archeological evidence (Akimtzev, 1945) or historic events (Van Baren, 1931; Zemiatchenskii, 1906; Ognev, 1927), the initial stage has been characterized by zonal trends in the chemical composition of the humus and in some cases by appearance of clay minerals but not by a morphologically recognizable differentiation of the soil horizons. The duration of this initial stage apparently is to be measured in decades or at most a few centuries.

The subsequent immature, mature, and senile stages of pedologic age apparently require a progressively longer time to develop fully the clay minerals or stable oxides and to develop the distinctive horizons of the soil profile.

Depending on the environment, the characteristics of a given pedologic age may differ from one region to another. Also dependent on the environment is the rate at which a soil develops to a given pedologic age. Environments not only are very different in different parts of the world, they have been very different at different times in the geologic past. It is difficult enough to judge the absolute or chronologic age of most soils; it is equally difficult, if not more so, to judge their pedologic age.



Wisconsin or younger soil profile superimposed on top of paleosol. Top few inches (a) are humus rich and dark gray or brown. This layer and a thinner lighter-colored layer (b) immediately below it are lime-free. If limy colluvial material has accumulated on surface, several inches (c) of lime-enriched paleosol occur at the base of this soil.

Pre-Wisconsin soil, the paleosol. Top several feet (d) consist of lime-free reddish-brown clay, in places probably clay loam. Structureless or prismatic structure. Any contained stones are inert materials like quartzite. Sand grains commonly pitted. Lower part of this clayey layer may contain tiny veinlets of $CaCO_3$. Under the lime-free clayey layer are many feet (e) of lime-enriched weathered parent material. In the upper part of this layer stones are commonly residual and can be cut with a knife. Increasing proportion of firm unweathered rock downward. Matrix, especially in upper part, may be clay like in (d), but this clay is generally impregnated with lime and is powdery. Lime may occur in closely spaced, anastomosing veins, in irregular blebs an inch or so in diameter, or finely and evenly disseminated throughout the layer.

At the base (f) of the paleosol is comparatively fresh and unweathered parent material. $CaCO_3$ commonly extends into joints in the upper part of this layer.

FIGURE 10.—Diagrammatic profile of pre-Wisconsin soil, or paleosol, in the Rocky Mountain region.

PALEOSOL IN THE ROCKY MOUNTAIN REGION

The paleosol discussed in this paper is pre-Lake Bonneville in age. It is older than the latest of the moraines in the Wasatch Range but is younger than the earlier ones. It is older than the oldest alluvial deposits along the South Platte River in the Denver Basin.

In its most complete development, at least as thus far observed, the paleosol is distinctive and readily recognized where complete profiles are preserved. It consists of several feet of lime-free reddish or brownish clay that grades downward into many feet of progressively less weathered and more strongly lime enriched parent material. The soil seems to be largely if not entirely the product of weathering of the parent material in place. The consistent great thickness, at least 30 feet in the Lake Bonneville Basin and at least 15 feet in the Denver Basin, distinguishes the paleosol from modern soils having a similar profile.

Figure 10 is a diagrammatic profile of the paleosol.

GEOGRAPHIC EXTENT

The paleosol has been recognized in a good many localities in Utah and Colorado and at one locality in New Mexico (fig. 11). It is probably widespread in the Rocky Mountain region and Great Basin. The areal extent of the paleosol at the localities shown in figure 11 ranges from a few acres to a few square miles.

In the vicinity of Utah Lake and Denver the paleosol has been identified, and systematic geologic mapping has shown the stratigraphic relations and made it possible to date it. At other localities shown in figure 11 the paleosol has been identified on the basis of lithologic and physiographic evidence.

Some of the localities where the paleosol has been identified are on steep slopes in the mountains, and others are on rather smooth or gently rolling upland surfaces. They range in altitude from 5,000 to more than 8,500 feet and occur in several different soil and floral zones. The range in the modern environment of the localities already recognized is considerable and probably as the study progresses will be extended.

As a matter of fact, the paleosol in the Rocky Mountain region is probably closely related to the gumbotils in the Middle West and to the pre-Wisconsin soils in the eastern States.

PARENT MATERIALS

As brought out in figure 11, the paleosol has been developed on a considerable variety of parent materials. These materials include Paleozoic and Mesozoic sedimentary rocks of all kinds, Tertiary lavas, and Pleistocene fanglomerate or moraines containing various proportions of different kinds of sedimentary, igneous, and metamorphic rocks. Despite this variety of parent materials, the paleosol looks much alike at all the localities; it is a lime-free clay layer overlying a thicker layer of weathered and lime-enriched parent material.

The variety of parent materials on which the paleosol in the Rocky Mountain region has developed offers an interesting comparison with the gumbotils in the Middle West, which have developed on sheets of glacial drift that are different in age but rather similar in composition. Similar glacial deposits in the Rocky Mountain region probably developed paleosols like the gumbotils.

CLAY LAYER

The upper clayey part of the paleosol commonly is eroded, and consequently its thickness varies greatly. The maximum thickness found thus far is 10 feet; in general, however, it is only a few feet thick, and in some places the clay layer is entirely removed.

The clay is massive and not stratified. Field tests utilizing the Cenco-Wilde hydrometer method indicate that the silt-clay content of the clayey layer is rarely less than 50 percent and locally is as high as 75 percent. The clay content is high even where the parent rocks are nonargillaceous.

The lower part of the clayey layer locally contains relic pebbles or cobbles that can be cut by a knife. This condition is especially characteristic of the soil where the parent material includes a rather large amount of dioritic or more basic igneous rocks. Firm pebbles in the clay are almost exclusively of the inert siliceous types.

A considerable percentage of the sand grains in the clay layer are subangular and deeply pitted. They could not have been transported very far and probably developed their form within the clay deposit of which they are a part.

The massive clay generally breaks with a prismatic structure. Its general physical appearance and feel are the same, regardless of the parent material or obvious variations in the environment of the locality in which the remnant of the paleosol is preserved.

The essential constituents, other than the alkalies, of three samples studied are given in the table, page 113. The high content of iron oxide made index measurements of the clay minerals impossible. A thermal analysis by George T. Faust and an X-ray powder examination by Joseph M. Axelrod, both of the United States Geological Survey, indicate that the clay is predominantly hydromica. A minor quantity of montmorillonite is present.

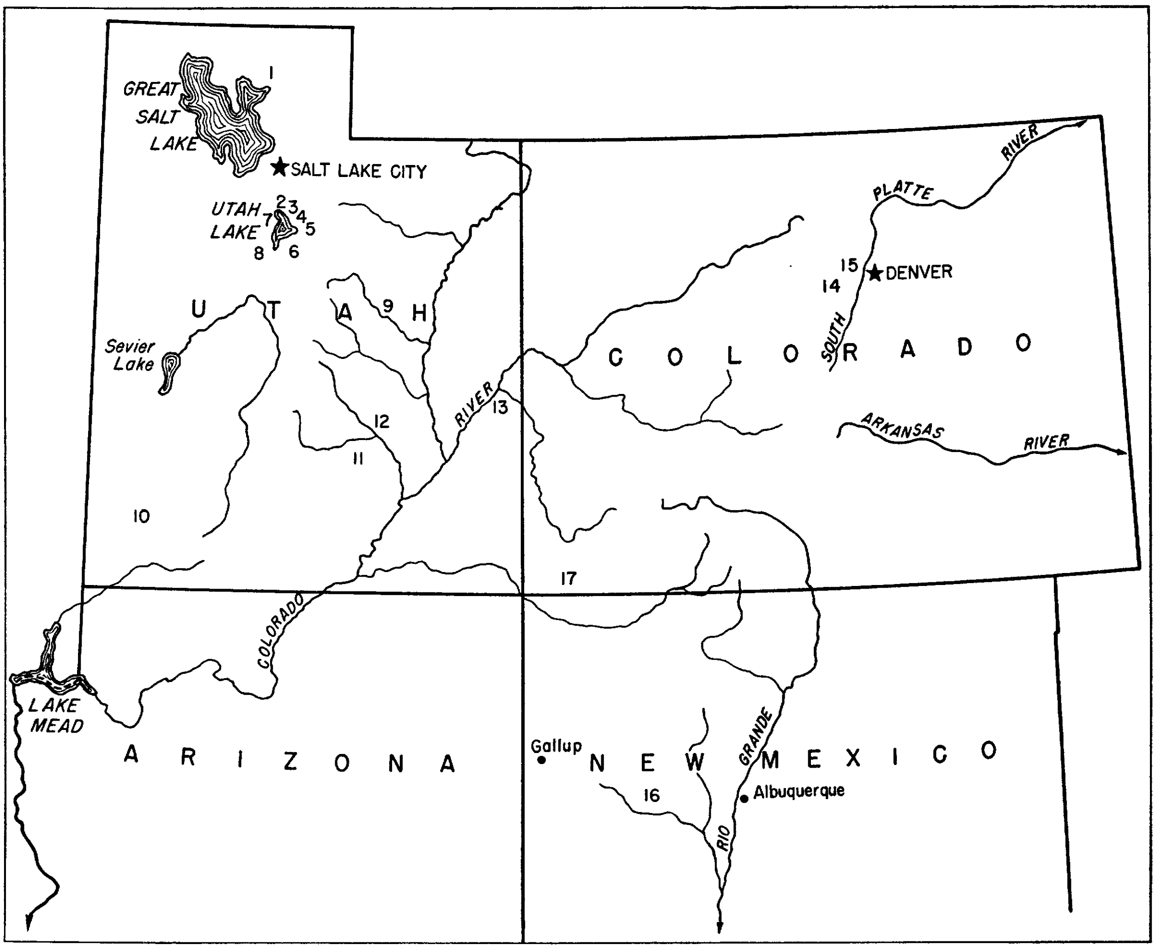


FIGURE 11.—Localities in Utah, Colorado, and New Mexico where pre-Wisconsin soil has been identified.

1. Wasatch Range between Brigham City and Logan, Utah. Parent material, Paleozoic limestone.
2. Traverse Range, Utah. Pennsylvanian limestone and quartzite; Tertiary or early Pleistocene fanglomerate composed of diorite, limestone, and quartzite debris.
3. Alpine Canyon, Utah. Glacial moraine composed chiefly of dioritic rock debris.
4. Wasatch Range, northeast of Pleasant Grove, Utah. Mississippian shale; Pennsylvanian limestone and quartzite; Tertiary or early Pleistocene fanglomertate composed of limestone, shale, and quartzite.
5. Wasatch Range, Provo Canyon, Utah. Same parent material as that at locality 4.
6. South side of Utah Lake Valley, Utah. Tertiary or early Pleistocene fanglomerate composed of limestone, shale, and sandstone.
7. West side of Utah Lake Valley, Utah. Same parent material as that at locality 6.
8. Tintic mining district, Utah. Tertiary latite.
9. Between Price and Woodside, Utah. Tertiary or early Pleistocene fanglomerate composed of sandstone, limestone, and shale derived from Cretaceaus formations.
10. Iron Springs district, Utah. Mesozoic formations (?).
11. Henry Mountains, Utah. Tertiary or early Pleistocene colluvial deposits and fanglomerate containing diorite, shale, and limy sandstone fragments.
12. Green River Desert, Utah. Earthy Mesozoic sandstone.
13. La Sal Mountains, Utah. Same parent material as that at locality 11.
14. Front Range, Idlewald, Colo. Fanglomerate composed of gneiss and schist fragments.
15. Denver Basin, Colo. Shale, earthy sandstone, and conglomerate of Denver formation; gravels and other surficial deposits overlying Denver formation.
16. Mount Taylor, N. Mex. Basaltic lava.
17. Mesa Verde National Park, Colo. Cretaceous shale and limy sandstone.

Examined under the petrographic microscope, sample 1 was found to contain approximately 20 percent of quartz and 20 percent of orthoclase, sample 2 about 25 percent of quartz and 20 percent of orthoclase, and sample 3 about 20 percent of quartz and 15 percent of orthoclase.

A number of other samples were studied by M. E. King in the Petrographic Laboratory, Research and Geology Division, United States Bureau of Reclamation at Denver. For identifying the clay minerals Mr. King used staining tests and confirmed them by X-ray diffraction and differential thermal analyses. He analyzed 18 samples of paleosols from 10 localities. Hydromica was found to be the principal clay mineral in the paleosol at six of the localities where the parent materials are limestone, shale, diorite, or unconsolidated deposits composed of these materials. Montmorillonite was found dominant in the paleosol at four

Partial chemical analyses, in percent, of samples of clays from some ancient soils in Utah

[J. J. Fahey, analyst]

	Loss on ignition	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	TiO_2	MnO
1. Old soil on oldest of glacial moraines by Dry Creek, above Alpine	6.78	67.37	13.86	5.10	1.67	0.02	0.75	0.003
2. Old soil on fanglomerate from near reservoir in Traverse Range about 2 miles northwest of Alpine	6.88	69.61	12.65	4.58	1.51	.02	.70	.003
3. Old soil formed on Manning Canyon shale, south side of Provo Canyon, by Pole Canyon road about 2 miles from Provo Canyon road	6.83	66.07	15.54	6.02	1.87	.02	.96	.003

localities, at two of which the parent material is glassy volcanic rock and at two in part loessial. In all cases tested the clay mineral found dominant in the clay layer was also found dominant in the underlying lime-enriched layer.

Mr. King also analyzed four other samples of alluvium, three of which were from clayey alluvial deposits believed to have been derived by erosion of the paleosol. Montmorillonite is the dominant clay mineral in all these samples of alluvium.

The clay more than a foot below the present surface commonly is reddish brown; less commonly it is red or dark reddish-gray. In terms of the standard color chart in use by the Division of Soil Survey, United States Department of Agriculture, the colors are of the hues 2.5 YR and 5 YR; the range in chroma is 2 to 6 and the range in value is 3 to 5, according to the Munsell system. Mineralogic and chemical studies also are needed to determine to what extent the color differences reflect variations in original composition or variations in the degree of oxidation of the materials at the locality. The range in color, however, is remarkably slight, considering the great range in kind and color of the parent materials and the rather large range in the kinds of environment in which the paleosol has been found.

The clay has lost lime carbonate and probably other salts by leaching. More than a foot below the surface its pH as determined colorimetrically ranges from 6.5 to 7.5 and increases downward. The degree of leaching in the old soil is impressive because even at localities where the parent material is mostly limestone, as at many places along the Wasatch Range, the clay is known to be lime-free to depths of as much as 10 feet.

A still unanswered question is the degree to which the clay layer represents weathered loessial materials. The similarity of the clay over so large an area and over so many different parent materials might suggest that at least part of the clay is weathered loess. However, we suspect that most of the clay is the residual product of weathering of the rocks on which it has formed, for the following reasons: Soft decomposed fragments of the rock may be found in the lower part of the clay; the clay layer is gradational downward into the lime-enriched layer of weathered parent rock; and the amount of lime in the lime-enriched layer under the leached clay appears to be proportional, at least roughly, to the amount of lime in the parent rock. If, for example, the clay layer of the paleosol in the Wasatch Range, which is a highly calcareous region, were derived largely from loess there should be a distinct lime-enriched layer even where the bedrock is granitic.

The clay layer of the paleosol in the Rocky Mountain region is like the upper part of the gumbotils in the Middle West, where the proportion of siliceous types of pebbles increases upward through the old profile. Kay and Pearce (1920, pp. 101–105), for example, found that 80 to 90 percent of the pebbles in the upper layer are siliceous, and this proportion decreases downward to about 20 percent in the underlying till.

Much additional work needs to be done investigating problems of paragenesis of clay minerals under various pedologic environments. There is some evidence that weathering of rocks into soil, under given environments, tends to result in the formation of distinctive types of clay minerals (Sedletzkii, 1941 and 1945). Unfortunately, developing the evidence to the point where use can be made of the findings is hampered by the fact that paleosols almost certainly are the product of a complex of environments.

In the Lake Bonneville and Denver Basins our preliminary data seem to indicate that the clay in the unquestionably Wisconsin or younger soils is largely montmorillonitic, whereas the clay in the paleosol appears to be largely illitic. Unfortunately, the Wisconsin and younger soils that have been tested are largely on fluvial, lacustrine, or eolian deposits rather than on bedrock, and perhaps the clay mineralogy is related to the processes of sedimentation rather than to processes of weathering. It would be significant, however, if the paleosol really is composed rather consistently of illitic clay regardless of differences in the kind of parent material from which it was formed.

Ginzburg (1946) has suggested that illite may weather to montmorillonite if the environment is changed so as to increase the salinity but that illite may weather to kaolinite if the environment is changed so as to increase the acidity. If there is merit in this suggestion it may be possible to correlate the clay mineralogy with the changes in Wisconsin and Recent climates.

Also needing investigation, and possibly related to problems of paragenesis of the clay minerals, is the matter of distribution of trace elements in the paleosol. Trace elements associated with various clay minerals may occur in a number of ways, for example, as discrete mineral fragments; in solid solutions replacing such elements as aluminum, silicon, iron, magnesium, potassium, and calcium; in the double layer surrounding the clay micelle; in the interplanar spaces of the clays; and in association with the organic-mineral colloidal complexes. Despite these variations in mode of occurrence certain pedogenic processes seem to result in stable vertical distribution trends of trace elements in soil profiles (Malinga, 1946, and Siniagin, 1946), and these distribution trends may be distinctive of certain environments. Where the paleosol is no longer within the zone of pedogenesis and where differences between the ancient and the modern environments are considerable, marked differences between the ancient and the modern trends in the trace element distributions may be expected.

Too few tests have been made to determine whether or not the distribution trends of trace elements are orderly in the paleosol in the Rocky Mountain region. The few random tests made thus far indicate only that the clay layer seems to have a somewhat higher content of lead and zinc than does the underlying lime-enriched layer.

LIME-ENRICHED LAYER

Beneath the clay is a layer of weathered parent material strongly enriched with lime carbonate. The thickness of this lime-enriched layer and the amount of carbonate it contains varies widely, depending on the composition and permeability of the parent material.

Where the paleosol has developed on very calcareous parent material, the lime-enriched layer may be strongly developed through a thickness of 20 feet or more. Such thicknesses are found in the Wasatch Range where the paleosol developed on Paleozoic limestones and on fanglomerate containing a considerable amount of limestone. On the other hand, where the parent material is not calcareous, or only moderately so, but contains sufficient calcium to develop calcium carbonate on weathering, the lime-enriched layer is only a few feet thick or only weakly developed through a greater thickness. For example, where the paleosol has developed on lavas or on some sedimentary rocks that are only moderately calcareous, like the Denver formation, the lime-enriched layer is 5 to 10 feet thick.

A complicating factor in evaluating variations in thickness of the lime-enriched layer is the variation in permeability reflecting stratification of the parent material. For example, glacial moraine in Alpine Canyon, Utah (locality 3, fig. 11), contains only a small amount of limestone, and there is little calcium in the granitic or dioritic rocks that comprise the bulk of the moraine. The lime-enriched layer in the paleosol on this moraine is feebly developed; it contains only a trace of secondary lime carbonate. This moraine, however, is permeable, and the carbonate is distributed through a zone at least 20 feet thick, whereas on other parent materials that are distinctly stratified, like the Denver formation, the lime-enriched layer is only a few feet thick but strongly developed.

The calcium carbonate in the lime-enriched zone occurs in several ways. Commonly it forms irregular lime-rich layers separated by less-rich layers. It occurs also in scattered irregular masses an inch or two in diameter, as a fretwork of tiny anastomosing veinlets, or it may be finely and rather uniformly distributed throughout the enriched layer. Where the parent material is gravelly the pebbles are generally crusted with lime. The pH of the lime zone ranges from 7.5 to slightly more than 8.0. The alkalinity increases downward.

In the Middle West small quantities of secondary calcium carbonate are reported below the gumbotils (Kay and Pearce, 1920, pp. 120–124, and Leighton and MacClintock, 1930, pp. 36–38), but the amount of secondary lime seems to be much less than in the Rocky Mountain region. To what extent this difference in lime content of the subsoil in the two regions reflects differences in composition and permeability of the parent materials or differences in the climatic regimen that existed when the paleosols were developed is a problem that needs more investigation; it touches on some rather fundamental concepts of soil genesis.

AGE OF THE PALEOSOL

STRATIGRAPHIC EVIDENCE IN THE LAKE BONNEVILLE BASIN

At the mouth of Alpine Canyon, Utah (locality 3, fig. 11), the paleosol, which includes a thick leached clay layer and a thick but weakly lime enriched layer, is developed on the older but not on the younger of the moraines in that canyon (Hunt, in preparation). The younger moraine was contemporaneous with one of the high-level stages of Lake Bonneville, and at many places in Utah Valley the paleosol is overlapped by the lake beds (fig. 12). Moreover, the oldest formation of the Lake Bonneville group, the Alpine formation, contains a much higher proportion of clay and silt than do the

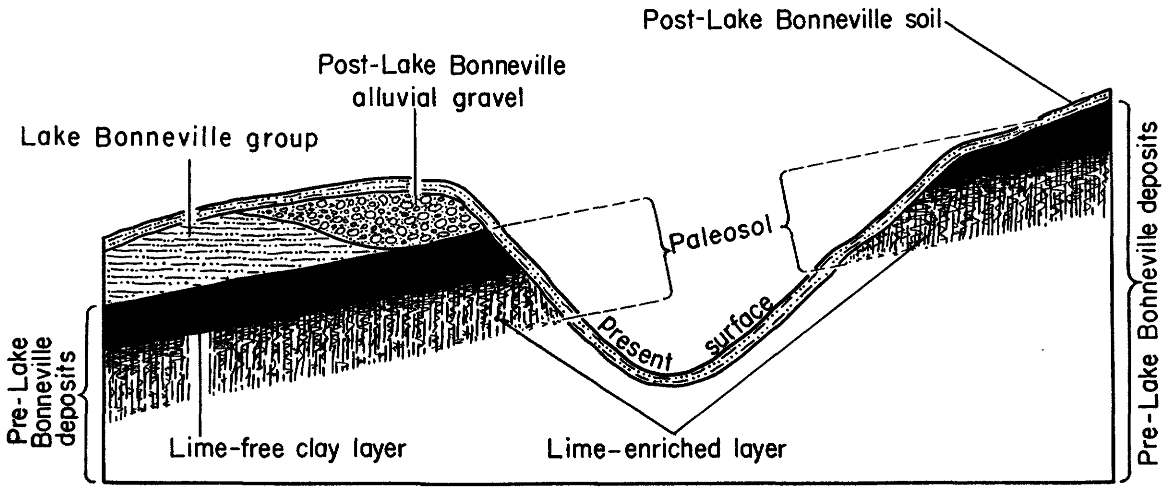


FIGURE 12.—Diagrammatic cross section illustrating some relationships between the geology and soil development in the Lake Bonneville Basin, Utah. Paleosol in the pre-Lake Bonnerville deposits is discordant with the present topography and is overlapped by the Lake Bonneville group and post-Lake Bonneville alluvial gravel. A post-Lake Bonneville soil is feebly developed on the Lake Bonneville and younger deposits and is superimposed on the old soil.

younger ones and probably represents the sediment that was formed by the erosion of the paleosol from adjoining highlands (Hunt, in preparation). There does not seem to be any other reasonable source for so much clay in the Alpine.

In the Lake Bonneville Basin, therefore, the paleosol must have developed during one of the Pleistocene interstadial periods that preceded Lake Bonneville.

STRATIGRAPHIC EVIDENCE IN THE DENVER BASIN

In the Denver Basin there is some paleontologic as well as general stratigraphic evidence that the paleosol is of pre-Wisconsin Pleistocene age.

Deposits along the South Platte River Valley identified as Wisconsin in age include a thick fill of cobble-size gravel evidently representing outwash from the early Wisconsin glaciers. Derived from this fill and extending eastward from it is an extensive loess. Along the valley this loess is overlain by a younger pebble-size gravel fill that evidently represents outwash from the late Wisconsin glaciers. Bones collected from the loess and younger gravel have been identified by C. L. Gazin of the United States National Museum and Jean Hough of the United States Geological Survey, who report that the collections include camel, bison, antelope, and extinct rodents and confirm a Pleistocene age for the deposits. The collections were not good enough to permit identification of species. Artifacts of bone and flint, identical with those associated with the Folsom culture at the Lindenmeier site, have been collected from the late Wisconsin gravel by Alice P. Hunt.

The paleosol is overlain by and must be older than the loess (fig. 13), but it has not yet been found under the early Wisconsin gravel. However, those gravels nowhere are weathered to clay; they are fresh firm stone and leave little doubt but that they are younger than the paleosol.

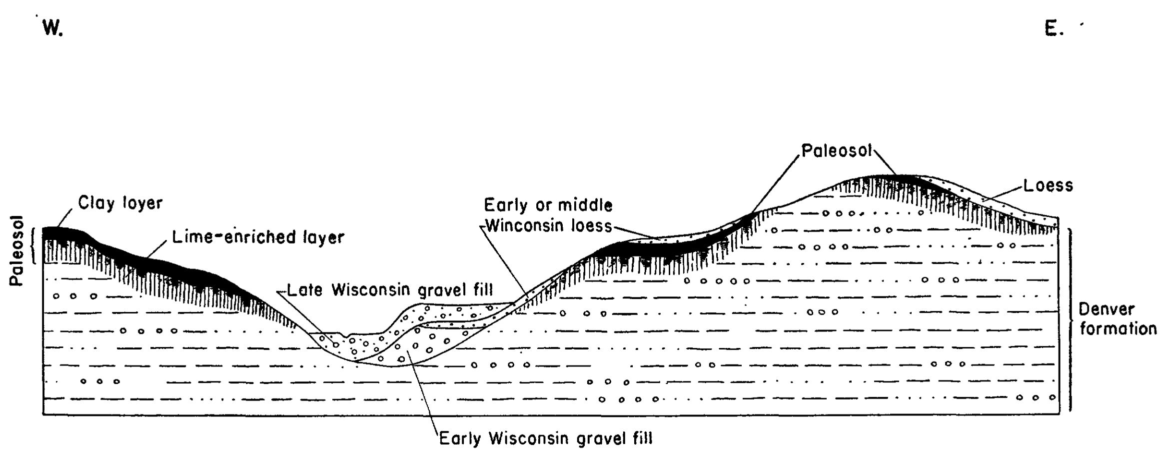


FIGURE 13.—Diagrammatic cross section illustrating topographic and stratigraphic relations of the paleosol in the Denver Basin. Paleosol has developed on the Denver formation and on old surficial deposits (not shown) that lie on the Denver. The paleosol is older than the loess and must be older than the early Wisconsin gravel fill, which was the source of the loess.

The paleosol has developed on some older gravels, and horse bones suggestive of Yarmouth age were collected from one of these. Some of these old weathered gravels are on the uplands and others are within the valleys, and these assuredly are Pleistocene also.

Along the tributaries of the South Platte River the oldest alluvium is distinctive in being composed very largely of clay. The younger alluvial deposits contain more silt, sand, and gravel. Correlation of the clay alluvium with the Wisconsin gravel fill in the South Platte River Valley is not established, but the general relations suggest that the clay alluvium is at least as old and perhaps somewhat older than the gravel fill. The clay alluvium in the Denver Basin, like the Alpine formation in the Bonneville Basin, apparently is the product of erosion of the paleosol.

The evidence in the Denver Basin, although not conclusive, leaves little doubt that the paleosol is pre-Wisconsin in age.

TOPOGRAPHIC EVIDENCE

In all the areas examined thus far the paleosol is associated with a distinct topographic unconformity. Throughout the Rocky Mountain region are found remnants of an old topographic surface or surfaces distinct from the more rugged and rocky topography that is being carved today. The old topography seems to have had as great relief as there is today, but the land forms had smoother contours. They were the product of a time when the processes of weathering and soil development exceeded those of erosion—quite the reverse of the Wisconsin and younger climatic environments in which the rate of erosion was and is greater than the rate of weathering.

As would be expected, the remnants of the old topography are preserved only in areas that have been protected against late Pleistocene and Recent erosion. These areas are mostly along the divides. In the mountains they are far back from the main drainage lines that discharged glacial meltwaters, but they may lie close to other drainage courses that have small catchment areas and have not been actively cutting during late Pleistocene and Recent time.

In the Wasatch Range, Utah, remnants of the old topography are preserved at all altitudes from the very base of the range to some of its highest divides. In parts of the Colorado Plateau, remnants of an old topography are preserved on some of the broad upland surfaces and even locally along the sides of some of the canyons. In the Denver Basin the old topographic surface had more relief than there is today, because the valleys that are there now are alluviated and the interstream divides are lower (fig. 13).

The paleosol is invariably associated with the old topographic surface; in fact the old topography provides an excellent clue for finding paleosol remnants.

The intimate and apparently invariable association of the paleosol with old topographic surfaces provides confirmatory evidence of the antiquity of the deposit. The old surfaces of course could be, and in many places no doubt are, much more ancient than the soil now on them. However, the paleosol in the Rocky Mountain region, like the gumbotils in the Middle West (Kay and Pearce, 1920, p. 89), does not occur on Wisconsin or younger deposits or on surfaces that are known to have been eroded during or since Wisconsin time.

In areas like the Great Basin, where Quaternary structural movements have been considerable, there has been a tendency to attribute topographic unconformities to the structural changes. The evidence at hand, however, suggests that changes in climate during the Pleistocene were fully as important as structural movements, if not more so, in developing those topographic unconformities, because the unconformities extend into provinces like the Colorado Plateau and into the High Plains where local differential structural movements have been slight, at least during the Pleistocene. It is quite possible that even during the Pleistocene our western mountains went through a succession of changes that at some stages gave rise to topographic forms like those we see today and at other stages gave rise to forms as rounded as those in the Appalachians. The relative importance of climatic changes as against structural movements in developing land forms needs to be reevaluated.

DIFFERENCES BETWEEN THE PALEOSOL AND THE WISCONSIN OR YOUNGER SOILS

On the Lake Bonneville and on other assuredly Wisconsin or Recent deposits the development of modern soils involves leaching of lime and other salts from the top layers and deposition of these materials under the leached layer. Except very locally where there is an excess of water this leaching during late Wisconsin and Recent time has not exceeded a couple of feet, at least in the region being considered, and nowhere on known Wisconsin or Recent deposits in this region have hard rocks been decomposed into residual clay in more than very small quantities. Except at scattered and isolated localities, where conditions of water supply are unusual, the soils developed on Wisconsin and Recent deposits in the Rocky Mountain region are characterized by the domination of the parent material in the profile, not only in the lower lime-enriched layer but also in the leached upper layer. This generalization apparently holds true also in the middle western States (Kay and Pearce, 1920, p. 89) and may apply in the eastern States as well.

The modern soils in the Rocky Mountain region are quite unlike the paleosol in that they are shallow and lack the strong development of clay that can be attributed to rock decomposition. Clayey parent materials, of course, like some loesses or alluvium, have given rise to clayey modern soils, but these rarely will be confused with paleosol. The characteristics of the paleosol are similar over a large region reaching into several western States, and the differences between it and the modern soils are equally widespread.

SOME PROBLEMS IN IDENTIFYING REMNANTS OF THE PALEOSOL

It is evident from the age of the paleosol and from its topographic position that it has been subjected to a great deal of erosion. At few places is the full thickness preserved, and outcrops at these places seldom expose all of it. One rarely sees in outcrops or excavations more than about a fourth of the total profile of the paleosol, and usually only the lime-enriched layers have survived erosion. All too commonly the leached clay, the most diagnostic layer, has been removed.

No very satisfactory criteria have been developed as yet for distinguishing erosion remnants of the lime-enriched lower layers of the paleosol from other kinds of caliche. The difficulty is not lessened by the fact that all the near-surface lime-enriched deposits, regardless of their age or origin, have been altered to some extent by modern soil processes.

Where as much as 2 feet of clay is preserved on top of the limy layers it is usually possible to determine where the material is the product of transportation or of weathering in place. Thinner clay remnants generally are not satisfactory because they are apt to have been disturbed by physical changes, such as frost heaving, or by plant, animal, or human activity. Such disturbance obscures stratification in transported materials and may contaminate residual materials with fragments of foreign rock, mineral grains, or salts.

Some lime-enriched deposits are too thick to have derived their lime from an overlying thin leached layer; in such cases the regional geology is sometimes helpful in determining whether the lime was developed by weathering in place or by other processes. If the drainage basin in which the lime-rich zone occurs lies wholly within formations that are only slightly or not at all calcareous the lime generally can be attributed to rock decomposition. Moreover, the lime layer can be attributed to concentration by soil processes rather than to lateral transportation by ground water where, as in parts of the Denver Basin, the lime-rich layers rise up the sides and across the tops of isolated hills composed of horizontal strata having different permeabilities. At such localities it is reasonable to infer that the clay layer originally was present in considerable thickness and covered the entire hill, that the clay has largely been removed by erosion, and that remnants of it are likely to be found in nearby protected places.

The regional geologic environment of some caliche deposits can be equally or even more diagnostic of an origin distinctly not related to paleosol, as, for example, the lime carbonate deposited by Lake Bonneville at headlands or other places that were exposed to strong surf action (Gilbert, 1890, p. 168, and Hunt, in preparation).

In the lime zone of the paleosol, clay commonly is developed in the upper few inches, and locally in the upper few feet. The occurrence of such clay in caliche deposits suggests that the deposit might represent the lower layer of a paleosol whose original clay surface layer has been largely removed. Also, in the lime zone of the paleosol the alkalinity increases downward, and the degree of weathering of the parent material increases upward. These conditions would be expected of processes that operated vertically, and their occurrence in caliche deposits also suggests that the deposit might represent the lower layer of a paleosol.

Such observations, however, are at best only suggestive, and before the paleosol can be used very extensively as a means for stratigraphic correlation additional ways must be found for distinguishing erosion remnants of its lime-enriched subsoil from other kinds of caliche. The paragenetic association of certain clay minerals with certain zonal soils, suggested by the work of Sedletzkii (1945), if confirmed by further work, may be valuable in identifying remnants of paleosol.

Much more remains to be learned about the old soil itself, including the mineralogy of its clays, the vertical zoning of the soluble forms of the metals and other elements, and its possible content of pollen and spores. Until these data are assembled and the facts sifted, the surest method for identifying a remnant of paleosol is to map the deposit carefully and determine its relation to the land surface, to the parent material, and to adjoining Pleistocene deposits. We still cannot establish the identity of paleosol from the evidence contained in a single exposure; at this stage determination still depends upon the areal relationships.

ORIGIN OF THE PALEOSOL AND ITS BEARING ON PLEISTOCENE HISTORY

The paleosol records a period when the processes of weathering greatly dominated over those of erosion. The climate that produced it must have been quite unlike the present climate or any of the succession of climates that have prevailed during and since Wisconsin time in the Rocky Mountain region.

Deep soils representing the residual effect of rock weathering commonly are attributed to considerable absolute age, but the age is probably one of the least important of all the factors that must have controlled the development of so deep and mature a profile as characterizes this soil (Hunt, 1948). Its depth is several times greater than the depth to which soil processes have operated during and since Wisconsin time. During the last 50,000 years or so the profile of the old soil has not been changed, except in its uppermost layers. Where it has been buried and protected by younger deposits it is the same as where it is still at the surface.

It is even possible that the paleosol actually required no longer time to develop than has been required by the shallow Wisconsin and younger soils in this region. Given favorable moisture and temperature conditions and appropriate animal and vegetable life to accelerate biochemical activity, it is not at all difficult to visualize rather rapid rock decomposition and deep soil development. That something of this sort did occur is suggested by the seeming nonexistence, at least in this region, of soils that are gradational in depth and maturity between the late Pleistocene or Recent soils and those that can be dated stratigraphically as pre-Wisconsin. The differences between the paleosol and the modern soil assuredly are due not to difference in the length of time required for them to develop but to major differences in the climates under which they were developed. Until we know more than we now know about the environment or environments under which the paleosol developed, we are in no position to evaluate time as a factor in its development.

The topographic unconformity with which the paleosol is associated is further evidence that climate rather than time is critical in controlling the development of the paleosol. Climate determines whether erosion or weathering will be dominant in a given topography; time is important only to the degree that it allows changes in climate.

In regard to rock weathering, the Wisconsin and post-Wisconsin climates have been virtually impotent, yet they have been operating for something like 50,000 years on the early Wisconsin deposits and for 10,000 or so years on some of the younger deposits. If the great difference between the paleosol and the younger soils were due largely to the time factor many millions of years would certainly have been required to develop the paleosol on the hard rock formations on which it is so commonly found. The geologic record obviously is against this.

Soil scientists will have to decide to what extent the old soil represents a complex of profiles superimposed on one another and the probable kind of climate or succession of climates that produced the profile that is found in the paleosol. The great depth of the clay and the softly contoured land forms on which the paleosol is present implies considerable moisture, but the development of the lime-enriched layer is difficult to explain if there was such abundant moisture. Would 40 inches of rain, distributed, let us say, in two rainy seasons—spring and fall—develop the kind and thickness of layers that are found in the paleosol? Whatever the conditions were that produced the soil, they appear to have been general over a wide area in the Rocky Mountain region.

In most of the western mountains where glacial deposits are found the older deposits generally are described as more weathered than the younger (Atwood, 1909; Blackwelder, 1915; Atwood and Mather, 1932, pp. 101–111; and Bryan and Ray, 1940). The differences, however, in the kind of weathering products in the old and in the young deposits need further study. Certainly in the Wasatch Range, and probably in several of the other ranges, the older glacial deposits are blanketed by the paleosol that has been the subject of this paper. A comparative study of pre-Wisconsin soils in the West and a comparison of these soils with the pre-Wisconsin soils, including the gumbotils, in the Middle West and with the presumed old soils of the southern Appalachians and northern Pennsylvania would be invaluable. It would contribute to better understanding of the origin of the old soils; it would improve our knowledge about the climatic and other variable factors that influenced their development; and it might lead to establishing the means for using soils for stratigraphic correlation.

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